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Review

A Review of the Global Climate Finance Literature

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Abstract: This study conducts a bibliometric analysis and literature review of studies on climate finance. Since the Paris Agreement was adopted in December 2015, the academic community has paid closer attention to this emerging topic, as witnessed by a sharp increase in the number of publications. Our review lists this field's most influential publications, authors, and journals, based on citations. The bibliometric analysis highlights the multidisciplinary nature of climate finance research, which spans environmental science, energy, economics, and finance. The citation analysis also reveals that, despite the exponential growth in publications related to climate finance, leading journals in finance and economics have so far published only a small number of articles in this literature. In addition, the citation analysis identifies four main themes in the knowledge domain: the financing of renewable energy; the impacts of climate change risks on the financial sector; investor preferences for green investments and the impact on corporations; and the pricing and hedging of climate change risk in financial markets.

Keywords: climate finance; climate change; green finance; bibliometric review

1. Introduction

Climate finance is an emerging field of study that has drawn significant attention from the academic community, especially since the adoption of the Paris Agreement in December 2015, which seeks to limit the increase in global average temperatures to below 2 °C above pre-industrial levels. Climate finance studies the funding of public and private investments for the mitigation of and adaptation to climate change [1]. More broadly, climate finance also investigates the awareness and attitudes of investors toward climate change risks, the effects of these risks on their investment decisions, and the pricing and hedging of climate change risks in financial markets [2].

Climate finance studies are important for at least two reasons. First, climate change mitigation to limit global warming requires huge investments in renewable energy and new technology, as well as investments to make the economy less energy-intensive. For example, Boehm et al. [3] estimate that climate finance flows need to increase to USD 5 trillion per year by 2030 to limit global warming to the more ambitious target of 1.5 °C. Relatedly, adaption to climate change will also require huge financial flows, especially to developing countries, which are most vulnerable to rising temperatures and sea-level rises. According to estimates by UNEP [4], adaptation costs for developing countries are expected to rise to USD 140–300 billion annually in 2030, up from USD 70 billion per year in 2020. Figure 1 provides an overview of the main sources of climate finance, amounting to USD 653 billion in 2019–2021, and their various uses for mitigation and adaption, based on estimates by the Climate Policy Institute [5].

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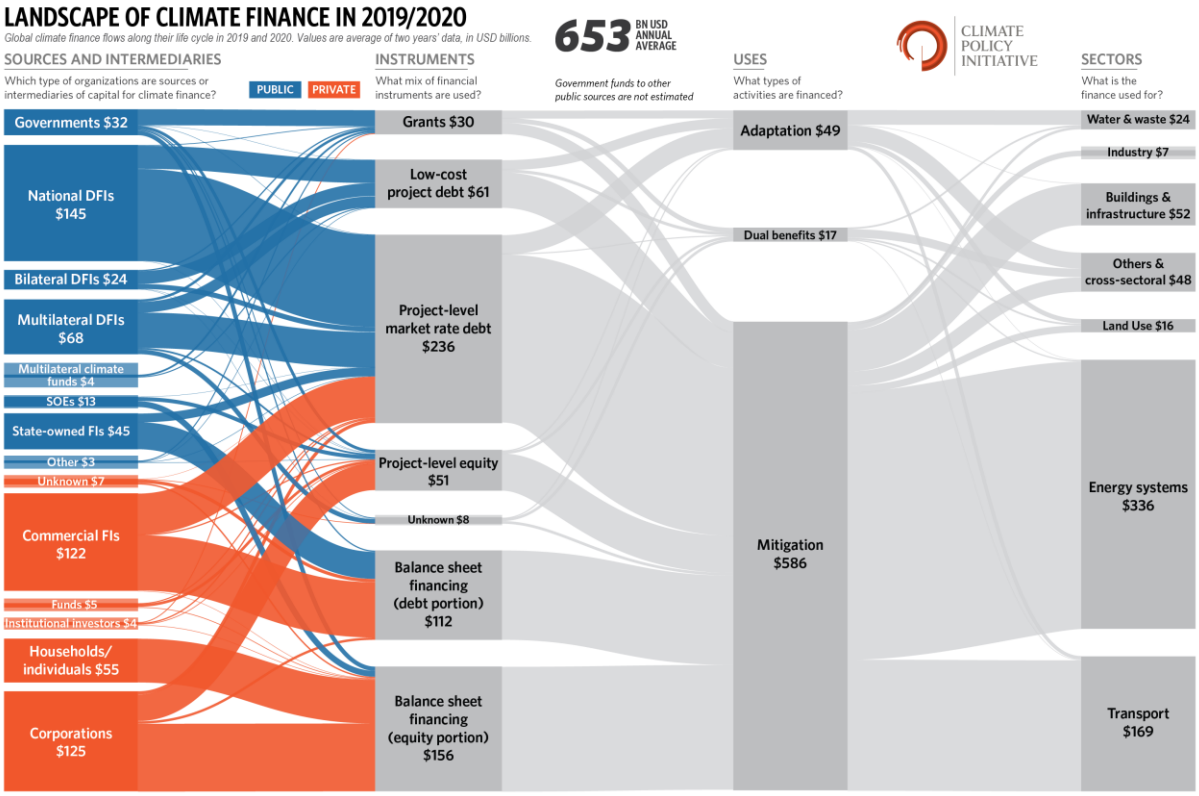

Figure 1. Climate finance sources and uses. Source: CPI [5]. Reprinted under a CC BY-NC-SA 4.0 License. DFI stands for development finance institutions.

Second, given the potentially large economic and social impacts of climate change, investors need to develop the capacity to measure and manage the impact of climate change risks on their investments, for both financial and real assets. An important related question is how climate change risks can be hedged by investors. Furthermore, to what extent are climate risks already priced into financial markets nowadays? The climate finance literature reviewed in this paper has started to address these urgent topics, showing a huge increase in published articles, especially in recent years (2015–2022).

This climate finance literature review addresses the following research questions:

1. What is the overall volume and distribution of published climate finance studies by time, country, and journal?
2. What articles and authors have had the most significant influence on climate finance research, based on citations?
3. What clusters of journals and authors that are often cited together can be identified in the climate finance literature?
4. What have been the main research topics in climate finance in the past, and what are they in the present?

To address these research questions, we conducted a bibliometric review of 1347 journal articles in the Scopus citation database that are related to climate finance. Our bibliometric review highlights the most cited articles, journals, and authors. Furthermore, through journal and author co-citation analyses, we identify sub-fields and clusters of related research in the climate finance literature. In addition, we analyze the most frequently cited keywords and their evolution over time to show the topical focus in climate finance research and how it has changed over time. Apart from the bibliometric review, we also shortly summarize and synthesize the content of the most cited articles to provide researchers with an overview of the field and the main topics covered in this literature. In addition, we review the most cited climate finance works published in the top finance field journals.

The added value of a bibliometric review is that it can highlight contributions from any field or journal because it only focuses on objective article properties such as keywords and citations. A substantive literature review can add more depth but is limited by the field-specific knowledge and subjective interests of the review authors. This matters especially in climate finance, which is a truly multidisciplinary subject involving the fields of finance, economics, energy policy, and environmental science, amongst others. Our bibliometric review identifies the most influential articles, providing a good entry point for those who are new to the field. In addition, for climate finance experts, it can highlight influential articles from other disciplines that otherwise may go unnoticed.

This paper contributes to the literature by combining a bibliometric review of the climate finance literature with a substantive review of the most cited articles and a review of highly cited articles in the top finance field journals. We extend an earlier bibliometric review of Zhang, Zhang, and Managi [6] of the green finance literature, which covered 381 publications in the Web of Science citation database from 2001 to 2018, to a review of 1347 journal articles in Scopus in the period 1991–2021. Furthermore, we complement and extend recent substantive reviews of the climate finance literature by Hong et al. [1] and Giglio et al. [2]. The latter two reviews focus on publications in leading finance and economics journals, which have only recently begun to publish articles on climate finance. Our review also includes and highlights influential earlier contributions published in non-core and multidisciplinary journals, as well as frequently cited climate finance articles in related fields, such as energy policy and environmental science.

2. Materials and Methods

2.1. Identification of Sources

This bibliometric review adopts the Scopus citation database to conduct the study because it has broader coverage than its primary industry competitor, the Web of Science (WoS) database [7]. We can further confirm this conclusion by comparing our study with a recent bibliometric study on climate finance using the WoS database [8], which includes far fewer documents from each year.

Following previous bibliometric reviews [9,10], we adopt the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for conducting this systematic review [11]. PRISMA outlines four steps to identify and extract documents for a bibliometric review, as shown in Figure 2.

First, we searched for articles containing the following terms in their title or keywords: climate finance, carbon finance, green finance, green investing, or green bonds (and alternative spellings: climate financing, carbon financing, green financing, or green investment). Second, we searched the abstract, title, and keywords for the combination of "climate change" (or "climate risk") and one of seven finance-specific terms: "asset pricing", "stock return", "stock market", "bond market", "financial market", "portfolio" & "investor", or "portfolio" & "hedging". We had to employ several finance-related search terms because some articles that did not explicitly refer to "climate finance" (or a related search term) in their title had to be identified using their abstract through a combination of "climate change" (or "climate risk") and the seven finance-specific search terms. For example, Choi, Gao, and Jiang [12] published a journal article titled "Attention to Global Warming" in the *Review of Financial Studies*' special issue on climate finance. This article's title does not seem related to climate finance, and Scopus does not store keywords for this journal. However, it contains "climate change" and "financial market" in its abstract, and therefore it was successfully detected by our set of search terms.

The authors started the initial literature search on 14 February 2022, yielding 1844 articles. Following Zheng and Kouwenberg [10], we limited this review to English journal articles, excluding 470 documents. Moreover, to increase the validity of our study, the authors cross-checked the reference lists of all 70 review-type papers in the database. After the comparison, we identified 102 additional articles not detected by the initial search. In the next step, the authors manually screened the documents to determine whether they

were a good fit for the study. Therefore, papers irrelevant to climate finance, those without author names, and duplicates of other studies were removed from the database. The scan led to the exclusion of 134 documents. The final database contains 1347 peer-reviewed journal articles on climate finance published since 1991.

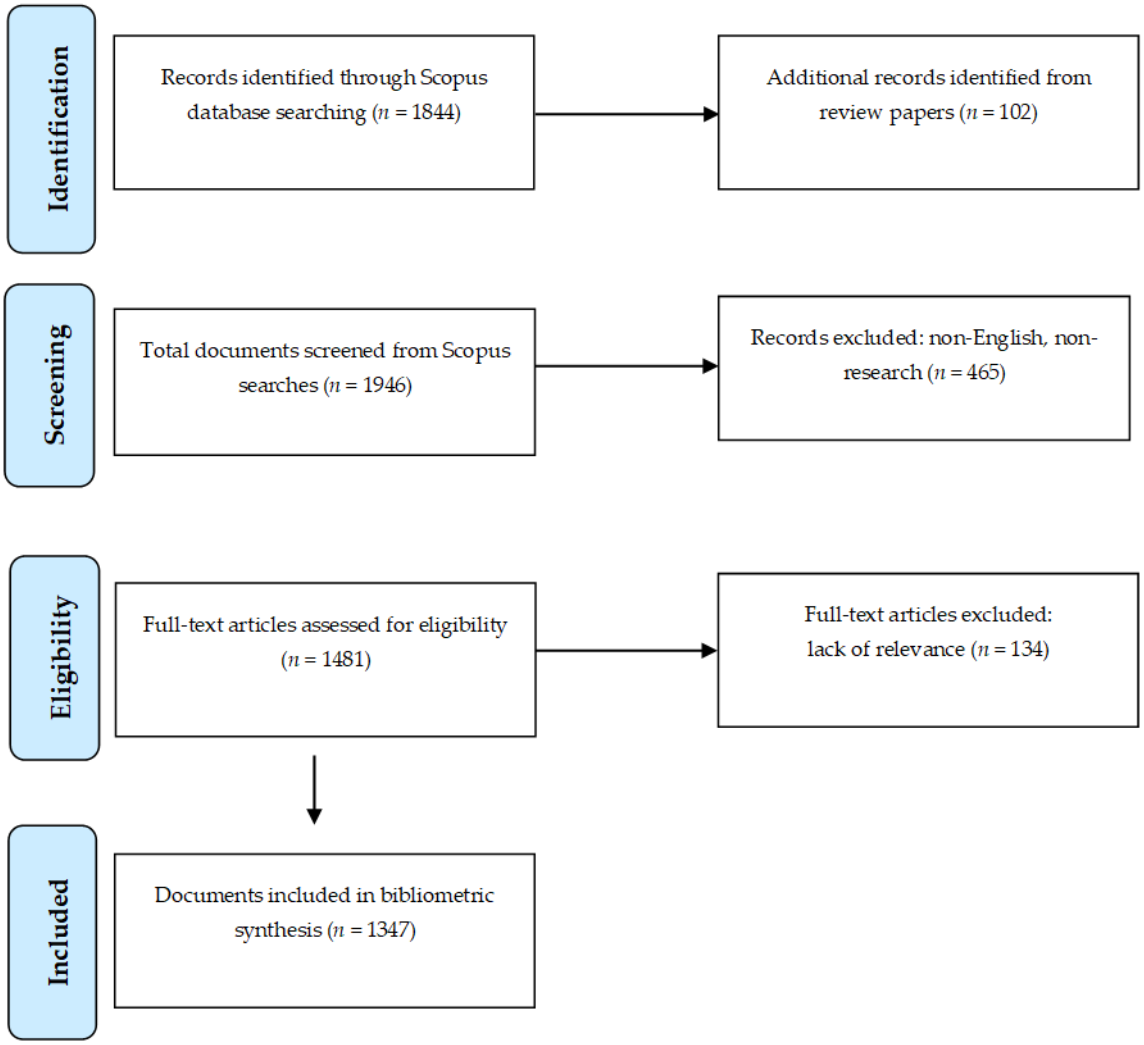

Figure 2. PRISMA flow diagram demonstrates the four steps of the systemic review process [10].

2.2. Data Extraction

The 1347 Scopus-cited journal articles were downloaded into a comma-separated value (.csv) file format for bibliometric analysis in VOSviewer. The downloaded data contain each article's citation information, bibliographical information, abstract and keywords, and references. The 1347 articles were also saved in Excel format for descriptive analysis and later imported into the Tableau software for topographical analysis.

2.3. Data Analysis

The bibliometric data analysis consists of two parts. The first part is the descriptive analysis which aims to reveal the essential features of the knowledge domain, such as the most frequently cited articles and the growth trajectory of climate finance studies. The authors perform those descriptive analyses in Excel. The second part is the bibliometric analysis, consisting of citation analysis, co-citation analysis, and a keyword co-occurrence analysis, performed in VOSviewer.

Citation analysis measures the frequency with which other Scopus-listed articles have cited a given unit (author or document) in the review database. Although academic works

can be cited for various reasons [13], academia generally uses citation counts as a measure of scholarly impact [14]. Therefore, citation analysis can reveal influential authors, articles, and journals within a knowledge domain. However, citation analysis is limited by the scope of the database. This limitation means a citation analysis only measures the citation counts from the same index source, while any citation from articles outside the index is not acknowledged [15]. Hence, the citation count tends to vary between different citation index platforms. For example, Heinkel, Kraus, and Zechner [16] had received 370 Scopus citations as of 17 April 2022, whereas they had received 1061 Google Scholar citations and 345 WoS citations as of the same day.

To some extent, co-citation analysis can partially mitigate the limitations of citation analysis. A co-citation occurs when two documents appear together in the reference list of another article [17,18]. For example, when two articles authored by Reboredo [19] and Reboredo and Ugolini [20] appear together on the reference list of a third document [21], these two documents are co-cited. When two documents are frequently co-cited together, it often indicates an intellectual similarity between them [22]. Because co-citation analysis explores the intellectual structure of a knowledge domain through the reference lists of the articles within a database, it therefore covers literature far beyond the coverage of the database used for the review and even goes beyond the coverage of the Scopus index. Given the ability of co-citation analysis to overstep the bounds of the citation database used, it complements traditional citation analysis and offers a more comprehensive understanding of a knowledge domain [10].

