The scope of green finance research: Research streams, influential works and future research paths

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Abstract: Green finance, which includes climate finance, refers to financial instruments or investments with the aim of promoting economic growth while at the same time advancing resource and energy efficiency, thereby reducing negative externalities such as greenhouse gas emissions, waste or pollution. Green finance is a highly relevant issue for climate change mitigation and adaptation, as well as for the transition to a renewable and sustainable energy economy. However, it constitutes a diverse and multi-layered field whose contents and interrelationships are not easily tangible. Using quantitative bibliometric methods, this article analyzes a dataset of 942 peer-reviewed articles on green finance and their 37,255 references. It provides a structured and objective overview of the nine main research streams, their prevalence over time, high-impact publications, and the degree of information exchange between them. The main streams of green finance research address different levels of analysis, focus on a range of topics from several scientific fields, and arguably evidence little intellectual exchange. Based on the findings, it is suggested how future research on green finance can coalesce across disciplines to increase its productivity and efficiency.

Keywords: green finance; climate finance; climate change; socially responsible investment; corporate social responsibility; environmental investment; sustainability; sustainable finance

1 Introduction

Climate change, which is induced by the emission of greenhouse gases, is expected to entail significant changes for the economy and society—which are already being observed [1,2]. Its effects include, for example, more frequent weather extremes, sea level rise, soil erosion, droughts and floods, which in turn may cause wildlife extinction, conflicts, poverty, and migration [3,4]. To mitigate these effects, 194 states that account for the bulk of global carbon emissions signed the 2015 Paris Agreement as part the *United Nations Framework Convention on Climate Change (UNFCCC)*. The agreement defines the goal of reducing greenhouse gas emissions in order to keep the global temperature increase below 2 °C. In the agreement, the developed countries have pledged to provide $100 billion annually in climate finance from 2020 [5], which illustrates the relevance of financial markets and investment for climate change mitigation. Yet, global emissions have continued to rise since the signing of the agreement [6].

The connection between climate change and the financial system is multifaceted. Financial markets are essential for financing climate change mitigation and adaptation, as set out in the 2015 Paris Agreement [5]. According to an OECD estimate, the $6.3 trillion of annual investment in smart and clean infrastructure required globally until 2030 necessitate an additional $0.6 trillion annually to make investments climate compatible [7]. Climate change may also have direct and indirect effects on financial markets. For example, natural disasters, extreme weather conditions or the regulation and restructuring of economic systems will affect the profitability of individual companies and entire industries. Indeed, climate change and its consequences are expected to pose severe financial challenges to many nations. In general, climate change may jeopardize financial stability through two different channels. Physical risks relate to the exposure to climate change-related weather events (e.g. floods, heat, rising sea levels) that could trigger contagion effects, threats to solvency, and asset devaluations in the financial system, while transition risks refer to uncertainty from the low-carbon transition of economies and resulting policy changes, technological transformation, or changing preferences and norms [8]. For example, a hurried renewable energy (or low-carbon) transition could result in major fossil fuel reserves not being used [9], which could have systemic consequences on financial markets, such as fire sales that could trigger a financial crisis [10], and have major implications for industry sectors that depend on fossil fuels, such as the automotive sector [11].

Green finance, which includes the topic of climate finance, refers to financial instruments, policies or investments with the aim to foster economic growth while promoting resource and energy efficiency, thus reducing negative externalities such as greenhouse gas emissions, waste

or pollution. To achieve the (climate-related) UN's Sustainable Development Goals [12], investments must provide environmental benefits. However, financial institutions may face a conflict of interest as green investments often yield lower rates of return while carrying greater technological risk [13]. Financial instruments associated with green finance for example include green bonds, sustainability bonds, social bonds or green loans, but also financial technologies, carbon trading, or fiscal policies (e.g., Pigouvian tax, subsidies, grants etc.). Sustainable finance and socially responsible investments in line with the *UN Principles for Responsible Investment (UN PRI)* [14] need not fall under the scope of green finance, as the *ESG (Environmental, Social, Governance)* investment criteria go beyond environmental factors, including also social and governance characteristics (e.g., gender equality or compliance).

The advancing knowledge about climate change and its implications makes green finance an increasingly important topic, which has so far received only limited attention in the informetric community. To date, only a single bibliometric study has reviewed the literature on green finance, yet it differs significantly from the present study's bibliometric approach and research questions. This research letter by Zhang et al. [15] provides a brief review of advances in green finance by providing summary statistics on 381 articles published by 2018. This includes journal, author, keyword and citation statistics. In conclusion, the authors note that a comprehensive review of the green finance literature is still lacking, and further investigation would be useful. Unlike this "state-of-the-art" bibliometric study, the present paper aims to empirically analyze the green finance literature on the basis of co-citation data, a proven method to objectively identify underlying research discourses from literature data [16–19]. A compact and objective picture of the different research streams of the green finance discourse, their high-impact publications, temporal evolution, and information exchange should prove valuable both for practitioners and scientists. Besides identifying the main schools of thought and the status of their discourses, the paper locates white spots in the scientific landscape, which offer themselves as starting points for future research.

A sample of 942 peer-reviewed articles on green finance is extracted from the Web of Science database. The references of these articles are used for the empirical analysis. The method of co-citation analysis assumes that publications with many common sources tend to be similar in content. Applying explorative factor analysis, the co-citation data are used to objectively identify the nine most important research streams on green finance. For each publication, we are able to determine its fit and importance for the respective discourse. Research streams and

their high-impact publications are reviewed, temporal developments of streams are visualized, and the information exchange between and within the research discourses is identified through network analysis. In sum, an objective and structured picture of the scope of green finance research is obtained.

This remainder of the paper is organized as follows. Section 2 describes the data and methods, while the results are presented in Section 3. These include an overview of green finance research streams, stream-specific reviews of the most relevant literature, their prevalence over time and an analysis of the information exchange across and within the streams. Section 4 discusses the results, mentioning implications, limitations, and future research opportunities. Section 5 concludes.

2 Data and methods

2.1 Data and search strategy

The literature data were obtained from Web of Science, a widely used curated database for the systematic identification and extraction of literature data [20]. A curated database offers several advantages. First, the search can be restricted to peer-reviewed articles, which ensures a certain quality standard but at the same time implies a limitation as more recent and potentially more relevant scientific contributions without quality assurance may be overlooked. Second, the database can be systematically queried using search terms. Finally, metadata can be extracted, such as the articles' references.

Several different search strategies were tested. Searching for certain terms in both titles and abstracts returned 11,712 publications, yet many of them were irrelevant to green finance because words such as "green", "sustainable", "environment" or "sustainability" are often mentioned in abstracts without the article explicitly focusing on these terms. For example, authors often point out the implications of their results for sustainability. By contrast, if both "green" and "finance" appear in a publication's title, green finance is almost always a direct object of investigation. Thus, in December 2020, the search was restricted to matches in titles only, yielding 942 peer-reviewed publications.

The search terms were *TI = ("green financ*" OR climate financ* OR "sustainab* financ*" OR carbon* financ* OR "sustainab* investing*" OR "sustainab* investment*" OR "environment* investing*" OR "environment* investment*" OR "green investment*")*. The words "green", "climate", "sustainbl*", "carbon" and "environment*" represent the

environment-/climate-related aspect of the topic, and “financ*”, “investing*” and “investment*” relate to the finance/investment side. An asterisk means that words can have different endings. For example, searching for "sustainab*" returns "sustainable" and "sustainability" as well as phrases such as “sustainability-oriented”.