Keyword co-occurrence analysis, or co-word analysis, extracts author keywords from the articles within a database to present a graphical network of the topics in the literature and their connections. The underlying assumption of keyword co-occurrence is that when two or more keywords are frequently adopted by the same document, they represent contextual and conceptual similarity [18]. Naturally, the proximity between the keywords on the graphical network map represents the relatedness of the keywords [23]. Moreover, compared with citation analysis or co-citation analysis, keyword co-occurrence analysis draws from the keywords adopted by authors to summarize the main topics in a knowledge domain and their links [24]. In addition, by mapping the occurrences of keywords by date, an author can identify the emerging trends within a knowledge domain and any shifts of topic focus within the knowledge base [25].

3. Results

3.1. Volume and Geographic Distribution of Published Studies

Figure 3 shows the annual number of publications on climate finance in the period of 1991–2021 (1258 out of 1347 articles), with 2021 being the last full year covered in our database. The year 2022 is excluded from the figure, as the data was collected in February 2022. We notice an exponential growth in the volume of climate finance articles, especially from 2015 onwards. Specifically, in the period of 2016–2021, the annual number of climate finance articles published in the Scopus database grew more than fivefold, from 68 to 369 per year.

One of the key developments that may have contributed to this trend is the signing of the Paris Agreement in December 2015, at the Paris Climate Conference [26]. Article 2.1c of the Paris Agreement states that countries must make "finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development" [26]. At COP21 developed countries also reiterated their commitment to mobilize at least USD 100 billion per year by 2020 to support climate change mitigation and adaptation in developing countries [27]. In addition, at COP21 targets were set to limit the increase in global average temperatures to below 2 °C above pre-industrial levels and to pursue efforts to limit it to 1.5 °C.

Climate finance was already on the agenda of policymakers long before 2015. For example, the United Nations Framework Convention on Climate Change (UNFCCC) established the Global Environment Facility (GEF) to fund climate change projects in 1994. The commitment of USD 100 billion per year to support climate-related efforts in developing

countries was made originally at COP15 in Copenhagen in 2009 [27]. Furthermore, at COP 16 in 2010, the Green Climate Fund (GCF) was launched to reduce greenhouse gas (GHG) emissions in developing countries and to help vulnerable countries adapt to climate change. However, Figure 3 suggests that academic interest in climate finance only took off seriously beginning in 2015. In conclusion, the evolution of the literature on climate finance can be linked to events in international climate change policy.

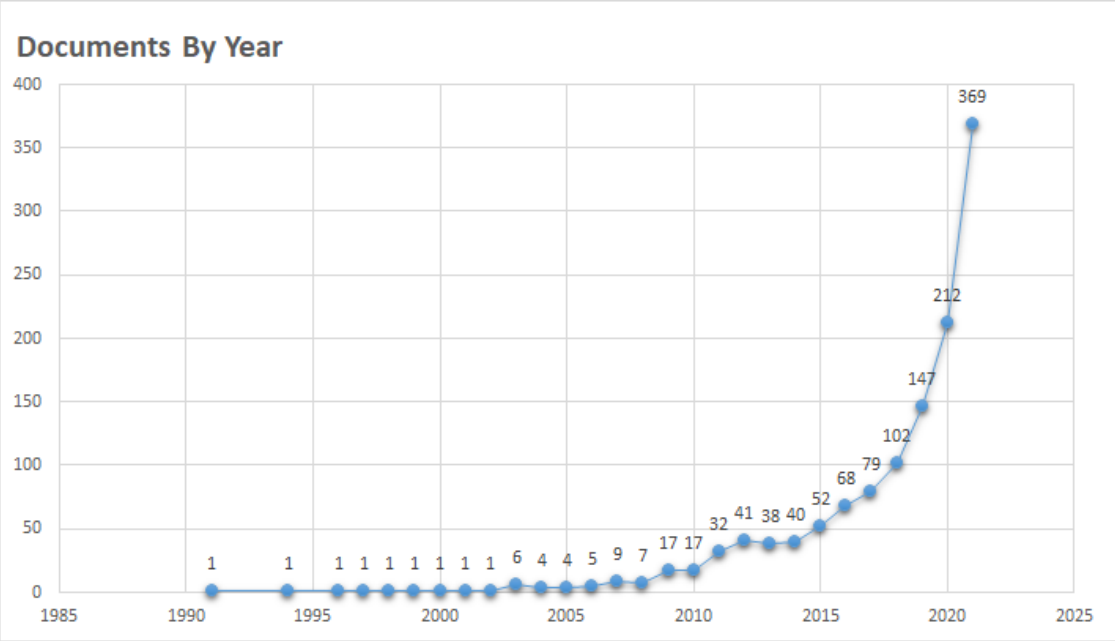

Figure 3. The number of climate finance publications over time, 1991–2021.

Figure 4 shows the geographical distribution of the climate finance literature based on the national affiliation of the authors. We observe that the climate finance literature is truly global, with contributions from all continents, covering 88 countries. China produced the largest number of publications on climate finance in the database (292), followed by the United States (251) and the United Kingdom (192). Relatively few articles in the climate finance literature have an author from Africa or Latin America.

When combing the 27 countries of the European Union (E.U.) together, the E.U. is clearly leading with 555 documents (a share of 27%), compared to 292 (14%) for China and 251 (12%) for the United States. Europe's share of the literature becomes even larger at 40% when we combine the E.U. with other Western European countries (the United Kingdom, Switzerland, Norway, Iceland, and Liechtenstein). For comparison, the share of these European countries in the total number of Scopus documents published in 1996–2021 is 34%, versus 21% for the United States and 12% for China. Hence, the United States contributes a substantially lower share of climate finance studies compared to its overall share in Scopus (12% vs. 21%), while this pattern is the opposite for European countries (40% vs. 34%) and China (14% vs. 12%).

The large gap in climate finance publications between the United States and Western Europe is likely caused by differences in public and political support for climate change mitigation policies. In the United States, concerns about climate change are politically polarized, with a large majority of Democrats supporting climate change policies, while Republicans largely oppose them [28]. As a result of these political divisions, the U.S. Senate never ratified the Kyoto Protocol. Furthermore, under the Trump administration in 2017, the United States withdrew from the Paris Climate Agreement, but it eventually rejoined the pact in 2021 under the Biden administration.

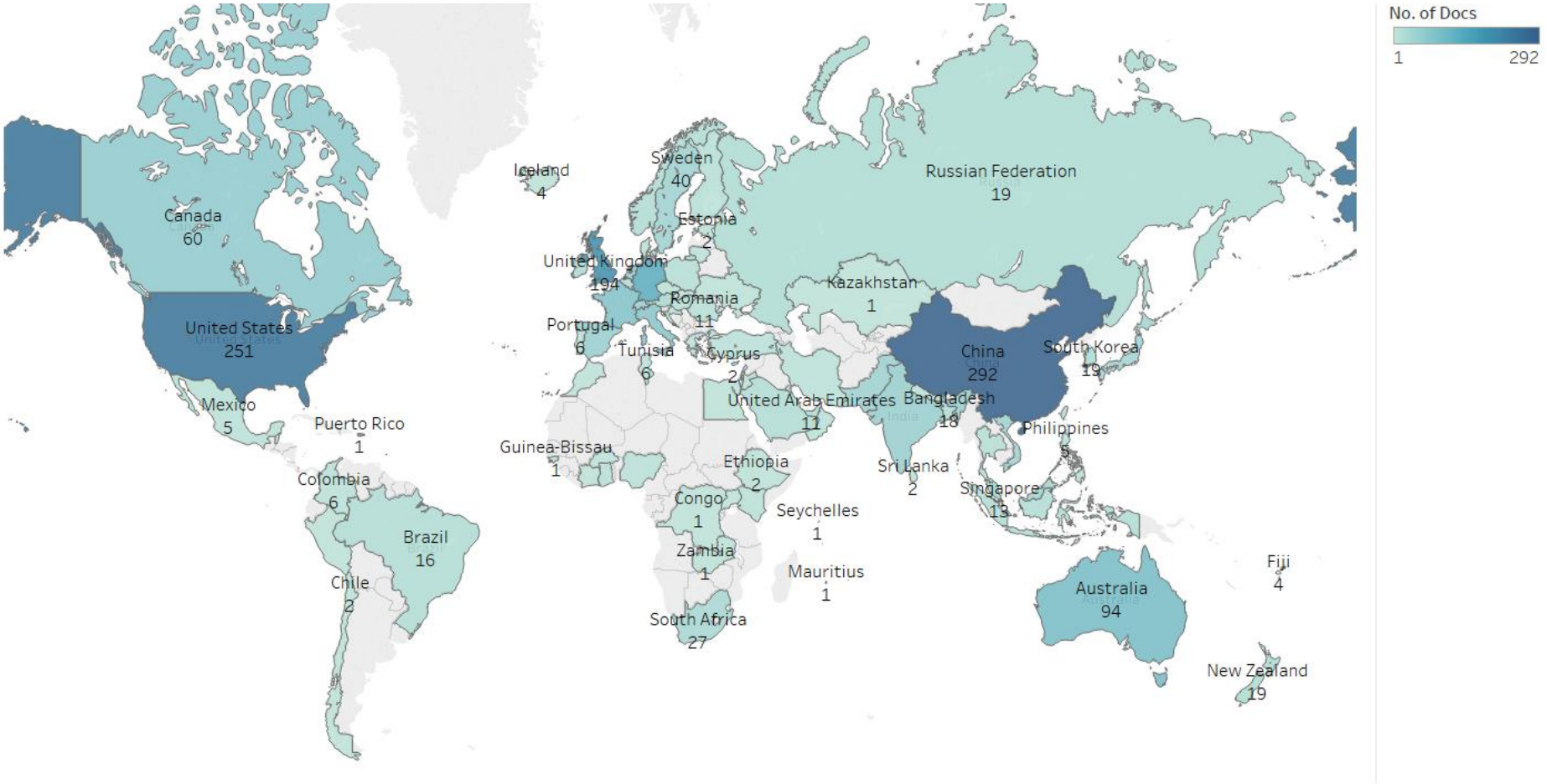

Figure 4. Global distribution of Scopus-indexed journal articles on climate finance by affiliation of the authors, 1991–2021.

By contrast, the E.U. has been one of the leaders in global climate action since the early 1990s, enshrining emission reduction targets in law, providing policy support for renewable energy investments, and introducing a CO_2 emission rights trading system. We highlight these regional differences in climate change beliefs and policies, as they can help explain why the most cited articles in the climate finance literature were nearly all written by authors affiliated with non-U.S. universities (e.g., universities in the E.U., Canada, Japan, the United Kingdom, Switzerland, China, etc.).

Regarding China's large share of the climate finance documents, it may partially be explained by China's overall lead in scholarly output in the Scopus database by 2020 [29]. On the other hand, China has also been pursuing climate change policies more actively in the last decade. For example, in 2020, China's President Xi Jinping announced that China aims to reach peak CO_2 emissions before 2030 and become carbon-neutral before 2060. China was the largest emitter of greenhouse gasses in 2020, whereas the United States has emitted the largest cumulative amount of greenhouse gasses since 1751, closely followed by the E.U. [30].

3.2. Journals

The next objective is to provide an overview of the journals most active in publishing climate finance articles, shown in Table 1.

Table 1. The 20 most active journals publishing climate finance articles ranked by volume of articles, 1991–2021 (n = 1347).

Rank	Journal	Publisher	Discipline	Articles	Scopus Citations	CPD
1	*Sustainability*	MDPI	Multi-discipl.	70	558	8
2	*Climate Policy*	Taylor & Francis	Environ. Sci.	60	1031	17
3	*J. Cleaner Production*	Elsevier	Multi-discipl.	50	1410	28
4	*Energy Policy*	Elsevier	Energy	46	2537	55
5	*J. Sustainable Finance & Investment*	Taylor & Francis	Finance	44	388	9
6	*Environ. Science and Pollution Research*	Springer	Environ. Sci.	31	229	7
7	*Energy Economics*	Elsevier	Energy & Econ.	29	730	25
8	*Finance Research Letters*	Elsevier	Finance	20	649	32
9	*Ecological Economics*	Elsevier	Environ. & Econ.	19	667	35
10	*Climate and Development*	Taylor & Francis	Environ. Sci.	16	190	12
11	*Energies*	MDPI	Energy	16	186	12
12	*International Environmental Agreements*	Springer	Multi-discipl.	14	183	13
13	*Resources Policy*	Elsevier	Multi-discipl.	14	24	2
14	*Climatic Change*	Springer	Environ. Sci.	13	160	12
15	*Business Strategy and the Environment*	Wiley	Multi-discipl.	12	337	28
16	*Environmental & Resource Economics*	Springer	Multi-discipl.	12	121	10
17	*Renewable and Sustainable Energy Reviews*	Elsevier	Energy	11	612	56
18	*Technological Forecasting and Social Change*	Elsevier	Multi-discipl.	11	366	33
19	*Review of Financial Studies*	Oxford Uni. Press	Finance	11	311	28
20	*Journal of Environmental Management*	Elsevier	Environ. Sci.	11	272	25

Note: CPD denotes citations per document.

The results reveal that climate finance is truly a multidisciplinary topic, with articles published in journals focusing on environmental science (e.g., *Climate Policy* and *Environmental Science and Pollution Research*), energy (*Energy Policy* and *Energy Economics*), finance (*J. Sustainable Finance & Investment* and *Finance Research Letters*), and economics (*Energy Economics* and *Ecological Economics*), as well as in broad multidisciplinary journals (*Sustainability* and *J. Cleaner Production*). Interestingly, only three journals in the top 20 by the number of articles are pure finance journals (*J. Sustainable Finance & Investment*, *Finance Research Letters*, and *Rev. Financial Studies*), whereas most top field journals in finance and economics in terms of scholarly impact are absent.

Table 2 ranks the journals based on the total number of Scopus citations received, including only citations to articles within our climate finance database. The top cited journals in the climate finance literature reflect the nexus of climate change (environmental science), energy policy, finance, economics, sustainability, as well as management. By far, the largest number of citations are to the journal *Energy Policy* (2537), with the top cited articles focusing on investment in renewable energy and its financing. Second is the *Journal of Cleaner Production* (1410), further emphasizing the importance of financing the transition to renewable energy in this literature. Third is the environmental science journal *Climate Policy* (1031), highlighting the multidisciplinary nature of the body of knowledge. In the fourth and fifth rankings are two cross-disciplinary economic journals, *Energy Economics* (730) and *Ecological Economics* (667), respectively. The first finance journal occurs in sixth position, *Financial Research Letters* (649).

Table 2. The 20 most influential journals publishing climate finance articles ranked by Scopus citations, 1991–2021 (n = 1347).

Rank	Source	Publisher	Coverage	Articles	Scopus Citations	CPD
1	*Energy Policy*	Elsevier	Energy	46	2537	55
2	*J. Cleaner Production*	Elsevier	Multi-discipl.	50	1410	28
3	*Climate Policy*	Taylor & Francis	Environ. Sci.	60	1031	17
4	*Energy Economics*	Elsevier	Energy & Econ.	29	730	25
5	*Ecological Economics*	Elsevier	Environ. & Econ.	19	667	35
6	*Finance Research Letters*	Elsevier	Finance	20	649	32
7	*Renewable and Sust. Energy Reviews*	Elsevier	Energy	11	612	56
8	*Sustainability*	MDPI AG	Multi-discipl.	70	558	8
9	*Nature Climate Change*	Nature Pub. Group	Environ. Sci.	7	438	63
10	*J. Sustainable Finance & Investment*	Taylor & Francis	Finance	44	388	9
11	*J. Environ. Econ. Management*	Elsevier	Environ. & Econ.	6	374	62
12	*J. Financial and Quantitative Analysis*	Cambridge Uni. Press	Finance	2	371	186
13	*Technological Forecasting and Social Change*	Elsevier	Multi-discipl.	11	366	33
14	*Business Strategy and the Environment*	Wiley	Multi-discipl.	12	337	28
15	*Review of Financial Studies*	Oxford Uni. Press	Finance	11	311	28
16	*Applied Energy*	Elsevier	Energy	8	277	35
17	*Journal of Environmental Management*	Elsevier	Environ. Sci.	11	272	25
18	*Mitig. Adapt. Strateg. Global Change*	Springer	Multi-discipl.	9	250	28
19	*Environmental Scienceand Pollution Res.*	Springer	Environ. Sci.	31	229	7
20	*J. Financial Economics*	Elsevier	Finance	9	220	24

Note: CPD denotes citations per document.