An advantage of applying quantitative methods is that the 942 extracted publications need not represent 100% of the publications on green finance. While the Web of Science database clearly does not cover all studies that contribute to the green finance discourse, the sample merely has to a) comprise a sufficiently large number of representative cases for the purpose of multivariate analysis and b) precisely fit the topic of analysis. Bibliometric data are highly skewed in their upper tails, which means that a small number of publications on a topic account for the largest share of scientific output and theoretical contribution [21]. This argument is based on several laws of information science formulated by Lotka [22], Bradford [23] and Zipf [24]. Yet given that our analysis is based not on the primary literature but on the underlying references, it can be assumed that the most significant references in the dataset are cited sufficiently often in the 942 extracted publications.

2.2 Co-citation analysis

Co-citation analysis can reveal the similarity or relationship between publications by measuring how frequently two articles are cited together [25]. A high number of co-citations shows that the two articles are both highly relevant to a scientific discourse, as many authors base their arguments and analyses on them. Consequently, clustered co-citation data can serve to analyze the intellectual structure of a scientific discourse [26].

The 942 extracted papers contain 37,255 references, 4,030 of which occur more than once and are therefore principally suited for co-citation analysis. In line with standard bibliometric practice [27], a threshold value based on an elbow criterion in the data distribution is determined to reduce the complexity of interpretation [20] and to account for the skewness of bibliometric data [21]. Setting the threshold at six co-citations yields the 326 most co-cited references of the 942 peer-reviewed articles on green finance. A symmetric co-citation matrix with 326 rows and columns is created (one for each publication) whose cells represent the frequency of co-citation between each article combination. In line with the literature [28], this matrix is used for the subsequent factor and network analyses.

2.3 Factor analysis

Exploratory factor analysis is a statistical method that reduces the number of variables in and thereby the complexity of a dataset without having to pre-formulate specific questions or hypotheses. Using the symmetric co-citation matrix, articles are divided into factors (in our context, research streams) based on underlying variables (publications). Thus, a research stream comprises those publications that feature similar co-citations.

The analysis yields two different metrics. First, *factor loadings* indicate how well a variable (article) fits a factor (research stream). These are correlation coefficients between a variable and a factor, which take values between -1 and 1 after undergoing a Varimax rotation—a method where the factors are rotated until their squared loadings show the maximum variance, facilitating their interpretation [29]. As a rule of thumb in the context of literature analyses, a factor loading of 0.4 means that an article belongs to a research stream, i.e. it explains a "sufficient" share of the variance. Values above 0.7 indicate that the article makes a significant contribution to the research stream [30]. We identify a research stream as the set of publications which have factor loadings of at least 0.4 with respect to the research stream. In contrast to this objective criterion, naming the research streams is a somewhat arbitrary task that relies on a contentual examination of the underlying publications.

Secondly, *factor scores* are determined by regression analysis and allow us to determine the ranking of individual variables within the factors. The higher the factor score of an article with regard to a research stream, the more relevant the former is to the latter [29]. To distinguish factor scores from factor loadings, note that an article may fit very well into a research stream but actually contribute very little to it. Review articles are an example of this.

In the factor analysis, publications that explain very little of their research stream's variance (more specifically, whose communalities are below 0.5) are successively removed to ensure that all articles are related [29]. This leaves 258 articles as the basis of the final analysis.

2.4 Network and density analysis

Having identified the separate research streams, we use network analysis to examine the connections and information exchange between the individual streams [31]. For this purpose, density scores are calculated from the co-citation matrix, which illustrate the intellectual exchange between and within research streams.

Using the UCINET software [32], co-citations are represented in a network as linkages between the articles (nodes). The sum of all actual co-citation relationships is set in relation to all possible relationships. For this purpose, the co-citation matrix is adjusted to a dummy variable basis, so that its cells assume the value of 1 if a relationship exists and 0 otherwise. In addition, the articles are grouped in the research streams identified in the factor analysis. The result is a 9x9 matrix that quantifies the exchange of information between the different research streams and within each stream, where a value of 0 means no information exchange at all and 1 signifies a complete exchange of information.

3 Research streams in green finance

Table 1 provides an overview of the nine research streams identified by factor analysis, sorted according to the proportion of variance explained, and the share of the 258 articles contained in each stream. The general content of each stream is briefly summarized and the peak period of publication output, the principal academic journals, and the most influential publications are listed. The factor analysis is done by principal component analysis and varimax rotation with Kaiser normalization. A *Kaiser-Meyer-Olkin (KMO)* measure of sampling adequacy of 0.559 and a highly significant Bartlett test of sphericity ($p < 0.0001$) confirm that factor analysis is a suitable methods of analysis [29,33].

Table 2 shows the most significant publications in each research stream along with their factor loadings and factor scores. Each research stream is briefly summarized in the following subsections with respect to its scope, theories and results.

Table 1. Research streams in green finance.

Stream	Variance explained	Share of articles	Brief description	Peak period(s)	Principal journals	Formative publications
Stream I: Effects of macroeconomic factors on environmental development	18.6%	36.8%	The influence of macroeconomic factors (e.g. financial development, economic growth, trade, urbanization) on environmental outcomes (e.g. emissions, energy consumption, environmental degradation).	2009-2019	Energy Policy (15%) Renew Sust Energy Rev (11%) Energy Econ (6%)	Tamazian et al. [34]; Zhang [35]
Stream II: Theory on the relationship between corporate social/ environmental and financial performance	8.6%	16.3%	Strategic, theoretical and organizational analysis of the effects of environmental policy and management on the financial performance of firms. Focus on the resource-based view of the firm and stakeholder theory.	1995-2005	Acad Manage J (15%) Acad Manage Rev (12%) Strategic Manage J (10%)	Klassen & McLaughlin [36]; Russo & Fouts [37]
Stream III: Climate finance policy, (historical) responsibility and distributive justice	5.0%	10.9%	A detailed overview of climate finance, looking at the interests and motivations of different stakeholders. Analysis and coordination of related policy and regulation in the context of green projects, distributive justice and environmental aid flow.	2001-2014	Climate Policy (15%) Climatic Change (15%) Global Env Change (7%)	Steward et al. [38]; Müller et al. [39]
Stream IV: Policy, competition and customer preferences as drivers of the adoption of emission-reducing technology	3.6%	5.8%	(Game) theoretic reflections on how regulation, environmental taxation, subsidies, competitive pressure and consumer preferences affect the adoption of emission-reducing technologies.	2012-2018	Eur J Oper Res (21%) J Clean Prod (14%) Int J Prod Econ (14%)	Dong et al. [40]; Krass et al. [41]
Stream V: Governance and interplay of climate change mitigation and adaptation finance	3.5%	7.4%	Analyses of the policy interplay between donor (developed) and recipient (developing) countries and the oversight of climate change prevention and mitigation funds.	2009-2015	Climate Policy (24%) Global Environ Polit (12%)	Pickering et al. [42]; Ciplet et al. [43]
Stream VI: Financial economics and the performance of socially responsible investments	2.8%	7.0%	Analysis (of the determinants) of the performance of socially responsible investments / funds and formative contributions to the financial economics discipline (capital market efficiency and portfolio management).	1952-1976; 2000-2008	J Bank Finance (18%) J Finance (18%) J Financial Econ (18%)	Statman [44]; Renneboog et al. [45]
Stream VII: Influence of donor and host country characteristics on climate change finance and the Clean Development Mechanism	2.7%	6.6%	(Re)shaping the relations and status quo of developed and developing countries in order to best respond to climate change (e.g., incentives, financing, subsidies, reporting and carbon taxes).	2009-2011	Climate Policy (13%) Energy Policy (13%)	Michaelowa & Jotzo [46]; Stadelmann et al. [47]
Stream VIII: Firm-level effects of carbon emissions and environmental performance	2.5%	3.9%	Analysis of how carbon emissions and disclosure by firms affect financial characteristics such as performance, R&D or market value.	2010-2015	Account Rev (11%) Eur Account Rev (11%)	Clarkson et al. [48]; Matsumura et al. [49]
Stream IX: Organization, development and reporting of carbon markets	2.4%	5.4%	How society can address carbon emissions through carbon markets, how such markets should be developed, organized and reporting.	2009-2011	Account Org Soc (23%) Antipode (15%)	Callon [50]; MacKenzie [51]

Table 2. The most relevant publications in each research stream.