Three high-impact finance journals also appear in Table 2, namely *J. Financial & Quant. Analysis* (371), the *Rev. Financial Studies* (311), and *J. Financial Economics* (220), at ranks 12, 15, and 20, respectively. Remarkably, these leading finance journals have published only 22 of the 1347 articles in our climate finance database. The *J. Finance*, often considered the top field journal for finance, did not even contribute a single article to the database. The relative lack of attention to climate finance in mainstream finance journals seems to have created a gap that *Finance Research Letters* has filled in (20 articles, 649 citations), as well as the specialized *J. Sustainable Finance & Investment* (44 articles, 388 citations). Overall, we conclude that climate finance is a multidisciplinary field, appearing in journals focusing on energy policy, environmental science and climate change, and economics and finance, as well as in cross-disciplinary journals such as the *Journal of Cleaner Production* and *Sustainability*.

The top finance journals have contributed relatively few articles to the climate finance literature. A study by Diaz-Rainey, Robertson, and Wilson [31] found that only 12 of 20,725 articles (0.06%) published in the leading 21 finance journals from 1998–2015 were related to climate finance. This conclusion also held when they repeated their search in 29 top business journals covering accounting, economics, management, marketing, and

operations research. Goodall [32] and Diaz-Rainey et al. [31] propose several possible explanations for the dearth of climate finance research in top finance journals. One is that finance as a discipline prefers to focus on selected theoretical models and empirical tests of those models, while ignoring practical problems that require a forward-looking and cross-disciplinary mindset.

Another possible explanation is that climate finance was not yet considered a relevant topic by the editors of elite finance and business journals until quite recently. The top finance journals have chief editors that are nearly all based in the United States, where climate change beliefs are more polarized and support for policy interventions by the federal government is much lower than in Europe. In line with this, we note that the top 10 journals publishing articles on climate finance in Table 1 all have senior editors that are affiliated with universities outside the United States (Europe, Canada, China, etc.). Among the top 20 climate finance journals in Table 1, only four journals had an editor based in the United States on their senior editor team (e.g., editors in chief or managing editors) as of December 2022. Those four journals are: *Resources Policy*, *Climatic Change*, *Rev. Financial Studies*, and *J. Environmental Management*.

The attitudes of editors at top finance journals may be changing, though, as our results show that the *Rev. Financial Studies* and *J. Financial Economics* have recently started to publish more research on climate finance. For example, in 2017 the *Rev. Financial Studies* launched a call for innovative research proposals on climate finance, resulting in a special journal issue published eventually in 2020 [1].

Journal Co-Citation Analysis

Figure 5 shows a journal co-citation analysis (JCA) map, in which the node sizes reflect the number of co-citations received by a given journal. A link between journals indicates that articles published in two journals were co-cited together. Furthermore, journals located closely to each other in a JCA map are often co-cited together, implying a degree of similarity in the content of the articles [18]. The assignment of color to nodes is based on the number of co-citations to articles published in the journal group, using a clustering technique [33]. Thus, articles published in a cluster of journals with a common color can be interpreted as having a relatively high similarity in their contents.

The largest nodes in Figure 5 are in the yellow cluster, dominated by *Energy Policy* and the *J. Cleaner Production*, the top two journals based on the number of co-citations. Other notable journals in this cluster are *Sustainability*, *Renewable and Sustainable Energy Reviews*, and *Renewable Energy*. The journals in the yellow cluster tend to focus on energy policy, renewable energy, and sustainability in general. The large node size of *Energy Policy* in Figure 5 shows that the climate finance knowledge domain is policy-driven, focusing on policies to finance the shift from conventional fossil fuels to renewable energy. This is consistent with Table 3, which lists the publications with the highest number of citations. Several of these articles are about public policies for stimulating renewable energy investment and were published in *Energy Policy*.

The purple cluster consists of specific journals in economics and finance like *Energy Economics*, *Finance Research Letters*, and the *J. Sustainable Finance & Investment* that have published relatively high numbers of climate finance articles (see Table 1). We interpret the purple cluster as a group of journals in economics and finance that has shown an early interest in publishing climate finance articles. The largest node in this cluster is *Energy Economics*, the leading field journal for energy economics and finance studies. Highly cited articles in *Energy Economics* on climate finance focus on the stock prices of clean energy firms [34], the impact of news about climate change on stock prices [35,36], and green bonds [19]. Articles in *Financial Research Letters*, the second largest node in the purple cluster, show a related focus on green investments.

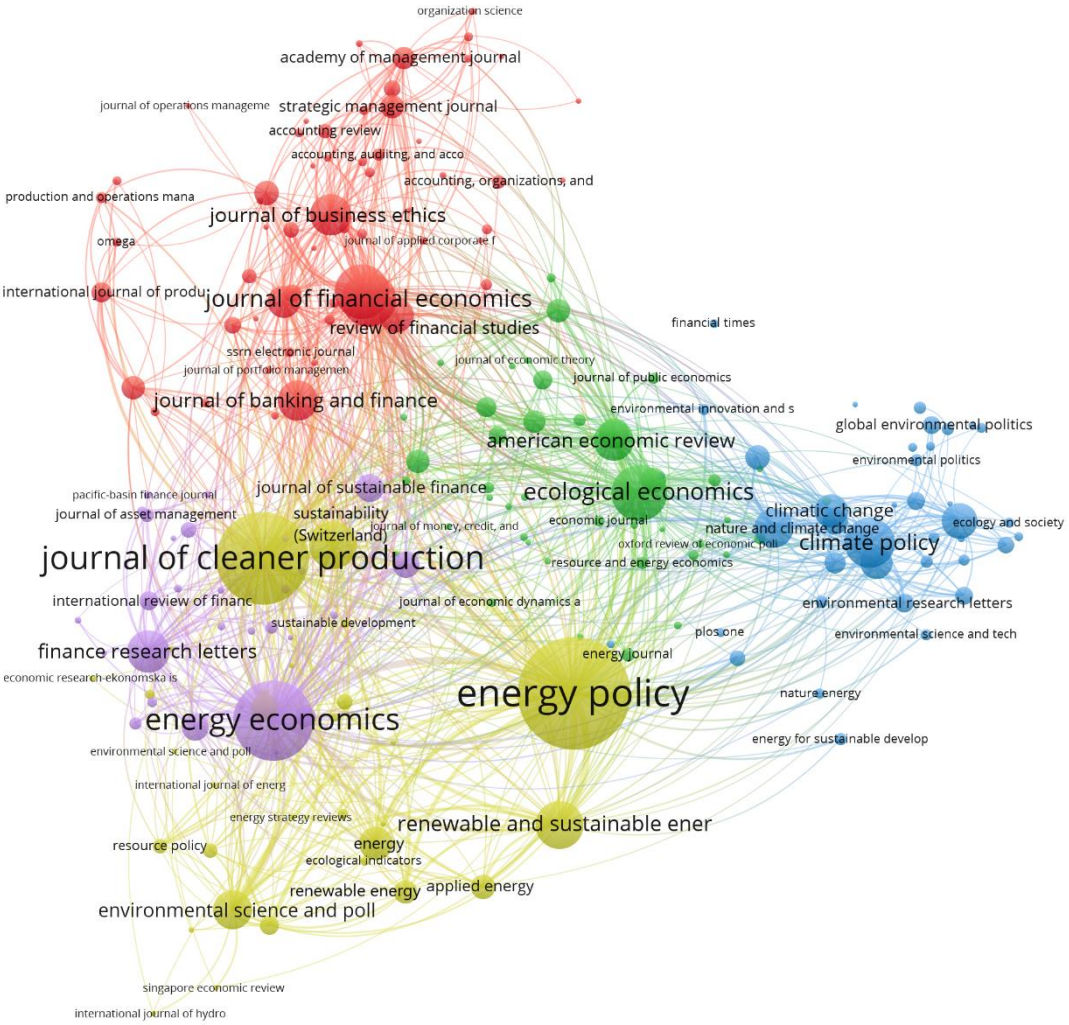

Figure 5. Source co-citation map based on 22,462 sources (threshold 20 co-citations, display top 200).

The top finance journals (*J. Financial Economics* and *Rev. Financial Studies*) show up separately in the red cluster, together with top management journals such as the *J. Business Ethics* and *Strategic Management Journal*. The journals in the red cluster have in common that they published relatively few climate finance articles, even though this cluster contains some of the most influential titles in finance, accounting, and management. This probably reflects the finding of Diaz-Rainey et al. [31] that the top journals in finance and business used to publish almost no studies on climate finance until recently. Co-citations to journals in the red cluster can also refer to general theories and findings in the field (e.g., the factor model of Fama and French [37]) rather than to articles specifically about climate finance.

The green cluster consists of economics journals, led by *Ecological Economics* and the *American Economic Review* in terms of the number of co-citations. *Ecological Economics* published several influential articles on the financial risks posed by climate change, including an early contribution by Busch and Hoffmann [38], and later Campiglio [39] and Dafermos, Nikolaidi, and Galanis [40]. *American Economic Review*, on the other hand, has not published any articles on climate finance in our database. Its large node rather reflects citations to the capital structure theory of Modigliani and Miller [41] and a widely cited theoretical article by Acemoglu et al. [42] on how technological innovation to limit carbon emissions can be stimulated by government policies such as carbon taxes and research subsidies.

Finally, the blue cluster consists of journals focusing on climate change and environmental science, such as *Climate Policy*, *Climatic Change*, and *Nature Climate Change*. The main emphasis of these journals is on understanding climate change, its causes, and its

consequences, as well as on policies for climate change adaptation and mitigation. Climate finance articles are also published in this group of journals, including several influential articles that estimate the impact of climate change risk on the financial system as a whole, such as Dietz et al. [43], Battiston et al. [44], and Campiglio et al. [45].

In sum, the journal co-citation map identifies a cluster of specific journals in economics and finance like *Energy Economics*, *Finance Research Letters*, and the *J. Sustainable Finance & Investment* that have shown an early focus on climate finance and are often cited together, separately from mainstream journals in finance and economics (which are in the red and green clusters). Another core pillar of the climate finance literature consists of journals focusing on energy policy, cleaner production, and sustainability (*Energy Policy* and *J. Cleaner Production*). Finally, the literature on climate change and environmental science is another important cornerstone of research in climate finance.

3.3. Influential Articles

We now turn our focus to the most influential articles and authors in the climate finance literature. Table 3 shows the 20 most influential articles based on the number of Scopus citations.

Table 3. The 20 most influential climate finance journal articles ranked by Scopus citations, 1991–2021.

Rank	Document	Source	Paper Type	Scopus Citations
1	Heinkel et al. (2001). The effect of green investment on corporate behavior [16]	*J. Fin. Quant. Anal.*	Conceptual	362
2	Bürer, M. J., & Wüstenhagen, R. (2009). Which renew. energy policy is a venture capitalist's best friend? [46]	*Energy Policy*	Empirical	263
3	Wüstenhagen, R., & Menichetti, E. (2012). Strategic choices for renewable energy investment [47]	*Energy Policy*	Conceptual /Review	250
4	Kumar et al. (2012). Stock prices of clean energy firms, oil and carbon markets [34]	*Energy Econ.*	Empirical	225
5	Chava, S. (2014). Environmental externalities and cost of capital [48]	*Mgmt. Science*	Empirical	215
6	Hintermann, B. (2010). Allowance price drivers in the first phase of the EU ETS [49]	*J. Environ. Econ. Manag.*	Conceptual /Empirical	200
7	Polzin et al. (2015). Public policy influence on renewable energy investments [50]	*Energy Policy*	Empirical	185
8	Awerbuch, S. (2006). Portfolio-based electricity generation planning [51]	*Mitig. Adapt. Strat. Glob. Chang.*	Conceptual	181
9	Luo et al. (2012). Corporate incentives to disclose carbon information [52]	*J. Int. Financ. Manag. Account*	Empirical	180
10	Campiglio, E. (2016). Beyond carbon pricing [39]	*Ecol. Econ.*	Conceptual	175
11	Delmas, M. A., & Montes-Sancho, M. J. (2011). U.S. state policies for renewable energy [53]	*Energy Policy*	Empirical	175
12	Battiston et al. (2017). A climate stress-test of the financial system [44]	*Nat. Clim. Change.*	Empirical	166
13	Zerbib, O. D. (2019). The effect of pro-environmental preferences on bond prices [54]	*J. Bank. Finance*	Empirical	140
14	Fisher-Vanden, K., & Thorburn, K. S. (2011). Voluntary corporate env. initiatives and shareholder wealth [55]	*J. Environ. Econ. Manag.*	Empirical	140
15	Dietz et al. (2016). 'Climate value at risk' of global financial assets [43]	*Nat. Clim. Change.*	Empirical	138
16	Dinica, V. (2006). Support systems for the diffusion of renewable energy tech.—an investor perspective [56]	*Energy Policy*	Conceptual	135
17	Barradale, M. J. (2010). Impact of public policy uncertainty on ren. energy investment [57]	*Energy Policy*	Empirical	134
18	Ellis et al. (2007). CDM: Taking stock and looking forward [58]	*Energy Policy*	Review	132
19	Otto et al. (2020). Social tipping dynamics for stabilizing Earth's climate by 2050 [59]	*Proc. Natl. Acad. Sci.*	Empirical /Review	130
20	Taghizadeh-Hesary, F., & Yoshino, N. (2019). The way to induce private part. in green finance [60]	*Finance Res. Lett.*	Conceptual	126

Ranked first is a theoretical article by Heinkel et al. [16] about the effect of green investment on corporate behavior. The authors use an equilibrium model to show that if a group of ethical investors in the market refuses to invest in a polluting firm, it will raise the

polluting firm's cost of capital. The polluting firm can respond by switching to a cleaner alternative and thus becoming socially responsible. However, it only does so if the firm's cost of "cleaning up" is relatively low compared to the increased cost of capital. More than 20% of the polluting firms' investors have to become green in this model to induce a change in policy at the polluting firm.

Interestingly, after writing this important and influential study on green investment in 2001, Heinkel, Kraus, and Zechner did not publish any other articles on climate finance, as these authors focus on corporate finance in general. Furthermore, the *J. Financial & Quant. Analysis*, a leading finance journal, did not publish any other articles on climate finance included in our database after Heinkel et al. [16], except for one related study in 2021 entitled "Climate Change News Risk and Corporate Bond Returns" by Huynh and Xia [61]. The 20-year gap between the two publications nicely illustrates the lack of interest in climate change in the field of finance until recently.

The fifth most cited article in Table 3, "Environmental externalities and cost of capital" by Chava [48], is an empirical study that tests whether investors demand a higher cost of capital for stocks that do not pass environmental screens, including climate change concerns. Using estimates of firms' implied costs of capital, Chava [48] shows that investors indeed demand significantly higher returns on stocks of firms with environmental concerns, supporting the model predictions of Heinkel et al. [16].

Ranked second and third based on citations in Table 3 are two articles published in *Energy Policy*, by Bürer and Wüstenhagen [46] and Wüstenhagen and Menichetti [47], respectively. Bürer and Wüstenhagen [46] conducted surveys and interviews with private investors in innovative clean energy firms to gain insights into investor preferences for renewable energy policy, such as feed-in tariffs and tax breaks. The second publication, Wüstenhagen and Menichetti [47], is an introduction to a special issue with the best papers presented at a 2010 conference on "Strategic choices for renewable energy investment." The selected papers focus on how investors make their renewable energy investment decisions and how these are influenced by energy policy. Three other articles in Table 3 published in *Energy Policy*, Polzin et al. [50], Delmas and Montes-Sancho [53], and Barradale [57], also focus on how public policy affects investment in renewable energy.

Ranked fourth in Table 3 is an empirical study by Kumar et al. [34] investigating the factors driving the prices of clean energy stocks. The study's main finding is that rising oil prices positively influence clean energy stock prices due to a substitution effect. However, carbon prices did not significantly impact clean energy stocks in the period investigated. Later work confirmed the weak association between carbon prices and clean energy stock returns [62], implying that investors in clean energy firms can diversify their portfolios by investing in carbon emission rights.

Hintermann [49], the sixth most cited study, analyzes the prices of carbon emission rights in the first phase of the E.U. Emissions Trading Scheme (EU ETS). The EU ETS is a so-called "cap-and-trade" system that puts a cap on total carbon emissions and requires selected polluting industries to obtain allowances for their actual emissions. Some of these emission allowances are distributed initially to the firms, but they can also be bought and sold in a secondary market. The advantages of allowance trading are that it puts a market price on the marginal cost of curbing CO_2 emissions (abatement), and it gives firms a strong financial incentive to reduce their emissions. Hintermann [49] developed a model for the price of emission rights based on fundamental factors such as coal and gas prices and tested it empirically. We refer to Hintermann, Peterson, and Rickels [63] for a review of the price dynamics of carbon rights.

Recent empirical work by Dechezleprêtre, Nachtigall, and Venmans [64] suggests that the EU ETS has substantially reduced CO_2 emissions without hurting corporate profits and employment. Relatedly, the 10th most cited article in Table 3, Campiglio [39], argues that carbon pricing may not be sufficient to incentivize banks to shift their lending from high-carbon firms to low-carbon firms due to market failures in the financial sector. Additional banking regulation may be needed to solve this problem, according to Campiglio [39].

Two other noteworthy frequently cited studies in the climate finance literature in Table 3 are Dietz et al. [43] and Battiston et al. [44], both published in *Nature Climate Change*. Dietz et al. [43] estimate the potential losses among global financial assets, such as stocks and bonds, due to the impact of climate change. Dietz et al. [43] use the dynamic integrated climate-economy (DICE) model of Nordhaus [65,66] to estimate the impact of global warming on GDP growth and subsequently on the value of global financial assets (whose cash flows are assumed to grow with GDP). Dietz et al. [43] estimate that the expected loss of financial assets amounts to USD 2.5 trillion (1.8% of the assets' value) in a baseline business-as-usual scenario. In a 1% worst-case tail outcome, the losses increase to a staggering USD 24.2 trillion (16.9%). Dietz et al. [43] show that policies to limit global warming to no more than 2 degrees Celsius would lead to a 0.2% higher value of financial assets after including mitigation costs, and a 9.1% higher value in the 1% tail scenario, relative to a business-as-usual scenario.

Battiston et al. [44] estimate the impact of climate risks on the financial system, including banks, investment funds, pension funds, and insurance companies. The financial sector has both direct exposure by investing in fossil-fuel companies whose assets may become "stranded" [67], as well as exposure to power producers using non-renewable energy, energy-intensive industries, and real estate exposed to climate change risk. Furthermore, there are indirect exposures through investments in other financial companies (e.g., banks) that have direct exposures. Battiston et al. [44] conclude that the financial sector's direct exposure to fossil-fuel securities is small (4–13%), but the combined direct and indirect exposure to climate-policy-sensitive companies is much larger (36–48%). In addition, Battiston et al. [44] carry out climate stress tests for banks in the E.U., estimating the possible losses in a worst-case scenario where investments in fossil-fuel energy companies and utilities become worthless.

Studies such as Dietz et al. [43] and Battiston et al. [44] that estimate the impact of climate change risk on the financial sector and global financial markets necessarily depend on many simplifying assumptions and are subject to great uncertainty, given the long-term nature of climate change risks and the unknown impact of future mitigation policies. However, these types of "climate value-at-risk" and "climate stress test" studies are important, as they raise awareness among financial institutions, investors, and regulators, to consider climate change as a risk factor that needs to be integrated into existing financial risk management frameworks. We refer to Battiston et al. [68] and literature reviews by Monasterolo [69] and Campiglio et al. [70] for more recent work in this area.

Topics and Methodologies in the Most Cited Articles

We now review the topics studied and the methodologies applied in the top 20 most cited articles in Table 3. First of all, we note that 11 out of the 20 most cited climate finance articles analyze policies to mitigate climate change, such as feed-in tariffs for renewable energy, tax breaks, and cap-and-trade systems. The motivation of these articles is mostly practical, rather than theoretical: ascertaining which government policies can best stimulate more private investment in renewable energy and new technology to mitigate climate change (e.g., Campiglio [39]). The underlying philosophy appears to be that: (1) climate change is a real long-term threat to society; (2) private sector investment in climate change mitigation is insufficient due to relatively high costs, market failures, and behavioral biases; and (3) policy intervention is therefore required. Most of these articles are published in *Energy Policy* and have authors based in Europe, a region where national policies to mitigate climate change have been implemented since the early 1990s. The methodologies used in these policy-oriented studies include conceptual models to evaluate the potential of policies to stimulate private climate finance flows [47], surveys to learn more about the preferred policies of renewable energy investors [46], and empirical tests of the effectiveness of policies implemented globally [50].

As a recommendation for future research, we note that this strand of literature can benefit from integrating theoretical frameworks from economics to better explain the

trade-offs involved in policies to support renewable technologies (see, e.g., [42,71,72]). Related Yi et al. [73] used evolutionary game theory and system dynamics to model how power producers respond to feed-in tariffs and renewable portfolio standards, providing policymakers with a new methodology for setting policy parameters (such as subsidies, quotas, and fines). Furthermore, the optimal policies need to be reassessed regularly, as technological innovations and economies of scale have greatly reduced the unit costs of renewable energy sources such as wind and solar recently.

The second most widely studied topic in Table 3 is the impact of climate change risk on asset prices. It includes the theoretical analysis of the impact of green investor preferences on corporate finance by Heinkel et al. [16] and subsequent empirical tests of this theory by Chava [48] and Zerbib [54]. Fisher-Vanden and Thorburn [55] tested the stock market's response to voluntary carbon emission disclosures by firms. Furthermore, it includes the analysis of carbon rights prices in the E.U. by Hintermann [49]. In addition, this theme encompasses the studies of Dietz et al. [43] and Battiston et al. [44] that propose methodologies for estimating the impact of climate change risk on the financial sector. The focus of these studies is on developing financial–economic theory and methodology for assessing the impact of climate change on financial assets, as well as empirical tests of the theory. Although Hintermann [43] and Battiston et al. [44] also include some implications for climate change policy, this strand of literature is less focused on policy.

Open issues for further research in this area are more refined modeling of asset losses due to climate change risk (see Hong et al. [1]), as well as how to model drivers of investor green preferences, such as climate change beliefs, perceptions about market failures, and moral values [74,75]. Another direction for future research is to derive more practical policy recommendations from asset pricing studies about how to increase private climate financing (see, e.g., Flammer [76]).

3.4. Co-Citation Analysis

Table 4 shows the 20 most influential documents based on a co-citation analysis. A co-citation occurs when two articles in the climate finance database together cite the same document. Co-citation analysis has the advantage that it extends to the combined reference lists of the articles, thus going beyond the limits of our climate finance database and the Scopus citation database.

Table 4. The 20 most co-cited articles by documents in the climate finance database, 1991–2021.

Rank	Document	Source	Paper Type	Co-Citations
1	Zerbib, O. D. (2019). The effect of pro-environmental preferences on bond prices: Evidence from green bonds [54]	*J. Bank. Finance*	Empirical	62
2	Reboredo, J. C. (2018). Green bond and financial markets: Co-movement, diversification and price spillover effects [19]	*Energy Econ.*	Empirical	52
3	Gianfrate, G., & Peri, M. (2019). The green advantage: Exploring the convenience of issuing green bonds [77]	*J. Clean. Prod.*	Empirical	49
4	Campiglio, E. (2016). Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy [39]	*Ecol. Econ.*	Conceptual	38
5	Wang, Y., & Zhi, Q. (2016). The role of green finance in environmental protection [78]	*Energy Procedia*	Conceptual	38
6	Taghizadeh-Hesary, F., & Yoshino, N. (2019). The way to induce private participation in green finance and investment [60]	*Finance Res. Lett.*	Conceptual	34
7	Hachenberg, B., & Schiereck, D. (2018). Are green bonds priced differently from conventional bonds? [79]	*J. Asset Manag.*	Empirical	33

Table 4. *Cont.*

Rank	Document	Source	Paper Type	Co-Citations
8	Reboredo, J. C., & Ugolini, A. (2020). Price connectedness between green bond and financial markets [20]	*Econ. Model.*	Empirical	31
9	Eyraud, L., Clements, B., & Wane, A. (2013). Green investment: Trends and determinants [80]	*Energy Policy*	Review/Empirical	29
10	Febi, W., et al. (2018). The impact of liquidity risk on the yield spread of green bonds [81]	*Finance Res. Lett.*	Empirical	29
11	Pham, L. (2016). Is it risky to go green? A volatility analysis of the green bond market [82]	*J. Sustain. Finance Invest*	Empirical	28
12	Zhang et al. (2019). A bibliometric analysis on green finance [6]	*Finance Res. Lett.*	Review	27
13	Bachelet, M. J., Becchetti, L., & Manfredonia, S. (2019). The green bonds premium puzzle [83]	*Sustainability*	Empirical	26
14	Broadstock, D. C., & Cheng, L. T. (2019). Time-varying relation between black and green bond price benchmarks [84]	*Finance Res. Lett.*	Empirical	25
15	Chava, S. (2014). Environmental externalities and cost of capital [48]	*Manag. Sci.*	Empirical	24
16	Climent, F., & Soriano, P. (2011). Green and good? The investment performance of U.S. environmental mutual funds [85]	*J. Bus. Ethics*	Empirical	21
17	Fama, E. F., & French, K. R. (1993). Common risk factors in the returns on stocks and bonds [37]	*J. Financ. Econ*	Empirical	21
18	Kumar et al. (2012). Stock prices of clean energy firms, oil and carbon markets [34]	*Energy Econ.*	Empirical	21
19	Tang, D. Y., & Zhang, Y. (2020). Do shareholders benefit from green bonds? [86]	*J. Corp. Finance*	Empirical	21
20	Heinkel et al. (2001). The effect of green investment on corporate behavior [16]	*J. Financial Quant. Anal.*	Conceptual	20

Remarkably, 16 out of the 20 most co-cited articles in Table 4 are on green bonds, green finance, or green investment based on the document title, which we will refer to as the green finance literature. By contrast, among the top 20 most cited papers in the database in Table 3, only three refer to green finance [16,54,60]. We believe there are several possible reasons for the dominance of green finance articles in the co-citation analysis. First, articles in the green finance literature tend to be cited together as a group (of two or more articles) rather than individually, which leads to more co-citations. Second, our keyword co-occurrence map in Section 3.6 shows that the keywords "green finance" and "green bonds" have been frequently used in the most recent climate finance literature since 2019. In other words, green finance is a recently trending topic. Combined with the vast volume of climate finance articles appearing in 2019 and 2020, this may have boosted the number of co-citations to the green finance literature.

The three most co-cited articles in Table 4 all focus on green bonds, which are fixed-income securities that raise capital for climate-related and environmental projects. Zerbib [54] compares the yield on green bonds to the yield on equivalent regular bonds by the same issuer to measure the impact of pro-environmental preferences on bond prices. Zerbib [54] finds that green bond yields are only 2 basis points (0.02%) lower than yields on otherwise equal non-green bonds, an almost negligible premium. Zerbib concludes that social and environmental preferences still have a limited impact on bond yields. He further conjectures that any observed lower cost of debt for companies with good environmental performance (e.g., as documented by Chava [48]) must be due to their lower risk, not due to the impact of investor preferences.

Relatedly, Gianfrate and Peri [77] estimate the yield premium on green bonds using a propensity-matching approach. This method has the advantage that it can also match green

bonds with similar non-green bonds by other issuers. Gianfrate and Peri [77] conclude that issuers can save 15 to 21 basis points in interest rate (yield) when issuing green bonds. This cost advantage of green bonds is important, as climate finance flows need to increase to USD 5 trillion per year by 2030 to achieve the 1.5 °C global warming limit of the Paris agreement, according to estimates by Boehm et al. [3].

Reboredo [19] studies green bonds from the investor perspective, estimating their risk and diversification benefits relative to other investments such as Treasury bonds, corporate bonds, stocks, and energy commodity futures. Reboredo [19] concludes that green bonds have negligible diversification benefits for investors in regular corporate bonds and Treasury bonds, as green bonds are close substitutes. However, green bonds have considerable diversification benefits for investments in stocks and energy markets, having only a weak link to large price fluctuations in those markets. In sum, the literature so far shows that green bonds allow investors to contribute to climate change mitigation efforts without sacrificing much in terms of expected return, while also reducing their overall portfolio risk if they are already invested in equity or energy markets.

3.5. Influential Authors and Sub-Fields in the Climate Finance Literature

We now turn our attention to the most cited authors in the climate finance knowledge base, displayed in Table 5. The most frequently cited author, with 517 citations to 12 articles, is Farhad Taghizadeh-Hesary of Tokai University in Japan. Taghizadeh-Hesary and Yoshino [60,87] propose conceptual frameworks and practical policy recommendations for making the financing of renewable energy projects more attractive and less risky for private investors. For example, the proposed solutions include green credit guarantee schemes, tax credits, and establishing community-based investment funds.

Table 5. The 20 most cited authors publishing climate finance articles by Scopus citations, 1991–2021.

Rank	Author	Institution	Nation	Docs.	Scopus Citations	CPD
1	Farhad Taghizadeh-Hesary	Tokai U	Japan	12	517	43
2	Rolf Wüstenhagen	U of St. Gallen	Switzerland	2	513	257
3	Shunsuke Managi	Kyushu U	Japan	6	408	68
4	Friedemann Polzin	Utrecht U	Netherlands	4	375	94
5	Robert Heinkel	U of British Columbia	Canada	1	362	362
6	Alan Kraus	U of British Columbia	Canada	1	362	362
7	Josef Zechner	U of British Columbia	Canada	1	362	362
8	Emanuela Menichetti	Obs. Méd. de l'Energie	France	2	350	175
9	Naoyuki Yoshino	Keio U	Japan	9	338	38
10	Olaf Weber	U of Waterloo	Canada	7	266	38
11	Mary Jean Bürer	HEIG-VD	Switzerland	1	263	263
12	Irene Monasterolo	Vienna U of Econ. & Business	Austria	6	263	44
13	Surender Kumar	U of Delhi	India	1	225	225
14	Akimi Matsuda	Nomura Securities	Japan	1	225	225
15	Antoine Mandel	Pantheon-Sorbonne U	France	2	219	110
16	Sudheer Chava	Georgia Inst. of Technology	United States	1	215	215
17	Beat Hintermann	U of Basel	Switzerland	2	214	107
18	Michael Migendt	EBS U	Germany	2	205	103
19	Florian A. Täube	CBS Cologne Business School	Germany	2	205	103
20	Juan Carlos Reboredo	U of Santiago de Compostela	Spain	5	204	41

Note: CPD denotes citations per document.

Another highly cited author, with 513 citations to only two articles, is Rolf Wüstenhagen of the University of St. Gallen. Wüstenhagen's research focuses on renewable energy in general, while his two articles in our climate finance database specifically analyze policies that can stimulate investment in renewable energy and minimize risk for investors [46,47].

Shunsuke Managi of Kyushu University in Japan is the third most cited author in the climate finance literature, with six documents. His highly cited works include an empirical

study on the factors driving the prices of clean energy stocks [34] and a study on the drivers of green bond market growth at the country level [88]. Furthermore, Zhang et al. [6] conducted a bibliometric review of the green finance literature, covering 381 papers from 2001 to 2018. In line with our study, Zhang et al. [6] concluded that there was a great lack of articles on green finance in mainstream finance and economics journals.

The fourth most cited author, Friedemann Polzin of Utrecht University in the Netherlands, studies the financing of sustainable innovation and entrepreneurship. His most cited papers in the literature include an empirical study on how different public policies influence renewable energy investments [50], as well as two systematic literature reviews on private finance for renewable energy, focusing on the barriers to investment and possible policy solutions [89,90].