Stream I. Effects of macroeconomic variables on climate-related development			**Stream II.** Theory on the relationship between corporate social/environmental and financial performance			**Stream III.** Climate finance policy, (historical) responsibility and distributive justice		
Publication	**FL**	**FS**	**Publication**	**FL**	**FS**	**Publication**	**FL**	**FS**
Abbasi & Riaz [52]	0.94	3.39	Nakao et al. [53]	0.94	3.59	World Bank [54]	0.88	2.82
Shahbaz et al. [55]	0.93	3.03	Barney [56]	0.94	3.61	Olsen & Fenhann [57]	0.88	2.95
Shahbaz et al. [58]	0.93	2.92	King & Lenox [59]	0.91	3.81	Steward et al. [38]	0.79	4.24
Boutabba [60]	0.93	3.02	King & Lenox [61]	0.90	3.87	Glemarec [62]	0.79	3.51
Dogan & Turkekul [63]	0.92	2.98	McGuire et al. [64]	0.90	3.94	Barrett [65]	0.78	2.98
Ozturk & Acaravci [66]	0.92	3.43	Margolis & Walsh [67]	0.90	3.63	Yamin & Depledgge [68]	0.78	3.26
Omri et al. [69]	0.92	2.13	Hart & Ahuja [70]	0.89	3.48	Sullivan [71]	0.77	2.97
Al-Mulali et al. [72]	0.92	2.60	Sharma & Vredenburg [73]	0.89	2.53	Müller [74]	0.77	3.20
Bekhet et al. [75]	0.92	2.23	Waddock & Graves [76]	0.89	2.34	Müller et al. [39]	0.76	4.25
Jalil & Ferifun [77]	0.91	4.48	Klassen & McLaughlin [36]	0.88	4.50	Klinsky & Dowlatabadi [78]	0.75	3.14
Dasgupta et al. [79]	0.91	2.87	Porter & van der Linde [80]	0.88	4.57	Sutter & Parreño [81]	0.74	3.43
Tamazian et al. [34]	0.91	5.54	Klassen & Whybark [82]	0.88	3.80	Eliasch [83]	0.73	2.83
Tamazian & Bhaskara Rao [84]	0.91	4.50	Orlitzky et al. [85]	0.87	4.41	Collier & Dollar [86]	0.71	2.70
Sadorsky [87]	0.90	3.28	Donaldson & Preston [88]	0.86	2.60	Olsen [89]	0.66	4.17
Zhang [35]	0.90	4.39	Russo & Fouts [37]	0.84	4.86	Hicks et al. [90]	0.63	3.50
			Hart [91]	0.80	4.25	Michaelowa & Michaelowa [92]	0.62	4.10

Stream IV. Policy, competition and customer preferences as drivers of the adoption of emission-reducing technology			**Stream V.** Governance and interplay of climate change mitigation and adaptation finance			**Stream VI.** Financial economics and the performance of socially responsible investments		
Publication	**FL**	**FS**	**Publication**	**FL**	**FS**	**Publication**	**FL**	**FS**
Choi [93]	0.92	4.65	Schalatek [94]	0.85	4.45	Statman [44]	0.83	6.77
Dong et al. [40]	0.91	6.22	Pickering et al. [42]	0.83	4.78	Renneboog et al. [45]	0.82	6.86
Krass et al. [41]	0.91	6.22	Ciplet et al. [43]	0.76	6.79	Bauer et al. [95]	0.80	5.19
Bi et al. [96]	0.91	2.94	Keohane & Victor [97]	0.72	4.28	Kempf & Osthoff [98]	0.79	4.21
Zhang et al. [99]	0.90	5.72	Haites [100]	0.72	2.60	Fama & French [101]	0.76	4.71
Swami & Shah [102]	0.90	4.29	Biermann et al. [103]	0.71	2.06	Markowitz [104]	0.74	2.80
Ji et al. [105]	0.89	3.89	Stadelmann et al. [103]	0.70	4.35	Schröder [106]	0.73	3.27
Liu et al. [107]	0.89	4.30	UNFCCC [108]	0.70	3.56	Moskowitz [109]	0.70	4.30
Huixiao & Wenbo [110]	0.89	6.17	Ballesteros et al. [111]	0.66	3.80	Derwall et al. [112]	0.66	4.91
Luo et al. [113]	0.88	4.91	Rübbelke [114]	0.60	4.39	Barnett & Salomon [115]	0.63	4.46
Toptal et al. [116]	0.86	5.10				Fama [117]	0.60	2.80
Yalabik & Fairchild [118]	0.86	3.77				Sharpe [119]	0.59	3.10
Xu et al. [120]	0.81	2.20						
Cao et al. [121]	0.75	2.79						

Stream VII. Influence of donor and host country characteristics on climate change finance and the Clean Development Mechanism			**Stream VIII.** Firm-level effects of carbon emissions and environmental performance			**Stream IX.** Organization, development and reporting of carbon markets		
Publication	**FL**	**FS**	**Publication**	**FL**	**FS**	**Publication**	**FL**	**FS**
UNFCCC [122]	0.84	4.78	Busch & Lewandowski [123]	0.88	5.59	Callon [50]	0.85	4.40
Linacre et al. [124]	0.82	4.99	Lee et al. [125]	0.88	3.26	Bumpus [126]	0.83	1.62
UN [127]	0.79	5.99	Horváthová [128]	0.85	4.15	Lohmann [129]	0.82	1.30
Tirpak et al. [130]	0.78	4.29	Tang & Luo [131]	0.83	4.33	Lohmann [132]	0.80	3.14
Michaelowa & Jotzo [46]	0.75	6.92	Clarkson et al. [48]	0.80	6.70	MacKenzie [51]	0.79	8.88
Schneider [133]	0.66	4.79	Matsumura et al. [49]	0.78	7.12	Lovell & MacKenzie [134]	0.72	3.73
Stadelmann et al. [47]	0.62	5.54	Fujii et al. [135]	0.78	5.78	Lohmann [136]	0.71	3.49
Michaelowa & Michaelowa [137]	0.54	5.77						

FL = factor loading; FS = factor score.

3.1 Effects of macroeconomic variables on environmental development

With 18.6% of the explained variance and 36.8% of all publications, Stream I is the largest—and therefore potentially most important—research discourse. Its articles focus on the influence of macroeconomic variables on countries' CO_2 emissions. The primary methods of analysis are *vector autoregression (VAR)* models, *vector error correction (VEC)* models and Granger causality analysis. Most of the studies are published in journals on (sustainable and renewable) energy policy and environmental management.

The publications focus on different economies, which may explain contradictory results. For example, while some studies find that financial development tends to raise emissions [52,60], others obtain the very opposite result [55,58,75,77]. Various studies also confirm the existence of the *Environmental Kuznets Curve (EKC)* [55,66,69,84], according to which economic development initially leads to environmental degradation. Beyond a certain level of development, however, societies rather tend to improve their relationship with the environment [138]. Another study finds no such evidence for the US [63]. Economic growth is related to higher energy use and corresponding emissions [55,58,72,75,87], while certain types of renewable energy generation can have a negative long-run effect on emissions [72].

These results have various implications. For example, Abbasi and Riaz [52] conclude that carbon emission mitigation strategies should be introduced in emerging economies, whose financial sectors are not yet very developed. Research shows causal links between macroeconomic variables of individual economies and carbon emissions, that can help strengthen economic growth while preventing environmental degradation. For example, Shahbaz et al. [55] find that coal consumption promotes long-term environmental degradation in South Africa, while trade openness has a negative impact. For Malaysia, Shahbaz et al. [58] identify that financial development reduces emissions while energy consumption and economic growth raise emissions. Similar studies focus on implications for the energy policies of individual countries such as India [60], the US [63], China [35,77] or Turkey [66] or groups of countries like the *Middle East and North Africa (MENA)* countries [69], *BRIC (Brazil, Russia, India, China and South Africa)* countries [34], Europe [72], and *Gulf Cooperation Council (GCC)* countries [75].

3.2 Theory on the relationship between corporate social/environmental and financial performance

The research stream with the second-highest share of explained variance (8.6%) comprises strategic and organizational analyses on firms' environmental management and financial performance. Its articles are mainly published in strategic management journals and are older on average than those in seven of the eight other research streams. Thus, stream II can be considered the theoretical and strategic basis for management science in the context of green finance and includes landmark publications in environmental, economic and managerial theory.

Barney [56] is the seminal scientific publication of the resource-based view—a managerial framework that aims to determine the optimal allocation of a company's resources in order to achieve a sustainable competitive advantage. King and Lenox [59] then examine the factors that influence a company's choice of a proactive environmental strategy and how this affects financial performance. In line with the resource-based view, they find a positive relationship between environmental and financial performance but point out that such results may be difficult to replicate across all firms. In a later study, the same authors identify that firm's waste prevention yields a financial gain, while other means of pollution reduction have no significant effect [61]. Other studies identify that pollution prevention as a corporate strategy is reduced to a minimum after one to two years and that those companies with the highest emissions have the greatest competitive advantage [70] and proactive responsiveness in the context of economic issues affects firm competitiveness [73]. Also building on the resource-based view of the firm, Russo and Fouts [37] identify a positive link between environmental and economic performance that increases with the level of growth in industries, while Klassen and Whybark [82] find a significant effect of environmental technology investments on manufacturing and environmental performance. Extending the resource-based view, Hart [91] introduces the natural-resource-based view of the firm, which examines the relationship between a firm's competitive advantage and its environmental strategy in terms of pollution prevention, product stewardship, and sustainable development.

Porter and van der Linde [80] introduce the Porter hypothesis, which states that environmental regulatory measures can yield product and process innovation, which can in turn improve the competitiveness of the affected firms. This higher competitiveness may even overcompensate the costs that the stricter regulation imposed on the firms. Information-based environmental

policy can be an effective means of supporting the transformation to a more sustainable society, given the positive correlation between environmental and financial performance [53].

In the context of stakeholder theory [88], Margolis and Walsh [67] discuss the demands on companies to meet social needs while their economic existence is based on making money for shareholders. Thus, money spent on social or sustainability causes could be considered misappropriated. Economic contractarianism prevents companies from working for the good of society or the environment. Thus, corporate social responsibility (CSR) must be aligned with stakeholder interests. In the context of corporate reputation, it has also been shown that CSR is of great importance for financial performance [64]—thus supporting stakeholder interests. Past and future financial performance is positively associated with CSR, suggesting a positive link between "good" management and CSR [36,76,85].

3.3 Stream III: Climate finance strategy, (historical) responsibility and distributive justice

The third research stream explains 5% of the variance, contains 10.9% of the analyzed publications and can be summarized under the topic of policy and financing options to support low-emission and climate-resilient development. Additionally, its publications focus on the (historical) responsibility for climatic change, distributive justice and environmental aid flow. Unlike streams I and II, it does not consist mainly of articles published in academic journals but comprises five books, five journal articles and two reports.

The publication with the highest factor loading, i.e. the best thematic fit with the stream, is a World Bank report that presents cross-disciplinary ideas and recommendations for overcoming conflict and securing development activities [54]. It identifies five key areas for action: 1) institutional legitimacy, 2) citizen security, justice and jobs, 3) agility and speed of institutional response, 4) layered approaches (regional, local, supranational, etc.), and 5) awareness of the changing global landscape. Four of the books in this research stream represent detailed and extensive basic knowledge on the overarching topic of climate finance, specifically on regulatory and funding strategies [38], policy challenges and potential methods for overcoming them [62], rules, institutions and procedures in the context of the climate change regime [68], and climate finance in the context of forestation [83]. Furthermore, Sullivan [71] discusses the financialization of environmental conservation.

The issue of the (historical) responsibility of different jurisdictions and countries appears in several of the stream's publications. For example, the greatest responsibility for climate change lies with developed countries, while less developed countries are expected to suffer

disproportionately from the impacts of climate change. Yet the historical contribution to climate change must not be confused with the moral responsibility to mitigate it [39]. Klinsky and Dowlatabadi [78] discuss distributive justice in the context of climate policy and argue that—previously overlooked—technological and ethical assumptions, as well as questions of sovereignty, substitution and ethics affect distributive justice outcomes. Müller [74] argues that high past emissions should not justify high future emission rights; instead, developing countries should receive more emission rights. Based on data from climate-vulnerable villages in Malawi, adaptation financing have been found to lead to more risk-taking and a sustainable reduction in climate vulnerability [65].

The *Clean Development Mechanism (CDM)*, one of the three mechanisms of the Kyoto Protocol for reducing greenhouse gas emissions, enables countries to implement emission-reduction projects in developing countries [139]. Sutter and Parreño [81] develop an analytical framework which they use to assess CDM projects in relation to the CDM's two objectives, 1) emissions reduction and 2) contribution to sustainable development in the host country. They find that while most projects will likely achieve an emissions reduction, less than 1% of them are likely to contribute to sustainable development. As a reaction to this [89], Olsen and Fenhann [57] propose a taxonomy for sustainability assessment that is based on text analyses and can be used to report, monitor and verify the realization of the sustainable development value of CDM projects.

The only book without a direct focus on climate finance deals with environmental aid flows, evaluating thousands of development projects by various donors and nations [90]. Similarly, Collier and Dollar [86] develop a poverty-efficient allocation of aid and compare it to the actual aid allocation. The result suggest that a more efficient allocation of aid could almost double the productivity of the resources used in terms of lifting people out of poverty. Since only very few CDM projects directly address poverty, Michaelowa and Michaelowa [92] suggest that aid for emissions reduction should be a different budget item, so that climate aid does not constitute a reallocation of poverty aid.

3.4 Stream IV: Policy, competition and customers preferences as drivers of the adoption of emission-reducing technology

The fourth research stream explains 3.6% of the variance, comprises 5.8% of the examined publications and can be assigned to the field of operations and production research—all articles are published in related academic journals. The overarching theme is the question of which

factors have an influence on firms' adoption of low-emission technology. The predominant methodology is game theory—e.g. Stackelberg games that simulate the behavior of companies in a market or supply chain.

The study with the highest factor score—and therefore the statistically most influential one—analyzes the extent to which different schemes (e.g. revenue-sharing, cost-sharing) by retailers affect producers and company profitability when consumers' environmental awareness and carbon taxes rise. As a result, it appears that carbon taxes should be designed differently depending on the type of coordination between companies [110]. Krass et al. [41] address the relationship between environmental taxes and the choice of green technologies. Their theoretical model shows that raising taxes can initially support green technology adoption, but a further increase can cancel or reverse this effect. They conclude that using subsidies and consumer rebates gives governments more scope to achieve the desired effects through taxation. Focusing on the *quick response* system in the fashion industry, Choi [93] examines how a carbon footprint tax could be integrated into the system to promote sustainability and regionality. He concludes that a sensibly designed tax not only encourages retailers to use local manufacturers but also reduces their business risk.

Consumer environmental awareness can be a significant factor in supply chain order volumes and companies can benefit from customizing products based on customer segments [99]. As consumers become more environmentally conscious, the profitability of retailers and manufacturers with low environmental efforts tends to increase when competition is low and decline when competition is high [107]. Competition for environmentally conscious customers can raise the effectiveness of corporate investments in environmentally friendly products [118].