Heinkel, Kraus, and Zechner also feature among the top 10 cited authors in Table 5, as Heinkel et al. [16] is the most cited climate finance article. Their theoretical contribution shows that the presence of green investors who refuse to invest in a polluting firm for ethical reasons will raise the polluting firm's cost of capital. Furthermore, if the proportion of ethical investors is sufficiently large, the increased cost of capital can induce the polluting firm to clean up. Apart from this single influential work in 2001, Heinkel, Kraus, and Zechner have not published other articles on climate finance. Thus, for some of the influential authors in the top 20, climate finance is not a core topic.

A notable exception is Irene Monasterolo, who is a professor of climate finance at EDHEC, France. Monasterolo is a co-author of "A climate stress-test of the financial system" [44], estimating the impact of climate risks on banks and institutional investors. Furthermore, Battiston, Mandel, and Monasterolo [68] developed CLIMAFIN, a tool that financial institutions can use to assess their exposure to physical climate change risks, as well as exposure to transition risks due to the shift toward carbon neutrality. We refer to the literature review of Monasterolo [69] for an overview of climate-related financial risks.

Author Co-Citation Analysis

We now apply author co-citation analysis to group authors into clusters based on the similarity of their co-citations [91,92]. The author co-citation map, shown in Figure 6, can be used to identify sub-fields within the climate finance knowledge base [92,93]. It was generated by using a threshold of at least 20 co-citations and displaying the top 200 authors based on co-citations.

Authors in the yellow cluster in Figure 6 focus on green finance, especially policies that stimulate investment in renewable energy, with Taghizadeh-Hesary, Yoshino, and Mohsin as the most influential authors. Both Farhad Taghizadeh-Hesary and Naoyuki Yoshino are affiliated with a Japanese university, and they frequently collaborate. Their earlier publications focused on the economic effects of fossil fuels [94,95], while their more recent work emphases green finance investments in renewable energy [60,87]. Another large node in this cluster is for the author Muhammad Mohsin, affiliated with Jiangsu University in China. Mohsin's research primarily focuses on environmental sustainability [96] and energy consumption in relation to economic growth [97]. Other notable authors in the yellow cluster include Nadeem Iqbal, Wasim Iqbal, and Abdul Khaliq Rasheed, who have in common that are all based in Asia and have co-authored articles with Mohsin or Taghizadeh-Hesary. In sum, scholars in the yellow cluster are located in Asia and form a close co-authorship network.

Authors in the green cluster are mostly Chinese scholars, affiliated with Chinese universities. Their publications tend to focus on green finance [78] and green bonds [86], topics which are often co-cited in the recent climate finance literature (see Table 4). Furthermore, authors in the green cluster also often study the impact of green finance policies specifically in China [98,99]. The largest node in the green cluster belongs to Yao Wang of the Central University of Finance and Economics (CUFE) in Beijing, China. Yao Wang heads the International Institute of Green Finance (IIGF), a green finance research unit and think tank that promotes the development of green finance in China and abroad.

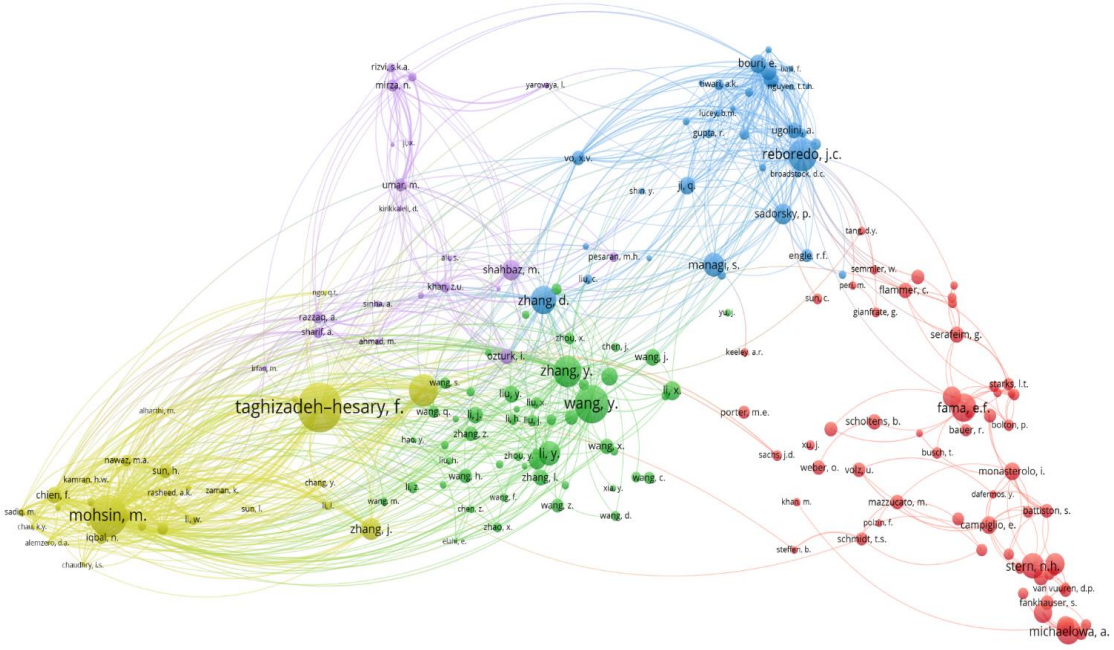

Figure 6. Author co-citation map based on 55,055 authors (threshold 20 co-citations, display top 200).

The purple cluster in Figure 6 groups authors that focus on carbon emissions, energy consumption, and their links with economic development and green finance. Muhammad Shahbaz, Asif Razzaq, and Muhammad Umar are among the notable authors in this group, who are all three from East Asia and affiliated with Chinese universities. These links with Asia may explain why the purple cluster is quite close to both the yellow and green clusters in terms of distance.

Authors in the blue cluster in Figure 6 mostly contribute to the empirical climate finance literature, studying the relation between the prices of green bonds, clean energy stocks, oil prices, and carbon rights. For example, the blue cluster includes Reboredo's [19] study on the link between returns on green bonds and other investments, and the work of Kumar et al. [34] on the stock prices of clean energy firms. Another notable author in the blue cluster is Perry Sadorsky, who also studied the link between clean energy stocks and oil prices [100,101]. Authors in this cluster frequently publish in the journal *Energy Economics*. Dayong Zhang, of the Southwestern University of Finance and Economics in China, is also in the blue cluster and is close to the center of the co-citation map. Zhang co-authored a bibliometric review of the green finance literature together with Shunsuke Managi [6].

Finally, the red cluster, including Nicholas Stern, Irene Monasterolo, and Patrick Bolton, amongst others, is focused on the economic and financial impacts of climate change (e.g., Stern [102]). The authors in this cluster tend to publish more in mainstream economics and finance journals compared to other clusters. Furthermore, co-citations to authors in the red cluster can also refer to general theories and findings in the finance and economics literature that are unrelated to climate change (e.g., Fama and French [37]). Interestingly, and in line with earlier findings, the red financial–economic cluster is quite disconnected from the other author clusters in Figure 6.

In sum, Figure 6 shows groups of frequently co-cited authors in the climate finance literature, with the clusters driven both by common topics as well as by regional co-author social networks. In particular, authors in the yellow, green, and purple clusters are mainly affiliated with universities in Asia, while the authors in the red cluster are mainly with universities in Western countries.

In terms of topics and methodology, green finance and government policies that can stimulate it are central topics for authors in both the yellow and green clusters, with an

emphasis on conceptual papers reviewing policies and empirical papers that test policy effectiveness. Authors in the blue cluster are more focused on empirical studies of clean energy stocks and oil prices, using econometric models to estimate their linkages. Finally, the red cluster is focused on the economic and financial impacts of climate change, with asset pricing and financial risk modeling as the main methodologies.

3.6. Topical Focus of the Climate Finance Literature

We now apply keyword co-occurrence analysis to identify the core topics studied in the climate finance literature. A keyword co-occurrence analysis counts how often keywords are jointly listed by authors, revealing which topics are conceptually similar or are often studied together. Figure 7 shows a keyword co-occurrence map generated with VOSviewer, where the proximity of the keywords in the network map represents the relatedness of the keywords [23]. Furthermore, the different colors in Figure 7 indicate how the popularity of keywords has changed over time [18], shifting from blue colors for earlier climate finance studies (in 2015) to yellow for more recent publications (2019 onward).

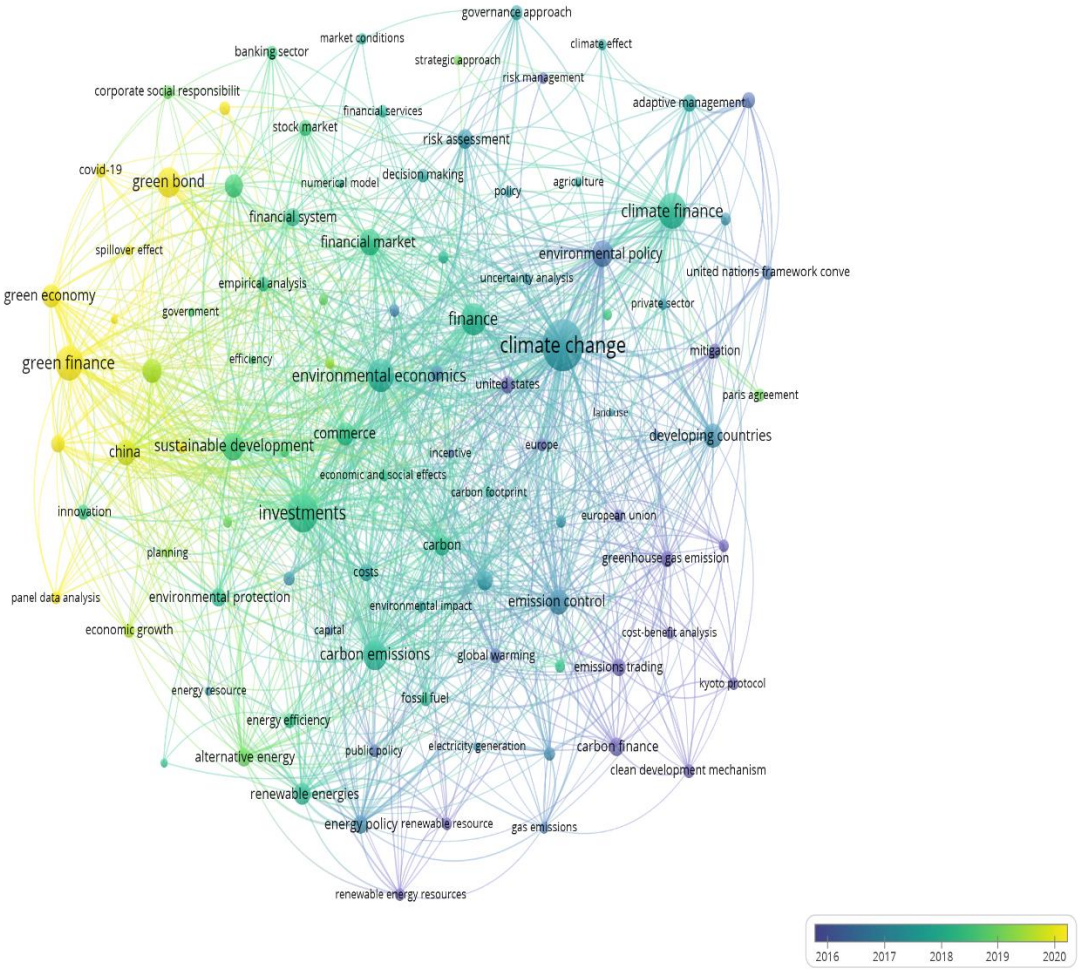

Figure 7. Keyword co-occurrence map with temporal overlay (min. 10 co-occurrences, display top 100).

The most commonly co-occurring keywords in the climate finance literature are "climate change" (470), "climate finance" (229), "green finance" (213), "investments" (276), and "environmental economics" (194). The temporal overlay shows that the focus of the literature has shifted from "carbon finance" and "carbon markets" initially in 2015 to "green finance" and "green bonds" in 2019. This shift in focus was probably stimulated by the substantial increase in green bond issuance since 2016 [76], which also provided finance researchers with new data to study the cost of debt for climate-related investments.

Typical finance keywords such as "Asset pricing" (14), "Financial risk" (10), "Risk management" (26), and "Portfolio diversification" (8) are still rarely mentioned in combination with climate change and other climate finance keywords, again confirming that studies on core finance topics such as the pricing and management of climate change risks are still relatively new in this literature. The next section provides an overview of recent studies on these topics in leading finance journals.

3.7. Recent Contributions in Leading Finance Journals

Our bibliometric review and earlier studies [6,31] revealed that the top field journals in finance have published only a few articles on climate finance so far. In an attempt to address this shortfall, recently in 2020 and 2021, leading finance journals such as the *Rev. Financial Studies* and *J. Financial Economics* published several articles and dedicated special issues on climate finance. Due to their recency, these new articles have not received sufficient citations yet to appear prominently in our bibliometric analysis. However, we expect this strand of literature to become influential in the next few years, as more scholars and journal editors in finance are now focusing on the topic.

For this reason, Table 6 lists the 20 most cited articles in the climate finance database published in the top six finance journals based on the journal ranking of Bajo, Barbi, and Hillier [103] (*J. Financial Economics*, *Rev. Financial Studies*, *J. Finance*, *J. Financial & Quant. Analysis*, *J. Banking & Finance*, and *J. Corporate Finance*). We note that 15 out of the 20 articles (75%) in Table 6 have been published since 2020, compared to only 2 articles (10%) earlier in Table 4, showing how recent the interest in climate finance in the top field journals is. In this section, we briefly review these highly cited finance articles in Table 6 to provide an overview and entry point for interested scholars from other fields.

Table 6. The 20 most cited articles in the climate finance database published in the Top 6 finance journals.

Rank	Document	Source	Paper Type	Scopus Citations
1	Heinkel et al. (2001), The effect of green investment on corporate behavior [16]	*J. Fin. Quant. Anal.*	Conceptual	380
2	Zerbib O.D. (2019), The effect of pro-environmental preferences on bond prices: Evidence from green bonds [54]	*J. Bank. Finance*	Empirical	169
3	Krueger P., Sautner Z., Starks L.T. (2020), The importance of climate risks for institutional investors [104]	*Rev. Fin. Studies*	Empirical	120
4	Tang D.Y., Zhang Y. (2020), Do shareholders benefit from green bonds? [86]	*J. Corporate Finance*	Empirical	108
5	Bernstein A., Gustafson M.T., Lewis R. (2019), Disaster on the horizon: price effect of sea level rise [105]	*J. Financial Economics*	Empirical	91
6	Flammer C. (2021), Corporate green bonds [106]	*J. Financial Economics*	Empirical	69
7	Choi D., Gao Z., Jiang W. (2020), Attention to global warming [12]	*Rev. Fin. Studies*	Empirical	53
8	Engle et al. (2020), Hedging climate change news [107]	*Rev. Fin. Studies*	Conceptual/ Empirical	53
9	Pedersen L.H., Fitzgibbons S., Pomorski L. (2021), Responsible investing: The ESG-efficient frontier [108]	*J. Financial Economics*	Conceptual/ Empirical	44
10	Bolton P., Kacperczyk M. (2021), Do investors care about carbon risk? [109]	*J. Financial Economics*	Empirical	42
11	Baldauf M., Garlappi L., Yannelis C. (2020), Does climate change affect real estate prices? [110]	*Rev. Fin. Studies*	Empirical	37
12	Hong et al. (2020), Climate finance [1]	*Rev. Fin. Studies*	Review	35
13	Ilhan E., Sautner Z., Vilkov G. (2021), Carbon Tail Risk [111]	*Rev. Fin. Studies*	Empirical	33
14	Barnett M., Brock W., Hansen L.P. (2020), Pricing uncertainty induced by climate change [112]	*Rev. of Fin. Studies*	Conceptual	32

Table 6. *Cont.*

Rank	Document	Source	Paper Type	Scopus Citations
15	Painter M. (2020), An inconvenient cost: The effects of climate change on municipal bonds [113]	*J. Financial Economics*	Empirical	31
16	Murfin J., Spiegel M. (2020), Is the risk of sea level rise capitalized in residential real estate? [114]	*Rev. Fin. Studies*	Empirical	24
17	Pástor, Stambaugh R.F., Taylor L.A. (2021), Sustainable investing in equilibrium [115]	*J. Financial Economics*	Conceptual	22
18	Eichholtz P., et al. (2019), Environmental performance and the cost of debt: Evidence from commercial mortgages and REIT bonds [116]	*J. Bank. Finance*	Empirical	22
19	Alok S., Kumar N., Wermers R. (2020), Do fund managers misestimate climatic disaster risk [117]	*Rev. Fin. Studies*	Empirical	17
20	Balvers R., Du D., Zhao X. (2017), Temperature shocks and the cost of equity capital [118]	*J. Bank. Finance*	Empirical	17

The two most cited articles in leading finance journals are Heinkel et al. [16] and Zerbib [54], with 380 and 169 citations, respectively. As mentioned earlier, the theoretical work of Heinkel et al. [16] analyzed how the presence of green investors can increase the cost of capital for a polluting firm. Zerbib [54] empirically tested whether yields on green bonds for climate-related projects are lower compared to equivalent non-green bonds due to the impact of pro-environmental investor preferences, finding an insignificant yield premium.