Besides taxes, government subsidies can also promote the adoption of low-emission technology. A thematic focus of the research stream is the impact of sustainability investments and subsidies on production and order volumes. For example, Dong et al. [40] find that effective sustainability investments can have a positive impact on order volumes, while Ji et al. [105] find that joint emission reduction strategies are profitable for members of supply chains. Similarly, co-opetition in manufacturing raises profitability and lowers emissions [113]. Bi et al. [96] analyze how subsidies should be allocated to profit-maximizing firms in a price- and pollution-sensitive market, and Cao et al. [121] examine the effects of a *cap and trade policy (CTP)* and *low carbon subsidy policy (LCSP)* on production and emissions. They find that a LCSP is preferable to a CTP only when environmental damages are below a certain threshold.

In the context of CTPs as an effective market-based mechanism to reduce emissions, Xu et al. [120] show that as emissions prices increase, optimal production levels decline.

Swami and Shah [102] identify that the optimal greening strategies of a manufacturer and a retailer correspond to the ratio of their eco-sensitivity and greening costs. Joint emission reduction strategies are profitable for members of supply chains [105]. Besides achieving their primary goal, investments in emission reduction can reduce costs for companies [116].

3.5 Stream V: Governance and interplay of climate change mitigation and adaptation finance.

The fifth research stream covers climate finance analyses of the policy interplay between donor (developed) and recipient (developing) countries and the oversight of climate change prevention and mitigation funds. It explains 3.5% of the variance and comprises 7.4% of the publications. Haites' [100] book provides a complete overview of international climate finance, investments and costs of actions, as well as funding needs and governance arrangements, and serves as a baseline for policymakers and researchers. Accordingly, it provides a suitable superstructure for the stream's scope and the articles therein. The 2014 biennial assessment and overview of climate finance flows by the UNFCCC Standing Committee on Finance is another high-impact publication in the stream [108].

Adaptability and flexibility are important factors for climate policy, since the participating governments may pursue very different interests [97]. Schaltek [94] argues for the democratization of climate finance governance, including principles such as accountability, transparency, and public and gender-responsive participation in decision-making. Citizens in donor and recipient countries should not only be informed of but also involved in the allocation of public funds. According to Stadelmann et al. [103], private finance plays a key role in reducing emissions, but reliable data is scare. The authors explain that "private climate finance" has yet to be clearly defined. Only then can the relevant data be collected, verified and used.

Ciplet et al. [43] assess how climate adaptation finance has become an important part of the public agenda and develop a definition of justice in adaptation finance. The authors point out that, in practice, adaptation finance reflects the interests of industrialized countries rather than the agreed-upon principles of justice. Similarly, Pickering et al. [42] describe that while aid agencies have substantial control over the implementation and distribution of development approaches to climate finance, the donor countries' environment and finance ministries have a significant and sometimes conflicting influence on adjustments and geographic distribution. International adaptation finance can have positive effects for donors and recipient countries,

e.g. due to spillover effects in international negotiations on climate change mitigation [114]. Biermann et al. [103] focus on the fragmentation of governance in international politics and how it could be reduced, climate change governance being their prominent and highly topical example.

3.6 Stream VI: Financial economics and the performance of socially responsible investments

The sixth stream explains 2.8% of the variance and comprises 7% of all articles. Its publications can be assigned to the subject area of financial economics and comprise two main groups. The first group consists of seminal articles on the efficiency of capital markets and portfolio management. More specifically, they form the basis for today's portfolio theory [104], the *Capital Asset Pricing Model (CAPM)* [119], its extension in the form of the Fama–French three-factor model [101], and the *Efficient Market Hypothesis (EMH)* [117]. These are essential insights for understanding the behavior of capital markets and the performance of investments.

The other group of publications builds on this basic financial literature and examines the performance of socially responsive investments in various contexts. Such investments pursue both financial and social objectives. The potential underperformance of socially responsible investment portfolios may be offset by selecting better-managed, stable companies [115]. Renneboog et al. [45]'s critical literature review of 2008 provides a well-rounded overview of the topic (as of 2008) and outlines various paths for future research on socially responsible investments.

The study by Moskowitz [109]—one of the first prominent studies of socially responsible stocks—identifies high positive correlations between a corporate social responsibility construct, firm awareness and organizational performance. Statman [44] provides evidence that socially responsible stocks performed as well as the S&P 500 Index, and socially responsible mutual funds outperformed conventional mutual funds over specific periods. Similarly, Bauer et al. [95] find no significant performance differences between ethical and conventional funds using a sample of 103 German, British and US funds between 1990-2001. Socially responsible stock indices are riskier than conventional benchmarks but do not yield larger returns [106]. Yet, "eco-efficient" socially responsible stock portfolios can enjoy superior performance [112]. Investment strategies building on socially responsible ratings, i.e. buying stocks with high social responsibility ratings and selling stocks with low ratings, can yield abnormal returns, which remain significant even after accounting for transaction costs [98].

3.7 Stream VII: Influence of donor and host country characteristics on climate change finance and the Clean Development Mechanism

Research stream VII explains 2.7% of the variance and comprises 6.6% of the articles. It deals with (supra)national considerations of climate change financing and includes several reports by public-sector organizations (e.g. UN [122], IEA & OECD [140] or Word Bank [124]) that examine how the relations between developed and developing countries should be (re)shaped in order to best respond to climate change. The incentives discussed include financing, subsidies, reporting and carbon taxes. Most of the publications appeared between 2009 and 2011—a comparatively short period.

The publication with the best fit based on its factor loading is a technical report on "Investment and financial flows to address climate change: an update" by the United Nations. It describes options, mechanisms and instruments for mitigation, adaptation and technological cooperation in response to climate change. It emphasizes that the required investments and financial flows for developing countries should be significantly higher and that the developed countries—which ought to take the lead in mitigating climate change—should increase their efforts to support the developing countries [122]. Another UN report highlights that grants and highly concessional loans represent crucial financial instruments for climate adaptation in developing countries and that carbon taxes are an important financing instrument [127]. However, Linacre et al. [124]'s report on the state of the carbon market—published one year after the UN's—cautions that the market stalled after years of robust growth, while emissions continued to rise.

The publication with the highest factor score, which is thus most formative for the stream, discusses how transaction costs and institutional rigidities reduce the attractiveness of the Kyoto Protocol's flexibility mechanisms compared to domestic options for reducing carbon emissions. The authors conclude that while demand from Annex B countries (i.e. countries that have formally stated their reduction targets in the Kyoto Protocol) remains the critical factor for the implementation of the CDM, its success will significantly depend on transaction costs and institutional barriers in the host countries [46].

Based on an analysis of aid agency project descriptions, Michaelowa and Michaelowa [137] show that the ideological orientation of donor governments and the environmental preferences of national constituencies influence project descriptions. In this context, Tirpak et al. [130] emphasize that transparency is key to fostering trust among the parties to the UNFCCC. Developed countries should report their financial support to developing countries under an

international climate change agreement in a complete, transparent, comparable, and accurate manner. Current climate finance reporting systems should be adapted to create a common reporting format. Two other publications in the stream also address the need for financial support to be meaningfully monitored, tracked, and reported in order to ensure and quantify the actual benefits of funding [133,140].

3.8 Stream VIII: Firm-level effects of carbon emissions and environmental performance

The eighth research stream explains 2.5% of the variance and comprises 3.9% of the articles. The contentual focus is on how carbon emissions and disclosure by companies affect their financial characteristics such as performance, inventories or market value. All key publications are scientific articles, primarily published in accounting journals (e.g. Accounting Review [49], European Accounting Review [48]) or business economics and environmental science journals (e.g. Journal of Industrial Ecology [123], Business Strategy and the Environment [135]). Most of the articles were published between 2010 and 2015.

Matsumura et al. [49]'s article has the highest factor score of the research stream. The authors analyze the relationship between firm value and (voluntarily disclosed) corporate carbon emissions. Using data from S&P 500 firms between 2006 and 2008, they show that firms that disclose carbon emissions are valued more highly, so the market appears to penalize non-disclosure. Based on European corporate data, Clarkson et al. [48] find that while company valuation does not depend on the firms' carbon credits, allocation deficits depress company value. This negative relationship is weaker for companies with better environmental records and those that operate in less competitive sectors. The voluntary disclosure of information about environmental initiatives or recognition in general is not rewarded by the stock markets [141]. Yet other studies find that corporate emissions permanently reduce firm value [125].

A meta-study of 32 empirical papers suggests that lower carbon emissions are generally associated with better corporate financial performance [123]. However, depending on the approach to measuring emissions, corporate environmental performance can have a positive (outcome-based approach) or negative (process-based approach) impact on financial performance [142]. Moreover, a study of Japanese manufacturing firms suggests that such relationships may not be linear but rather inverted U-shaped [135], and the capital market penalizes companies with negative environmental performance more than it punishes those with positive performance [125]. Also, the effects may differ depending on the time period considered [128].

3.9 Stream IX: Organization, development and reporting for carbon markets

The ninth and smallest stream in terms of variance explained (2.4%) comprises 5.4% of the publications, all of them scientific articles published in academic journals in social sciences and/or business management (e.g. Antipode's special issue "The 'New' Carbon Economy" [126,134] or Accounting, Organizations and Society [50,51,136]). The overarching theme of the discourse is carbon markets, their pricing mechanisms and effective trading. These markets are associated with various uncertainties regarding their organization, calculation tools, and the fundamental role they are expected to play in the context of technological progress and other intervention measures. Callon [50] views carbon markets as collective experiments that may help to better understand markets and their dynamics.

MacKenzie [51] provides an overview of the development of carbon markets and discusses how their effectiveness could be improved. Other articles examine how the creation of a commodity and markets for carbon dumping affects climate change mitigation science and technology, and the extent to which this creates technopolitical contradictions [132] or possibly even exacerbates the climate problem [129]. Bumpus [126] illustrates the opportunities and challenges of carbon commoditization with a hydropower plant and a cookstove project in Honduras, and presents the case for reforming the carbon offset market. The Kyoto Protocol's carbon accounting system marginalizes non-business, non-governmental, and non-expert contributions to climate stability, creating resistance against new carbon dumping projects [132]. The accounting profession itself has an essential role to play in managing the new carbon economy in the context of calculations, measurements, expertise, cost-benefit analysis and the techniques of carbon accounting [134,136].

3.10 Temporal development of the research streams

Figure 1 visualizes the prevalence of the research streams over time. Panel a) shows their relative prevalence since 1952; panel b) shows the same data but in cumulatively terms. This presentation is mirrored in panels c) and d) using absolute rather than relative figures. The early phases of this literature on green finance featured only publications from research streams II and VI (1952 to 1986). From 1987 to 1990, the research stream I grew to about 20% of the scientific discourse. This share remained quite stable over time, reaching 30% by 2019. The relative importance of stream II peaked between 1999 and 2005 (about 40% of the total ecosystem) but dropped to about 15% in 2019. Shortly after the Kyoto Protocol in 1997, research streams III and V emerged, whereas stream VII already appeared in 1991.

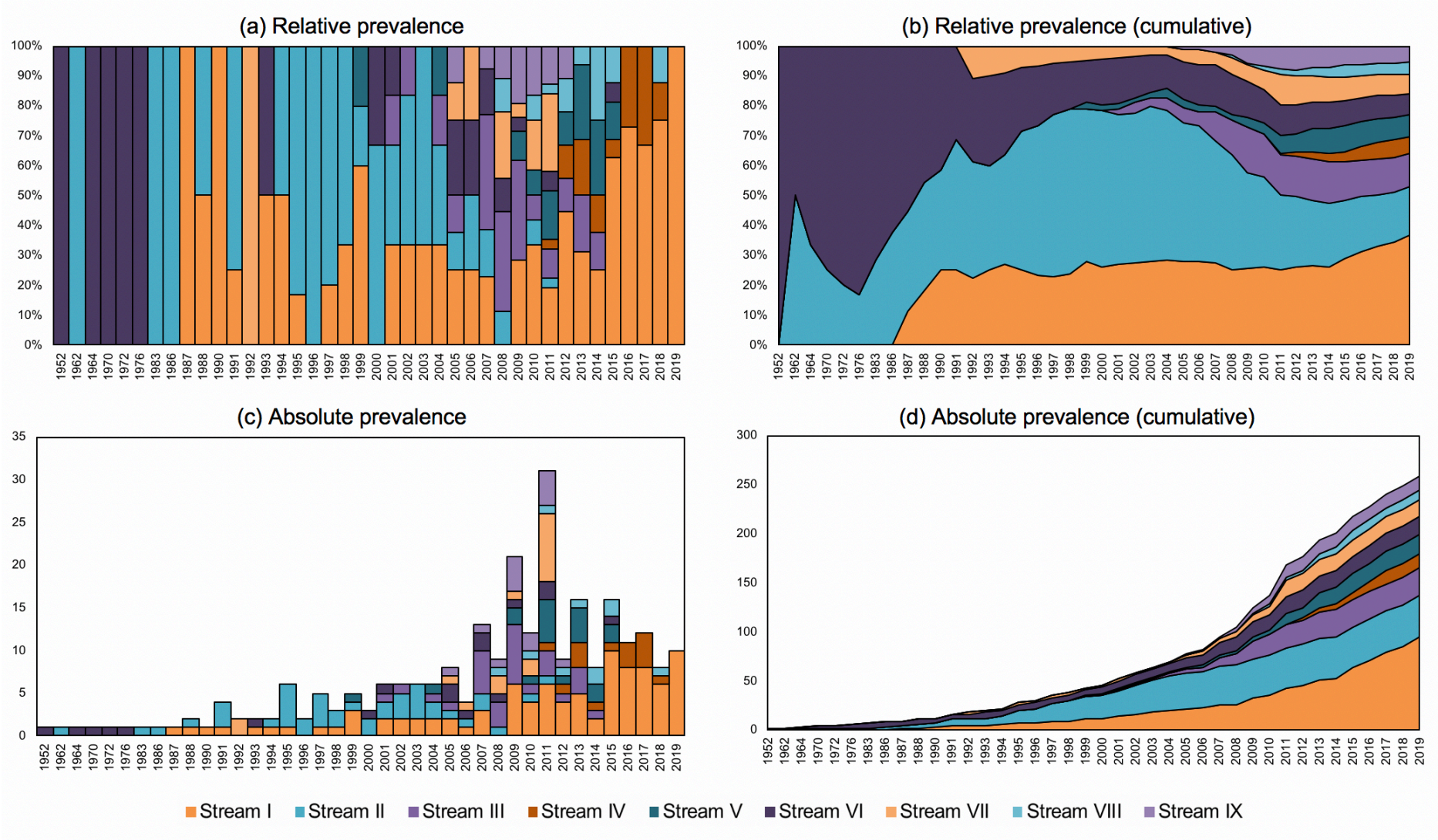

Fig 1. Relative and absolute prevalence of the research streams over time. Years without publications are omitted.

2009 and 2011 saw the most publications on green finance. While the number of publications is higher after the peak in 2011 than before it, the trend is declining. Research streams I and IV brought forth very influential literature between 2015 and 2019—for the other streams, the seminal publications tended to occur before this time. This suggests that these two streams in particular are currently still under development. This is to be expected given the importance of current developments, such as macroeconomic variables for stream I or technological progress for stream IV.

3.11 Information exchange between and within research streams

Figure 3 shows density scores, which indicate the degree of intellectual exchange between and within the research streams. In principle, density scores can be read like percentages. Across all articles, the density score is 17.2%—the proportion of the publications that refer to at least one other publication in the sample.