Relatedly, Flammer [106] analyses why companies issue green bonds for climate-change-related projects. As the proceeds of the bonds cannot be used for other projects and a green bond needs to be certified, it would be easier to simply issue a general corporate bond to obtain funds. Flammer [106] argues that green bonds can be preferred by companies for three possible reasons: to signal a commitment to pro-environmental policies, as a form of green-washing without commitment to greener policies, and as a way to reduce the cost of finance. Flammer [106] examines all three motivations empirically and finds that issuers of green bonds improve their environmental performance after issuance by lowering CO_2 emissions. Subsequently, these firms also receive better environmental ratings from rating agencies. In addition, stock prices react positively to news about a green bond issuance, especially the first time a company issues them. Flammer does not find a significant difference in yields between green bonds and matched non-green bonds issued by other companies, suggesting that obtaining a lower borrowing cost is not a primary motive. Flammer [106] concludes that companies issue green bonds as a credible signal of their commitment to reducing their environmental impact.

Directly related and consistent with Flammer [106], Tang and Zhang [86] also find that the stock market reacts positively when a firm issues a green bond, especially the first time, and that green bonds do not provide lower financing costs (yields) for issuers. Furthermore, Tang and Zhang [86] document that stock liquidity improves and institutional ownership increases after a company issues a green bond, suggesting that green bond issuers can attract more media attention and expand their investor base (e.g., ethical investors and impact investors). Hence, despite the fact that there is no direct payback in terms of a lower borrowing rate, green bonds offer several other benefits to issuers, such as signaling a commitment to green policies, a higher stock price, better stock liquidity, and attracting new investors.

Another important topic is whether the market prices the risk of climate change. One complicating factor is that climate change is a long-term risk, and companies have time to mitigate the impact. For example, companies can relocate to reduce physical climate risks (e.g., flooding or extreme heat) and adapt their processes to limit indirect climate risks (e.g., switching to renewable energy sources). Therefore, studies about the pricing of climate change risk often focus on assets tied to a specific location, such as real estate and

municipal bonds. For example, some counties and cities in the United States are exposed to much higher sea-level-rise risk, such as New Orleans and New York. Painter [113] analyzes the yield on municipal bonds and finds that counties exposed to climate risk pay significantly higher borrowing costs on longer-maturity bonds. Hence, investors in the municipal bond market appear to identify counties subject to higher climate risk and price their bonds lower accordingly. Relatedly, Eichholtz et al. [116] show that mortgages on environmentally certified buildings have lower interest rates than comparable non-green buildings, implying that banks and investors recognize the lower risk and higher income associated with energy-saving policies.

There is evidence suggesting that the real estate market also prices climate change risks, as Bernstein et al. [105] show that coastal properties exposed to sea-level-rise (SLR) risk sell at a 7% discount compared to otherwise similar homes. Interestingly, Bernstein et al. [105] find that the discount is mainly driven by properties that are not expected to be flooded in the next 50 years, suggesting that markets are already pricing the long-horizon costs of climate change. Furthermore, the rents of these high-SLR-risk properties are not affected, confirming that expected long-term damage drives the discount in property prices (rather than any short-term impacts). On the contrary, Murfin and Spiegel [114] find that SLR risk is not priced yet in U.S. residential real estate. Several factors can explain these contrasting results; for example, SLR risk may be priced only by more sophisticated real estate investors and those who believe in climate change. Supporting that explanation, Baldauf et al. [110] show that local beliefs about climate change in the United States to a large extent determine whether there is a price discount for houses affected by flood risk.

A related research topic is whether stock markets discount the value of listed companies with high climate change risk exposure. Bolton and Kacperczyk [109] report evidence that they do, as stocks of firms with higher CO_2 emissions earn significantly higher stock returns, especially after the 2015 Paris Agreement. Bolton and Kacperczyk interpret this result as follows: Investors realize that firms with higher CO_2 emissions are subject to future regulatory risks, such as limits on emissions and carbon pricing schemes, as well as high competitive risks from new entrants with better technology (e.g., using renewables). As a compensation for these risks, investors require a higher expected stock return for investing in "brown" firms with high CO_2 emissions. This also implies that brown firms face a higher cost of capital, raising the hurdle rate for their expansion plans. Relatedly, Balvers et al. [118] find that exposure to temperature shock risk also raises the cost of equity capital.

Pástor et al. [115] analyze how climate risk exposure and the environmental preferences of investors should impact stock prices in equilibrium. Their model predicts that green stocks have relatively low expected returns due to their lower climate change risk and investors' preference for holding them, whereas brown stocks have higher expected returns for the opposite reasons. A follow-up empirical study by Pástor, Stambaugh, and Taylor [119] investigates why in practice green stocks can temporarily deliver stronger performance than brown stocks. This tends to happen when there are unexpected increases in investor preferences for green investments (e.g., large flows to ESG funds) or shocks that raise investor awareness about climate change risk (e.g., extreme weather events or new environmental regulations). Choi et al. [12] indeed find that stocks of carbon-intensive firms perform poorly when the weather is abnormally warm and investors pay more attention to climate change risks, as evidenced by increased Google search volume.

Hence, although brown stocks earn higher expected returns in the long-term to compensate for their higher risk exposure, they will go through bouts of underperformance when there is news that heightens awareness about climate change risk or worsens investors' dislike of these stocks. Engle et al. [107] show how investors can hedge this risk by investing in a stock portfolio that tends to perform well when negative climate risk news arrives. Relatedly, Andersson, Bolton, and Samama [120] create portfolios of low-carbon-emission stocks that closely track a broad market index like the S&P 500 to reduce exposure to climate change risk. Ilhan et al. [111] show that the cost of downside risk protection in

the options market is more expensive for U.S. firms with high carbon emissions and that this cost differential increases when there is negative news about climate risks.

Apart from studying asset prices, finance researchers have also directly surveyed investors to ask how they deal with climate change risk. A survey by Krueger et al. [104] confirms that most institutional investors are concerned about climate change risk and that they have already acted to manage or reduce their exposure in the previous five years. For example, they integrated ESG into their investment process, analyzed their portfolio's carbon footprint and stranded asset risk, or went even further by actively reducing those exposures. About 25% of the institutional investors in the survey already hedged climate risk or took it into account in their valuation models. Interestingly, divestment was the least employed risk management strategy (by 20%). Investors rather preferred to engage in discussions with firm managers about the financial consequences of climate risks. The surveyed investors also believed that stock valuations already reflect climate change risk to a large extent, although not yet fully. Relatedly, Pedersen et al. [108] propose an equilibrium framework for analyzing the costs and benefits of responsible investing.

One of the complexities for investors who aim to manage climate change risks is that the possible trajectory of climate change and its impacts are subject to great uncertainty, involving different climate models and their parameters (scientific uncertainty), future policy responses (policy uncertainty), and mitigation efforts by companies and households (economic uncertainty). Uncertainty is a form of ambiguity [121], where both the future outcomes and their probabilities are not known exactly. Barnett et al. [112] propose a modeling framework that can price the social costs of this ambiguity due to climate change using asset pricing techniques from the finance literature.

For more information on the recent climate finance literature publications in mainstream journals in Table 6, we refer readers to literature reviews by Hong et al. [1], Giglio et al. [2], and Campiglio et al. [70]. In their introduction to a special issue about climate finance, Hong et al. [1] provide an overview of recent climate finance research in leading finance journals and several interesting avenues for new research. Giglio et al. [2] and Campiglio et al. [70] review the climate finance literature with an emphasis on asset pricing and financial risks.

Topics and Methodologies in the Most Cited Finance Articles

We now summarize the common topics and methodologies in the top 20 most cited articles in top finance journals. First of all, 16 out of 20 study the impact of climate change risk on asset prices. This strand of literature includes the theoretical analysis of the impact of green investor preferences on corporate finance by Heinkel et al. [16] and the equilibrium asset pricing models with ESG investors and climate change risk of Pástor et al. [115] and Pedersen et al. [108]. It also includes several empirical studies that test the impact of climate change risk on asset prices for real estate prices [105,110,114], stock prices [12,109,118], municipal bonds [113], stock options [111], and green bonds [54,86,106]. Relatedly, Engle et al. [107] propose a novel methodology for hedging climate change risk with a long–short stock portfolio.

Thus, climate finance studies in the top field journals focus on: (1) extending asset pricing theory to include climate change risk and investor ESG preferences, (2) testing these theories with large financial datasets, and (3) developing methodologies for measuring and hedging the financial risks of climate change. Absent in leading finance journals are the type of policy-oriented articles that are among the most frequently cited in the wider climate finance literature (see Table 3). More generally, missing in articles published in top finance journals are the notions that market failures and behavioral biases require policy intervention by governments to avert a climate crisis, as argued by Nordhaus [66,122] and Stern [102], and that more private climate finance flows need to be mobilized urgently. As Diaz-Rainey et al. [31] argued, top finance journals prefer to focus on selected theoretical models and their empirical tests, while ignoring practical problems that require a forward-looking mindset. Another explanation is that top finance journals have chief editors that are

nearly all based in the United States, where climate change beliefs are politically polarized and support for public policy interventions in free markets is low.

The methodologies applied in the finance literature in Table 6 are generally rigorous, but they are also limited due to the emphasis on the rational actions of firms, consumers, and investors in free markets. The models could be extended further to include environmental externalities, market failures, behavioral biases, and moral beliefs as driving forces of investor ESG preferences and government interventions (e.g., carbon taxes and cap-and-trade systems). Without such extensions, it is hard to fully assess the long-term financial impacts of climate change, as shifts in investor ESG preferences and regulatory interventions by policymakers that could leave carbon assets stranded to remain a deus ex machina. Another direction for increasing the relevance of the research is to provide more practical recommendations for stimulating climate finance flows, such as Flammer [76] and Blanchard, Gollier, and Tirole [123] recently did.

4. Limitations

The purpose of this research review was to document the number of articles on climate finance published over the years, to identify the most cited articles, and to highlight groups of journals and authors that are often jointly cited. For this purpose, we applied a bibliometric analysis to publication records from the Scopus citation database, analyzing 1347 articles published between 1991 and 2022. We also summarized the main research topics studied in the climate finance literature in the past and present, using both a keyword analysis and a substantive review of the most frequently cited articles.

One limitation of the bibliometric review is that our combination of search terms may not have identified all relevant climate finance studies in the Scopus citation database. For this reason, the authors cross-checked the reference lists of the 70 review-type articles found in the search and added 102 articles that were undetected initially. However, we may still have missed some relevant related articles. For example, some of the literature on sustainable and ESG investing may also be relevant for climate finance but is excluded from our search. We decided not to extend the scope of our search further, as otherwise the number of articles included would become too large to analyze effectively (e.g., complicating manual screening of the content), or the database would consist of many articles without direct relevance to climate finance.

Another limitation of a bibliometric review is that citation counts can be increased by social networks of (co-)authors who frequently cite each other, and by editors who explicitly ask authors to cite recently published studies in their journals to raise the impact factor. For example, in the author co-citation analysis in Figure 6, we noted clusters of authors in Asia that frequently collaborate on green finance articles. In addition, citation analysis is backward-looking and puts less emphasis on recently published articles that have had less time to accumulate high citation counts. We countered this drawback by adding a separate review of articles in top finance journals (Table 6), which have only recently started to publish more climate finance articles; 15 out of the 20 reviewed articles were published since 2020.

One limitation of our substantive review of the article contents and findings is that it may reflect the interests and biases of the authors, who are both finance scholars. This limitation was partially alleviated through the use of the bibliometric analysis and limiting our summary of the literature to the top 20 most frequently cited papers only. We subjectively decided to add the top 20 articles in six leading finance journals to the review in a separate section. Our aim was to account for the fact that mainstream finance journals have only recently started to publish more climate finance articles (since 2019), and we expect these new contributions to become highly cited in the future.

5. Conclusions

Our bibliometric review reveals that the climate finance literature has grown exponentially, especially from 2015 onwards. The annual number of climate finance articles in the

Scopus citation database has grown more than fivefold from 68 per year in 2016 to 369 in 2021. Drivers of this surge in interest likely include the adoption of the Paris Agreement in 2015 that aims to limit the increase in global average temperature to well below 2 °C and that intends to make finance flows consistent with a path towards significantly lower greenhouse gas emissions. Since 2015 there has also been a large increase in global climate finance flows [5] and a boom in green bond issuance to finance climate-related projects [76]. An analysis of keywords shows that the focus of the literature has shifted from an initial focus on "carbon finance" and "carbon markets" in 2015 to "green finance" and "green bonds" more recently in 2019.

In terms of geographical distribution, authors affiliated with universities in the E.U. countries produced 27% of the climate finance documents, followed by China (14%), the United States (12%), and the United Kingdom (9%). Western European countries contribute a larger proportion of climate finance studies compared to their share in global scientific output, while for the United States the pattern is the opposite. This is probably the result of the E.U.'s lead in climate change policy since the early 1990s, while in the United States climate change is a politically polarized issue and support for federal policy intervention has been less consistent through the years. Our review shows that the most cited articles in the climate finance literature tend to have authors from Europe, while the senior editors of the journals that publish most climate finance articles tend to be based outside the United States as well.

Climate finance is truly a multidisciplinary topic, as the literature is published in environmental science, energy, economics, and finance journals, as well as interdisciplinary journals. The most influential climate finance journal in terms of total citation count is *Energy Policy*, followed by the *J. Cleaner Production* and *Climate Policy*. Other often cited journals are *Energy Economics*, *Ecological Economics*, and *Financial Research Letters*. A close inspection of the most cited journals and articles showed that one of the leading topics in the literature is the financing of renewable energy transitions, as well as policies that encourage more private investments in renewable energy.

A journal co-citation analysis revealed a large cluster of journals focusing on energy policy, cleaner production, and sustainability (e.g., *Energy Policy* and *J. Cleaner Production*). Furthermore, the literature on climate change and environmental science is another important foundation for research in climate finance. In addition, the journal co-citation map identified a group of non-core journals in economics and finance like *Energy Economics*, *Finance Research Letters*, and the *J. Sustainable Finance & Investment* that have shown an early focus on climate finance and are often cited together, separately from mainstream journals in finance and economics, which are in two separate clusters.

Remarkably, the four leading field journals in finance (*J. Financial Economics*, *J. Finance*, *Rev. Financial Studies*, and *J. Financial & Quant. Analysis*) together have published only 22 of the 1347 articles in our climate finance database. This reconfirms the earlier findings of Diaz-Rainey et al. [31] and Zhang et al. [6] that mainstream finance and economics journals did not show interest in the topic. A potential explanation put forward by Diaz-Rainey et al. [31] is that finance as a discipline ignores practical problems that require a forward-looking and cross-disciplinary mindset and instead prefers to focus on deriving and testing selected theoretical models. Furthermore, the senior editors of top finance journals are almost exclusively based in the United States, where beliefs about climate change are more polarized and there is less support for federal climate change policies than in Europe. However, attitudes are shifting, as our results show that leading finance journals have recently started to publish more research on climate finance since 2019, including several dedicated special issues. We have reviewed this nascent literature in a separate section, as we expect it to become more influential in terms of citations in the coming years.