70.4% of all articles in research stream I cite at least one other article in stream I. However, very few links exist to the other research streams. Stream VIII has the highest—though still very low—degree of intellectual exchange with stream I, at 3.4%. Stream IV is also rather isolated by this measure.

As is to be expected, we find the highest density scores within the individual research streams, although the numbers vary substantially. For example, more than 88% of the articles in streams III and VIII cite articles within the respective stream, as opposed to only 46.2% in stream IX and 58.1% in stream VII. Between the streams, only three density scores exceed 30%. In five of the 36 inter-stream relationships, no cross-citation takes place at all. Streams IV (micro/ meso-level focus on consumers) and VIII (meso-level focus on firms) are particularly isolated.

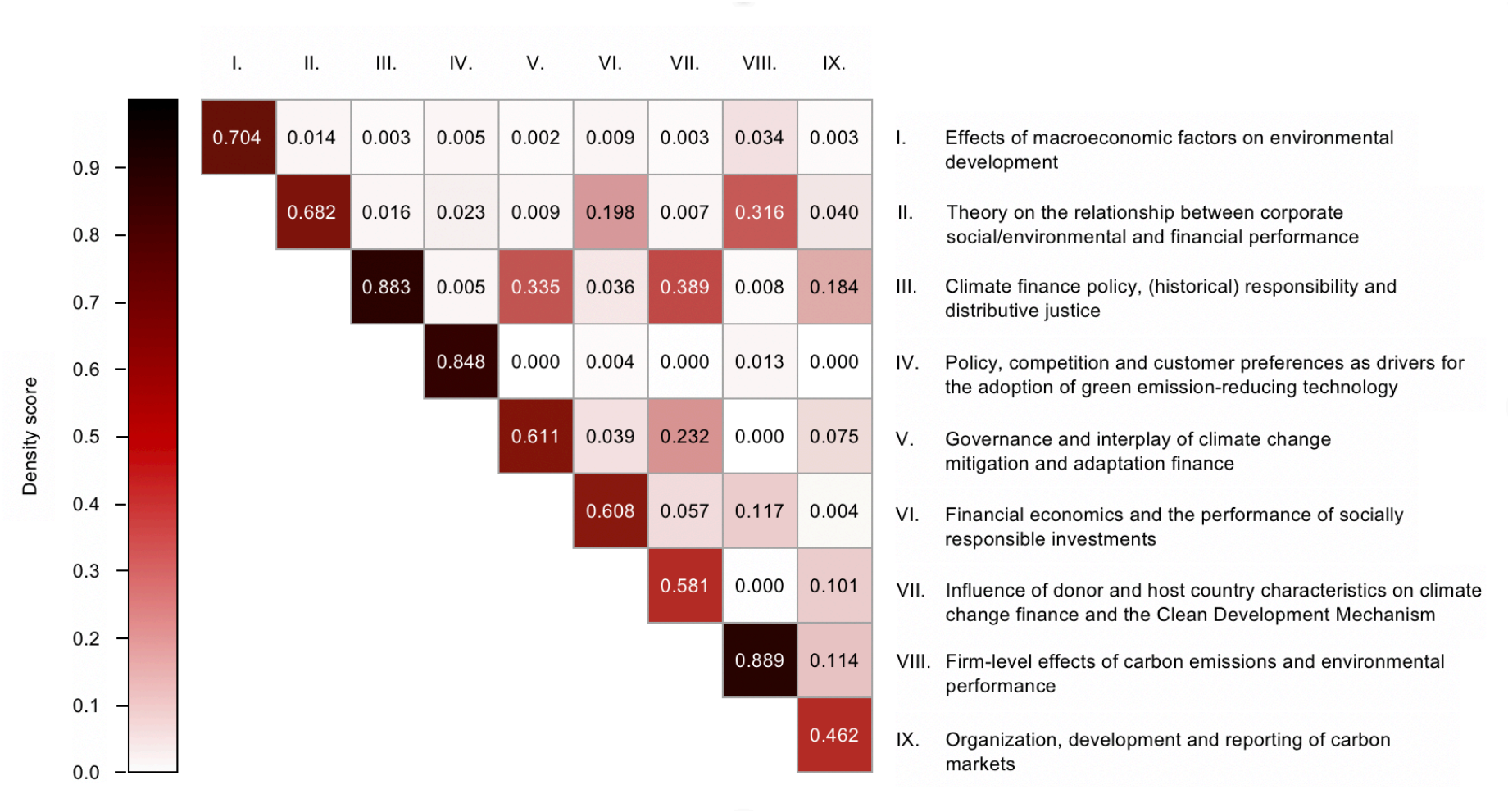

Figure 3. Density scores indicating intellectual exchange between and within research streams.

4 Discussion

The analysis has identified nine major research streams in the discourse on green finance, which spans several disciplines and levels of analysis, a variety of stakeholders, and many complex issues, illustrating the great relevance and scope of the topic. Superficially, the identified research streams can be divided into two supercategories based on their stakeholder focus. The first group comprises policy-making governmental or regulatory bodies (streams I, III, IV, V, VII and IX). The second group concerns the free economy, which includes companies, financial institutions, and (capital) markets (streams II, VI and VIII). Strikingly, very little attention is paid to individual citizens or specific population groups as stakeholders. While consumer preferences feature as a metric in the fourth stream, they only serve as a factor of decision-making by producers and retailers.

The area which the analysis has shown to be most important to the discourse is the investigation of macroeconomic relationships and influences on climate change, energy consumption and environmental degradation (stream I). These studies are addressed at supranational organizations, governmental bodies and regulators. Given that these entities ought to have the greatest influence on the environmental variables under consideration, it seems reasonable that they are the subject of the largest research effort, especially since most countries still put economic growth before environmental protection—the huge market for fossil fuel subsidies being a suitable example [143]. The fact that various studies confirm the existence of the EKC [55,66,69,84] and that economic growth raises emissions [55,58,72,75,87] calls for national and international policy to counteract these negative effects—possibly building on other work in the research stream, such as subsidizing renewable energy [52,72]. The other five research streams that also focus on public-sector stakeholders deal with national strategy, international relations, and stakeholder motivation. The third stream discusses climate finance, including strategy [38], policy challenges [62], rules and procedures [83], and distributive justice [78]. Stream IV examines how and when it pays off for companies to use green technologies, while the fifth stream focuses on the interplay between the policies of donor vs. developing countries, funding needs and governance. Stream VII addresses the suitability of incentives, financing, carbon taxes and subsidies for combating climate change. Lastly, stream IX discusses the structure, organization and monitoring of carbon markets.

By contrast, firms are the stakeholders investigated by the second most important research stream (II), which covers strategic management issues, focusing on how companies can act

sustainably yet competitively. Companies can combine financial success with environmental performance through appropriate strategic alignment [59,61], ensuring that their CSR efforts are consistent with the interests of their stakeholders [64]. The scientific debate provides companies with a knowledge base—economic theory (e.g. the resource-based view [56], stakeholder theory [88] or the Porter hypothesis [80]) can help them align their business strategy with environmental factors. Stream VI focuses on the financial market, specifically on the performance of socially responsible stocks [98,112]. In this respect, the discourse complements the strategic knowledge base for companies, but it also addresses all other financial market participants, such as investors and financial institutions. Finally, stream VIII looks at the impact of carbon emissions on corporate success and firm value.

In summary, a great deal of scientific effort has gone into modeling (macro-)economic relationships, designing climate change policies, and investigating firms' strategic and operational orientation in the field of green finance. Around these central topics, smaller and more specialized scientific discourses formed around the turn of the millennium. However, the density analysis has revealed that hardly any information exchange occurs between the individual research streams. The proportion of applied and empirical contributions has increased significantly over time, as evidenced in particular by stream I, which is based solely on empiricism and explains more than 18% of the variance in the explorative factor analysis. Stream II, which is mainly theoretical in nature, was most important before 2006 and has since declined in relation to the other streams. While evidence is essential for understanding climate change mitigation and adaptation and other environmental issues, the question remains to what extent that evidence is accurate, meaningful and properly used in the scientific debate [144].

Green finance research is developing rapidly. New research streams continue to emerge, which shows that new methods, theories and insights still have something to contribute to the research system (cf. Figure 2). From 1952 onward, the first significant foundations of what only later became green finance were laid in the areas of strategic management (stream II) and financial economics (stream VI). These essential theories have been shaping economics and finance to this day. Research stream I emerged in 1986 and has accounted for a significant share of the scientific complex ever since. Until 2004, the green finance literature was dominated by streams I and II, with streams VII (from 1992), V (from 1999) and IIII (from 2001) already being established during this period. The period 2005 to 2014 saw the most diverse scientific output of the various research streams. During this time, stream IV emerged in 2011 and, together with stream I, shaped the years 2015 to 2019. The recent dominance of these two

streams (and, to a lesser extent, streams V and VII) suggests that many more seminal publications on their topics, methods and theories may be expected in the near future.

4.1 Future research

The fact that the scientific system rewards "new" and "statistically significant" results [145] may give scientists false incentives (e.g. "p-hacking" [146]), which could have particularly critical implications for topics like climate change and green finance due to the major problems in appropriately and consistently capturing and reporting climate change, environmental degradation, development projects, emissions, and other relevant variables [133,140]. Accordingly, more studies should aim to validate existing results, for example through replication/extension [147,148] or meta-analyses [123], to better understand and standardize disparate data.

Similarly, informetric studies can serve to standardize and contextualize results. Several reviews have already dealt with various aspects of green finance or climate finance (e.g. [149,150]). What does not exist at present, however, are suitable scoping reviews [151] that systematically classify and analyze empirical literature (e.g. the publications of stream I). A systematic survey and overview of the data sources used and the results can 1) offer other scientists, regulators and firms much easier access to the subject matter, 2) reveal potential problems and discrepancies that could be tested, for example by replication studies, and 3) identify where further research may be needed.

The most important research streams primarily focus on governments, companies and financial institutions. Consumers, their perceptions and behavior are hardly considered—a gap and opportunity for future research. Consumers are often not able to identify meaningful behavioral changes for themselves [152], which underlines the complexity of the relationship between this group of stakeholders and green finance or climate change. Science must provide consumers with simple (cost-effective or financially rewarding) ways to live environmentally and climate friendly lives. Thus, marketing and psychology research should increasingly address these issues, embed results from other disciplines in its own research and make the results available to other disciplines. Several existing studies can serve as a point of departure for such a new research stream [153–156].

Already in 2009, Barrett [157] described the need for a "technological revolution" to reduce emissions. No single technology can solve the climate crisis any more than a single government's policy can. Technological changes must affect global markets for a global impact

[157]. The development, validation, application and continuous improvement of financial technology can make a significant contribution to this technological revolution. In addition to the financial implications of the emission-reducing technology described in research stream IV, this also includes the development of financial technology and markets, such as the carbon markets discussed in research stream IX.

The concept of tokenizing assets via blockchain and the automated handling of standard processes via smart contracts allows the creation of entirely new (financial) markets and applications [16,158]. Scientific findings already exist in the context of carbon markets [159,160], water management [161], (renewable) energy markets [18,162], sustainable manufacturing [163], and renewable energy investments [164]. Similarly, machine learning, artificial intelligence methods and digital twin technology promise to make the existing (environment-related) financial system more efficient and/or transparent. The scientific community should research which green finance-related technology options arise and can be developed as financial technology or markets. In this context, one avenue can be to technical solutions to standardize the auditing or reporting process. A decentralized and transparent infrastructure for the (real-time) tracking and reporting of subsidies, grants, aid or ESG-related criteria could contribute significantly to reducing information asymmetries [165].

The density analysis has revealed several white spots in the exchange of information between the scientific discourses. In particular, the first research stream has virtually no overlap with the other eight streams. This suggests that the analysis of national or regional macroeconomic data should be better integrated into the general scientific discourse. Climate change-related causal relationships will not be the same for all economies, which is why any statements on topics of, for example, financing, regulation or policy from streams II to V should be differentiated according to the region(s) considered.

In general, hardly any exchange of information occurs between the first four research streams, which indicates plenty of empty space in the research landscape. The fact that these topics, each of which is highly relevant for green finance and climate finance, are so poorly connected illustrates the broadness and complexity of the topic but also shows the potential for future scientific contributions, which would merely have to bring together different disciplines and schools of thought. The lack of overlap between the analysis of the impact of carbon emissions on corporate financial performance (stream VIII) and country-specific influences on climate change finance (stream VII) constitutes another clear research gap. Likewise, strong contentual links are to be expected between the governance and policy interplay of countries (stream V)

and stream VIII. The same is true for many if not all of the other "white spots" revealed by the density analysis.

4.2 Limitations

This study is subject to some limitations, which will be briefly discussed below. First, the results strongly depend on the choice of the scientific database (Web of Science) and the search terms (cf. Section 2.1). Alternative databases, e.g. Scopus or Google Scholar, would have yielded different results. Future studies could test the suitability of the Web of Science database and whether the selection of search terms properly captures the green finance literature. We initially retrieved only peer-reviewed articles, although their sources then naturally also include other literature. While this ensures a certain quality of the publications, it entails the limitation that potentially relevant new or gray literature is not considered—which immediately suggests another avenue for further bibliometric analyses.

Second, it should be noted that while the methods of co-citation analysis, factor analysis, and network analysis ensure objectivity, the naming of the research streams is entirely subjective and may strongly influence the impression that the results convey. Finally, it must be noted that this form of bibliometric analysis constitutes but a historical view of the scientific discourse. The results cannot serve as a basis for determining future developments in green finance research but merely offer readers an understanding of the status quo of the underlying intellectual structure and theory.

5 Conclusion

This study conducted a meta-review of the scientific environment surrounding the term ‘green finance’ on the basis of quantitative bibliometric methods. Green finance, which includes climate finance, refers to any financial instrument, regulation or investment that generates economic growth on the one hand and promotes resource efficiency on the other. Based on co-citation data of 37,255 references from 942 peer-reviewed publications, the nine most important intellectual discourses (research streams) were identified by means of exploratory factor analysis. For each research stream, we ranked and briefly described the most influential publications, and the temporal development and information exchange between the research streams were presented. The results provide a scientific basis for the various stakeholders in the field of green finance, including national and supranational administrations, companies, financial institutions, and consumers.

The identified research streams can be divided into two overarching thematic clusters, the first of which covers macroeconomic and policy effects, relationships and analysis, while the second one deals with firms' strategic alignment and compatibility with environmental policy issues. However, the analysis has shown that very little exchange of information occurs between most of the research streams. This can be interpreted as an inefficiency of the green finance research complex, as scientists fail to take up potentially relevant findings from other subject areas. Simultaneously, these white spots in the research environment mark opportunities for future research. It is striking that most of the scientific discourse concerns nations, governments, or institutions, while very little attention is devoted to citizens and consumers. This offers marketing and psychology scholars an opportunity to shape a new research stream.

The meaningful classification or scoping of the increasingly empirical publications on green finance represents another important topic for researchers in the field, given the challenges of monitoring and reporting environmental policy measures and indicators. Research in the area of innovative financial technology, digital markets and the modeling, traceability and reporting of processes (e.g. using blockchain, smart contracts, artificial intelligence, machine learning, digital twin) also offers a promising direction for future research.

In conclusion, this study has sought to provide a wholistic understanding of the intellectual structure of green finance research. Remarkably, that literature itself fails to provide a wholistic view of its object area, as the individual research streams are hardly connected with each other, although global environmental issues such as climate change clearly require interdisciplinary treatment. In this respect, science should serve as a role model for the global society.

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