We can identify four major themes among the most cited articles in the literature that we reviewed. The first theme is the study of renewable energy financing and policies that can stimulate more private investments in renewable energy projects. Frequently cited contributions include Barradale [57], Delmas and Montes-Sancho [53], Wüstenhagen and

Menichetti [47], Polzin et al. [50], and Taghizadeh-Hesary and Yoshino [60,87], amongst others. The leading outlet for articles on this topic is *Energy Policy*. Articles in this group tend to have a practical focus and are among the earliest influential publications in the climate finance literature, apart from Heinkel et al. [16]. For future research, this strand of literature could benefit from integrating more theoretical frameworks from the economics and finance literature as the basis for policy recommendations. Furthermore, as technological innovation and economies of scale have greatly reduced the cost of renewable energy recently, the optimal policies can change over time and need to be reassessed regularly.

A second major theme consists of studies that try to estimate the impact of climate change risks on the financial sector and global financial markets. Primary contributions are by Dietz et al. [43] and Battiston et al. [44], both published in *Nature Climate Change*. This group of studies develops new methods that allow financial institutions and investors to assess the impact of climate change risk on their balance sheets. It has led to new tools such as "climate value-at-risk" and "climate stress tests" that can be integrated into existing financial risk management frameworks. We refer to Battiston et al. [68] and Monasterolo [69] for recent work in this area. Relatedly, Krueger et al. [104] recently surveyed institutional investors about their perceptions of climate change and their ways of dealing with the associated risks. Open issues for further research in this area are more refined modeling of the asset losses due to climate change risk (see Hong et al. [1]), as well as how to model shifts in investor preferences, new technology, and government policy that trigger stranded asset risk.

The third main theme is the effect of investor preferences for green investments on corporate behavior and the cost of capital. An early theoretical work in this area by Heinkel et al. [16] is the most cited article in the climate finance literature. Another influential article is an empirical study by Chava [48], documenting that investors demand a higher cost of capital for listed companies that do not pass environmental screenings. A recent focal area of study is green bonds for financing climate-related projects. Why do companies issue green bonds, what are the benefits to investors, and what is their yield premium compared to regular bonds? Key studies on green bonds are Reboredo [19], Zerbib [54], Gianfrate and Peri [77], and Flammer [106], which are often co-cited together as a group. This strand of literature has made great progress in analyzing green bond datasets that have recently become available, but there is still relatively little research on how corporations adapt to climate change risk and shifts in investor preferences for sustainability. More evidence is also needed on the drivers of investor ESG preferences, such as climate change beliefs, perceptions about market failures, and moral values [74,75].

A fourth theme consists of the pricing and hedging of climate change risk in financial markets. The most frequently cited early contribution is by Hintermann [49] in the *J. of Environmental Economics and Management*, who developed and tested an economic model for the prices of E.U. carbon emission rights. Our review reveals that leading finance-field journals have recently published several studies on the impact of climate change risk on the prices of stocks [109], options [111], residential real estate [105,110,114], and municipal bonds [113]. The findings of these studies reveal that financial markets already discount long-term climate change risks today and that assets with high exposure trade at a discount, although the full extent of these risks may not yet be fully priced in [70]. We note that most empirical studies are based on datasets up to 2017, while since then there have been large increases in sustainable fund flows, major changes in climate change policies (e.g., in the United States under the Biden administration), and several attention-grabbing extreme climate events globally. New research is therefore needed to test whether financial markets are pricing climate change risk more efficiently nowadays. Another direction for future research is to provide more practical recommendations that can stimulate climate finance flows, rather than only focusing on asset pricing theories and their empirical tests; see Flammer [76] and Blanchard et al. [123], for example.

In stark contrast to the large strand of asset pricing research in climate finance, the corporate response to climate change risk and ESG investor preferences is much less

explored in the literature. Future research could investigate behavioral biases of managers, such as status quo bias, ambiguity aversion, and path-dependency in investment decisions, that can deter investment in new technology for climate change mitigation. Another important topic for future research is the role of investor activism and boards of directors in guiding corporate strategy and investments toward achieving lower CO_2 emissions and reducing exposure to climate change risk [124]. Also, a less explored topic is how to integrate climate change mitigation and adaption into investment models and project evaluations under uncertainty [125,126].

Furthermore, an essential area for further research is the funding of technological innovations in the corporate sector that can help mitigate climate change risks, such as carbon capture and storage (see, e.g., Chen, Wang, and Ye [127]). Another important issue for future research is how private climate finance flows can be stimulated in developing countries that lack large domestic institutional investors [128]. Finally, new studies could focus on financial innovations that can make markets for carbon rights and carbon offsets more liquid, efficient, and accessible to corporations and investors worldwide [129,130]. In conclusion, although the climate finance literature has grown exponentially recently, there are still many important unanswered questions and unexplored areas for further study in the coming years.

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References

1. Hong, H.; Karolyi, G.A.; Scheinkman, J.A. Climate finance. *Rev. Financ. Stud.* **2020**, *33*, 1011–1023. [CrossRef]
2. Giglio, S.; Kelly, B.; Stroebel, J. Climate finance. *Annu. Rev. Financ. Econ.* **2021**, *13*, 15–36. [CrossRef]
3. Boehm, S.; Lebling, K.; Levin, K.; Fekete, H.; Jaeger, J.; Waite, R.; Nilsson, A.; Thwaites, J.; Wilson, R.; Geiges, A.; et al. State of Climate Action 2021: Systems Transformations Required to Limit Global Warming to 1.5 °C. World Resources Institute, 2021. Available online: https://www.wri.org/research/state-climate-action-2021 (accessed on 2 January 2023).
4. UNEP. Adaptation Gap Report 2022. UN Environment Programme, 2022. Available online: https://www.unep.org/resources/adaptation-gap-report-2022 (accessed on 2 January 2023).
5. Naran, B.; Connolly, J.; Rosane, P.; Wignarajah, D.; Wakaba, E.; Buchner, B. Global Landscape of Climate Finance: A Decade of Data 2011–2020. Climate Policy Initiative, 2022. Available online: https://www.climatepolicyinitiative.org/publication/global-landscape-of-climate-finance-a-decade-of-data (accessed on 2 January 2023).
6. Zhang, D.; Zhang, Z.; Managi, S. A bibliometric analysis on green finance: Current status, development, and future directions. *Finance Res. Lett.* **2019**, *29*, 425–430. [CrossRef]
7. Vieira, E.S.; Gomes, J.A. A comparison of Scopus and Web of Science for a typical university. *Scientometrics* **2009**, *81*, 587–600. [CrossRef]
8. Yu, X.; Mao, Y.; Huang, D.; Sun, Z.; Li, T. Mapping Global Research on Green Finance from 1989 to 2020: A Bibliometric Study. *Adv. Civ. Eng.* **2021**, *2021*, 9934004. [CrossRef]
9. Hallinger, P.; Kovačević, J. A bibliometric review of research on educational administration: Science mapping the literature, 1960 to 2018. *Rev. Educ. Res.* **2019**, *89*, 335–369. [CrossRef]
10. Zheng, C.; Kouwenberg, R. A Bibliometric Review of Global Research on Corporate Governance and Board Attributes. *Sustainability* **2019**, *11*, 3428. [CrossRef]
11. Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Int. J. Surg.* **2010**, *8*, 336–341. [CrossRef]
12. Choi, D.; Gao, Z.; Jiang, W. Attention to global warming. *Rev. Financ. Stud.* **2020**, *33*, 1112–1145. [CrossRef]

13. Osareh, F. Bibliometrics, citation analysis and co-citation analysis: A review of literature I. *Libri* **1996**, *46*, 149–158. [CrossRef]
14. Meho, L.I. The rise and rise of citation analysis. *Phys. World* **2007**, *20*, 32. [CrossRef]
15. Hallinger, P. A meta-synthesis of bibliometric reviews of research on managing for sustainability, 1982–2019. *Sustainability* **2021**, *13*, 3469. [CrossRef]
16. Heinkel, R.; Kraus, A.; Zechner, J. The effect of green investment on corporate behavior. *J. Financ. Quant. Anal.* **2001**, *36*, 431–449. [CrossRef]
17. Small, H. Co-citation in the scientific literature: A new measure of the relationship between two documents. *J. Assoc. Inf. Sci.* **1973**, *24*, 265–269. [CrossRef]
18. Zupic, I.; Čater, T. Bibliometric methods in management and organization. *Organ. Res. Methods* **2015**, *18*, 429–472. [CrossRef]
19. Reboredo, J.C. Green bond and financial markets: Co-movement, diversification and price spillover effects. *Energy Econ.* **2018**, *74*, 38–50. [CrossRef]
20. Reboredo, J.C.; Ugolini, A. Price connectedness between green bond and financial markets. *Econ. Model.* **2020**, *88*, 25–38. [CrossRef]
21. Piñeiro-Chousa, J.; López-Cabarcos, M.Á.; Šević, A. Green bond market and Sentiment: Is there a switching Behaviour? *J. Bus. Res.* **2022**, *141*, 520–527. [CrossRef]
22. Hallinger, P.; Suriyankietkaew, S. Science Mapping of the Knowledge Base on Sustainable Leadership, 1990–2018. *Sustainability* **2018**, *10*, 4846. [CrossRef]
23. Bornmann, L.; Haunschild, R.; Hug, S.E. Visualizing the context of citations referencing papers published by Eugene Garfield: A new type of keyword co-occurrence analysis. *Scientometrics* **2018**, *114*, 427–437. [CrossRef]
24. Radhakrishnan, S.; Erbis, S.; Isaacs, J.A.; Kamarthi, S. Novel keyword co-occurrence network-based methods to foster systematic reviews of scientific literature. *PLoS ONE* **2017**, *12*, e0172778. [CrossRef]
25. Zhang, J.; Xie, J.; Hou, W.; Tu, X.; Xu, J.; Song, F.; Wang, Z.; Lu, Z. Mapping the knowledge structure of research on patient adherence: Knowledge domain visualization based co-word analysis and social network analysis. *PLoS ONE* **2012**, *7*, e34497. [CrossRef] [PubMed]
26. UNFCCC. Decision 1/CP.21: Adoption of the Paris Agreement, UNFCCC Secretariat, Bonn. 2015. Available online: https://unfccc.int/resource/docs/2015/cop21/eng/10a01.pdf (accessed on 2 January 2023).
27. OECD. *Aggregate Trends of Climate Finance Provided and Mobilised by Developed Countries in 2013–2020*; OECD Publishing: Paris, France, 2022. [CrossRef]
28. Pew Research Center. In Response to Climate Change, Citizens in Advanced Economies Are Willing To Alter How They Live and Work. 2021. Available online: https://www.pewresearch.org/global/2021/09/14/in-response-to-climate-change-citizens-in-advanced-economies-are-willing-to-alter-how-they-live-and-work (accessed on 2 January 2023).
29. Thelwall, M.; Sud, P. Scopus 1900–2020: Growth in articles, abstracts, countries, fields, and journals. *Quant. Sci. Stud.* **2022**, *3*, 37–50. [CrossRef]
30. Ritchie, H.; Roser, M.; Rosado, P. *CO_2 and Greenhouse Gas Emissions. Our World in Data, 2020*. Available online: https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions (accessed on 2 January 2023).
31. Diaz-Rainey, I.; Robertson, B.; Wilson, C. Stranded research? Leading finance journals are silent on climate change. *Clim. Chang.* **2017**, *143*, 243–260. [CrossRef]
32. Goodall, A.H. Why have the leading journals in management (and other social sciences) failed to respond to climate change? *J. Manag. Inq.* **2008**, *17*, 408–420. [CrossRef]
33. Waltman, L.; Van Eck, N.J.; Noyons, E.C. A unified approach to mapping and clustering of bibliometric networks. *J. Informetr.* **2010**, *4*, 629–635. [CrossRef]
34. Kumar, S.; Managi, S.; Matsuda, A. Stock prices of clean energy firms, oil and carbon markets: A vector autoregressive analysis. *Energy Econ.* **2012**, *34*, 215–226. [CrossRef]
35. Griffin, P.A.; Jaffe, A.M.; Lont, D.H.; Dominguez-Faus, R. Science and the stock market: Investors' recognition of unburnable carbon. *Energy Econ.* **2015**, *52*, 1–12. [CrossRef]
36. Ziegler, A.; Busch, T.; Hoffmann, V.H. Disclosed corporate responses to climate change and stock performance: An international empirical analysis. *Energy Econ.* **2011**, *33*, 1283–1294. [CrossRef]
37. Fama, E.F.; French, K.R. Common risk factors in the returns on stocks and bonds. *J. Financ. Econ.* **1993**, *33*, 3–56. [CrossRef]
38. Busch, T.; Hoffmann, V.H. Emerging carbon constraints for corporate risk management. *Ecol. Econ.* **2007**, *62*, 518–528. [CrossRef]
39. Campiglio, E. Beyond carbon pricing: The role of banking and monetary policy in financing the transition to a low-carbon economy. *Ecol. Econ.* **2016**, *121*, 220–230. [CrossRef]
40. Dafermos, Y.; Nikolaidi, M.; Galanis, G. Climate change, financial stability and monetary policy. *Ecol. Econ.* **2018**, *152*, 219–234. [CrossRef]
41. Modigliani, F.; Miller, M.H. The cost of capital, corporation finance and the theory of investment. *Am. Econ. Rev.* **1958**, *48*, 261–297.
42. Acemoglu, D.; Aghion, P.; Bursztyn, L.; Hemous, D. The environment and directed technical change. *Am. Econ. Rev.* **2012**, *102*, 131–166. [CrossRef]
43. Dietz, S.; Bowen, A.; Dixon, C.; Gradwell, P. 'Climate value at risk'of global financial assets. *Nat. Clim. Chang.* **2016**, *6*, 676–679. [CrossRef]
44. Battiston, S.; Mandel, A.; Monasterolo, I.; Schütze, F.; Visentin, G. A climate stress-test of the financial system. *Nat. Clim. Chang.* **2017**, *7*, 283–288. [CrossRef]

45. Campiglio, E.; Dafermos, Y.; Monnin, P.; Ryan-Collins, J.; Schotten, G.; Tanaka, M. Climate change challenges for central banks and financial regulators. *Nat. Clim. Chang.* **2018**, *8*, 462–468. [CrossRef]
46. Bürer, M.J.; Wüstenhagen, R. Which renewable energy policy is a venture capitalist's best friend? Empirical evidence from a survey of international cleantech investors. *Energy Policy* **2009**, *37*, 4997–5006. [CrossRef]
47. Wüstenhagen, R.; Menichetti, E. Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research. *Energy Policy* **2012**, *40*, 1–10. [CrossRef]
48. Chava, S. Environmental externalities and cost of capital. *Manag. Sci.* **2014**, *60*, 2223–2247. [CrossRef]
49. Hintermann, B. Allowance price drivers in the first phase of the EU ETS. *J. Environ. Econ. Manag.* **2010**, *59*, 43–56. [CrossRef]
50. Polzin, F.; Migendt, M.; Täube, F.A.; von Flotow, P. Public policy influence on renewable energy investments—A panel data study across OECD countries. *Energy Policy* **2015**, *80*, 98–111. [CrossRef]
51. Awerbuch, S. Portfolio-based electricity generation planning: Policy implications for renewables and energy security. *Mitig. Adapt. Strateg. Glob. Chang.* **2006**, *11*, 693–710. [CrossRef]
52. Luo, L.; Lan, Y.C.; Tang, Q. Corporate incentives to disclose carbon information: Evidence from the CDP Global 500 report. *J. Int. Financ. Manag. Account.* **2012**, *23*, 93–120. [CrossRef]
53. Delmas, M.A.; Montes-Sancho, M.J.U.S. state policies for renewable energy: Context and effectiveness. *Energy Policy* **2011**, *39*, 2273–2288. [CrossRef]
54. Zerbib, O.D. The effect of pro-environmental preferences on bond prices: Evidence from green bonds. *J. Bank. Financ.* **2019**, *98*, 39–60. [CrossRef]
55. Fisher-Vanden, K.; Thorburn, K.S. Voluntary corporate environmental initiatives and shareholder wealth. *J. Environ. Econ. Manag.* **2011**, *62*, 430–445. [CrossRef]
56. Dinica, V. Support systems for the diffusion of renewable energy technologies—An investor perspective. *Energy Policy* **2006**, *34*, 461–480. [CrossRef]
57. Barradale, M.J. Impact of public policy uncertainty on renewable energy investment: Wind power and the production tax credit. *Energy Policy* **2010**, *38*, 7698–7709. [CrossRef]
58. Ellis, J.; Winkler, H.; Corfee-Morlot, J.; Gagnon-Lebrun, F. CDM: Taking stock and looking forward. *Energy Policy* **2007**, *35*, 15–28. [CrossRef]
59. Otto, I.M.; Donges, J.F.; Cremades, R.; Bhowmik, A.; Hewitt, R.J.; Lucht, W.; Rockström, J.; Allerberger, F.; McCaffrey, M.; Doe, S.S.P.; et al. Social tipping dynamics for stabilizing Earth's climate by 2050. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 2354–2365. [CrossRef] [PubMed]
60. Taghizadeh-Hesary, F.; Yoshino, N. The way to induce private participation in green finance and investment. *Financ. Res. Lett.* **2019**, *31*, 98–103. [CrossRef]
61. Huynh, T.D.; Xia, Y. Climate change news risk and corporate bond returns. *J. Financ. Quant. Anal.* **2021**, *56*, 1985–2009. [CrossRef]
62. Dutta, A.; Bouri, E.; Noor, M.H. Return and volatility linkages between CO2 emission and clean energy stock prices. *Energy* **2018**, *164*, 803–810. [CrossRef]
63. Hintermann, B.; Peterson, S.; Rickels, W. Price and Market Behavior in Phase II of the EU ETS: A Review of the Literature. *Rev. Environ. Econ. Policy* **2016**, *10*, 108–128. [CrossRef]
64. Dechezleprêtre, A.; Nachtigall, D.; Venmans, F. The joint impact of the European Union emissions trading system on carbon emissions and economic performance. *J. Environ. Econ. Manag.* **2022**, *118*, 102758. [CrossRef]
65. Nordhaus, W.D. Rolling the 'DICE': An optimal transition path for controlling greenhouse gases. *Resour. Energy Econ.* **1993**, *15*, 27–50. [CrossRef]
66. Nordhaus, W.D. *A Question Of Balance: Weighing the Options on Global Warming Policies*; Yale University Press: New Haven, CT, USA, 2014; ISBN 978-03-0013-748-4.
67. Van der Ploeg, F.; Rezai, A. Stranded assets in the transition to a carbon-free economy. *Annu. Rev. Resour.* **2020**, *12*, 281–298. [CrossRef]
68. Battiston, S.; Mandel, A.; Monasterolo, I. CLIMAFIN Handbook: Pricing Forward-Looking Climate Risks Under Uncertainty. Working Paper, Climate Finance Alpha, 2019. Available online: https://ssrn.com/abstract=3476586 (accessed on 28 October 2022). [CrossRef]
69. Monasterolo, I. Climate change and the financial system. *Annu. Rev. Resour. Econ.* **2020**, *12*, 299–320. [CrossRef]
70. Campiglio, E.; Daumas, L.; Monnin, P.; von Jagow, A. Climate-related risks in financial assets. *J. Econ. Surv.* **2022**, forthcoming. [CrossRef]
71. Lehmann, P.; Söderholm, P. Can Technology-Specific Deployment Policies Be Cost-Effective? The Case of Renewable Energy Support Schemes. *Environ. Resour. Econ.* **2018**, *71*, 475–505. [CrossRef]
72. Popp, D. Environmental Policy and Innovation: A Decade of Research. *Int. Rev. Environ. Resour. Econ.* **2019**, *13*, 265–337. [CrossRef]
73. Yi, Z.; Xin-gang, Z.; Yu-zhuo, Z.; Ying, Z. From feed-in tariff to renewable portfolio standards: An evolutionary game theory perspective. *J. Clean. Prod.* **2019**, *213*, 1274–1289. [CrossRef]
74. Bauer, R.; Ruof, T.; Smeets, P. Get real! Individuals prefer more sustainable investments. *Rev. Financ. Stud.* **2021**, *34*, 3976–4043. [CrossRef]
75. Andre, P.; Boneva, T.; Chopra, F.; Falk, A. Fighting Climate Change: The Role of Norms, Preferences, and Moral Values. CEPR Discussion Paper No. DP16343, 2021. Available online: https://ssrn.com/abstract=3886831 (accessed on 28 October 2022).
76. Flammer, C. Green bonds: Effectiveness and implications for public policy. *Econ. Energy Environ. Policy* **2020**, *1*, 95–128. [CrossRef]

77. Gianfrate, G.; Peri, M. The green advantage: Exploring the convenience of issuing green bonds. *J. Clean. Prod.* **2019**, *219*, 127–135. [CrossRef]
78. Wang, Y.; Zhi, Q. The role of green finance in environmental protection: Two aspects of market mechanism and policies. *Energy Procedia* **2016**, *104*, 311–316. [CrossRef]
79. Hachenberg, B.; Schiereck, D. Are green bonds priced differently from conventional bonds? *J. Asset Manag.* **2018**, *19*, 371–383. [CrossRef]
80. Eyraud, L.; Clements, B.; Wane, A. Green investment: Trends and determinants. *Energy Policy* **2013**, *60*, 852–865. [CrossRef]
81. Febi, W.; Schäfer, D.; Stephan, A.; Sun, C. The impact of liquidity risk on the yield spread of green bonds. *Financ. Res. Lett.* **2018**, *27*, 53–59. [CrossRef]
82. Pham, L. Is it risky to go green? A volatility analysis of the green bond market. *J. Sustain. Financ. Investig.* **2016**, *6*, 263–291. [CrossRef]
83. Bachelet, M.J.; Becchetti, L.; Manfredonia, S. The Green Bonds Premium Puzzle: The Role of Issuer Characteristics and Third-Party Verification. *Sustainability* **2019**, *11*, 1098. [CrossRef]
84. Broadstock, D.C.; Cheng, L.T. Time-varying relation between black and green bond price benchmarks: Macroeconomic determinants for the first decade. *Financ. Res. Lett.* **2019**, *29*, 17–22. [CrossRef]
85. Climent, F.; Soriano, P. Green and good? The investment performance of US environmental mutual funds. *J. Bus. Ethics* **2011**, *103*, 275–287. [CrossRef]
86. Tang, D.Y.; Zhang, Y. Do shareholders benefit from green bonds? *J. Corp. Financ.* **2020**, *61*, 101427. [CrossRef]
87. Taghizadeh-Hesary, F.; Yoshino, N. Sustainable solutions for green financing and investment in renewable energy projects. *Energies* **2020**, *13*, 788. [CrossRef]
88. Tolliver, C.; Keeley, A.R.; Managi, S. Drivers of green bond market growth: The importance of Nationally Determined Contributions to the Paris Agreement and implications for sustainability. *J. Clean. Prod.* **2020**, *244*, 118643. [CrossRef]
89. Polzin, F. Mobilizing private finance for low-carbon innovation–A systematic review of barriers and solutions. *Renew. Sustain. Energy Rev.* **2017**, *77*, 525–535. [CrossRef]
90. Polzin, F.; Egli, F.; Steffen, B.; Schmidt, T.S. How do policies mobilize private finance for renewable energy?—A systematic review with an investor perspective. *Appl. Energy* **2019**, *236*, 1249–1268. [CrossRef]
91. Börner, K.; Chen, C.; Boyack, K.W. Visualizing knowledge domains. *Annu. Rev. Inf. Sci. Technol.* **2003**, *37*, 179–255. [CrossRef]
92. White, H.D.; McCain, K.W. Visualizing a discipline: An author co-citation analysis of information science, 1972–1995. *J. Am. Soc. Inf. Sci.* **1998**, *49*, 327–355. [CrossRef]
93. McCain, K.W. Mapping authors in intellectual space: A technical overview. *J. Am. Soc. Inf. Sci.* **1990**, *41*, 433. [CrossRef]
94. Taghizadeh Hesary, F.; Yoshino, N. Monetary policies and oil price determination: An empirical analysis. *OPEC Energy Rev.* **2014**, *38*, 1–20. [CrossRef]
95. Yoshino, N.; Taghizadeh–Hesary, F. Monetary policy and oil price fluctuations following the subprime mortgage crisis. *Int. J. Monet. Econ.* **2014**, *7*, 157–174. [CrossRef]
96. Mohsin, M.; Kamran, H.W.; Nawaz, M.A.; Hussain, M.S.; Dahri, A.S. Assessing the impact of transition from nonrenewable to renewable energy consumption on economic growth-environmental nexus from developing Asian economies. *J. Environ. Manag.* **2021**, *284*, 111999. [CrossRef] [PubMed]
97. Sun, H.; Mohsin, M.; Alharthi, M.; Abbas, Q. Measuring environmental sustainability performance of South Asia. *J. Clean. Prod.* **2020**, *251*, 119519. [CrossRef]
98. Zhang, B.; Yang, Y.; Bi, J. Tracking the implementation of green credit policy in China: Top-down perspective and bottom-up reform. *J. Environ. Manag.* **2011**, *92*, 1321–1327. [CrossRef]
99. Zhou, X.; Tang, X.; Zhang, R. Impact of green finance on economic development and environmental quality: A study based on provincial panel data from China. *Environ. Sci. Pollut. Res.* **2020**, *27*, 19915–19932. [CrossRef]
100. Henriques, I.; Sadorsky, P. Oil prices and the stock prices of alternative energy companies. *Energy Econ.* **2008**, *30*, 998–1010. [CrossRef]
101. Sadorsky, P. Correlations and volatility spillovers between oil prices and the stock prices of clean energy and technology companies. *Energy Econ.* **2012**, *34*, 248–255. [CrossRef]
102. Stern, N. The economics of climate change. *Am. Econ. Rev.* **2008**, *98*, 1–37. [CrossRef]
103. Bajo, E.; Barbi, M.; Hillier, D. Where should I publish to get promoted? A finance journal ranking based on business school promotions. *J. Bank. Financ.* **2020**, *114*, 105780. [CrossRef]
104. Krueger, P.; Sautner, Z.; Starks, L.T. The importance of climate risks for institutional investors. *Rev. Financ. Stud.* **2020**, *33*, 1067–1111. [CrossRef]
105. Bernstein, A.; Gustafson, M.T.; Lewis, R. Disaster on the horizon: The price effect of sea level rise. *J. Financ. Econ.* **2019**, *134*, 253–272. [CrossRef]
106. Flammer, C. Corporate green bonds. *J. Financ. Econ.* **2021**, *142*, 499–516. [CrossRef]
107. Engle, R.F.; Giglio, S.; Kelly, B.; Lee, H.; Stroebel, J. Hedging climate change news. *Rev. Financ. Stud.* **2020**, *33*, 1184–1216. [CrossRef]
108. Pedersen, L.H.; Fitzgibbons, S.; Pomorski, L. Responsible investing: The ESG-efficient frontier. *J. Financ. Econ.* **2021**, *142*, 572–597. [CrossRef]
109. Bolton, P.; Kacperczyk, M. Do investors care about carbon risk? *J. Financ. Econ.* **2021**, *142*, 517–549. [CrossRef]

110. Baldauf, M.; Garlappi, L.; Yannelis, C. Does climate change affect real estate prices? Only if you believe in it. *Rev. Financ. Stud.* **2020**, *33*, 1256–1295. [CrossRef]
111. Ilhan, E.; Sautner, Z.; Vilkov, G. Carbon tail risk. *Rev. Financ. Stud.* **2021**, *34*, 1540–1571. [CrossRef]
112. Barnett, M.; Brock, W.; Hansen, L.P. Pricing uncertainty induced by climate change. *Rev. Financ. Stud.* **2020**, *33*, 1024–1066. [CrossRef]
113. Painter, M. An inconvenient cost: The effects of climate change on municipal bonds. *J. Financ. Econ.* **2020**, *135*, 468–482. [CrossRef]
114. Murfin, J.; Spiegel, M. Is the risk of sea level rise capitalized in residential real estate? *Rev. Financ. Stud.* **2020**, *33*, 1217–1255. [CrossRef]
115. Pástor, Ľ.; Stambaugh, R.F.; Taylor, L.A. Sustainable investing in equilibrium. *J. Financ. Econ.* **2021**, *142*, 550–571. [CrossRef]
116. Eichholtz, P.; Holtermans, R.; Kok, N.; Yönder, E. Environmental performance and the cost of debt: Evidence from commercial mortgages and REIT bonds. *J. Bank. Financ.* **2019**, *102*, 19–32. [CrossRef]
117. Alok, S.; Kumar, N.; Wermers, R. Do fund managers misestimate climatic disaster risk. *Rev. Financ. Stud.* **2020**, *33*, 1146–1183. [CrossRef]
118. Balvers, R.; Du, D.; Zhao, X. Temperature shocks and the cost of equity capital: Implications for climate change perceptions. *J. Bank. Financ.* **2017**, *77*, 18–34. [CrossRef]
119. Pástor, Ľ.; Stambaugh, R.F.; Taylor, L.A. Dissecting green returns. *J. Financ. Econ.* **2022**, *146*, 403–424. [CrossRef]
120. Andersson, M.; Bolton, P.; Samama, F. Hedging climate risk. *Financial Anal. J.* **2016**, *72*, 13–32. [CrossRef]
121. Ellsberg, D. Risk, ambiguity, and the Savage axioms. *Q. J. Econ.* **1961**, *75*, 643–669. [CrossRef]
122. Nordhaus, W. Climate change: The ultimate challenge for economics. *Am. Econ. Rev.* **2019**, *109*, 1991–2014. [CrossRef]
123. Blanchard, O.J.; Gollier, C.; Tirole, J. The Portfolio of Economic Policies Needed to Fight Climate Change. Peterson Institute for International Economics Working Paper No. 22–18, 2022. Available online: https://ssrn.com/abstract=4276886 (accessed on 28 October 2022). [CrossRef]
124. Flammer, C.; Toffel, M.W.; Viswanathan, K. Shareholder activism and firms' voluntary disclosure of climate change risks. *Strateg. Manag. J.* **2021**, *42*, 1850–1879. [CrossRef]
125. Ginbo, T.; Di Corato, L.; Hoffmann, R. Investing in climate change adaptation and mitigation: A methodological review of real-options studies. *Ambio* **2021**, *50*, 229–241. [CrossRef]
126. Novoselov, A.; Potravny, I.; Novoselova, I.; Gassiy, V. Social Investing Modeling for Sustainable Development of the Russian Arctic. *Sustainability* **2022**, *14*, 933. [CrossRef]
127. Chen, H.; Wang, C.; Ye, M. An uncertainty analysis of subsidy for carbon capture and storage (CCS) retrofitting investment in China's coal power plants using a real-options approach. *J. Clean. Prod.* **2016**, *137*, 200–212. [CrossRef]
128. Stoll, P.P.; Pauw, W.P.; Tohme, F.; Gruening, C. Mobilizing private adaptation finance: Lessons learned from the Green Climate Fund. *Clim. Change* **2021**, *167*, 1–19. [CrossRef]
129. Kim, J.; Park, K. Improving liquidity in emission trading schemes. *J. Futures Mark.* **2021**, *41*, 1397–1411. [CrossRef]
130. Quemin, S.; Pahle, M. Financials Threaten to Undermine the Functioning of Emissions Markets. Working Paper, Potsdam Institute for Climate Impact Research, 2022. Available online: https://ssrn.com/abstract=3985079 (accessed on 28 October 2022). [CrossRef]

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