Journal of Banking Regulation (2026) 27:24
https://doi.org/10.1057/s41261-026-00317-1

ORIGINAL ARTICLE

Banks and climate risk: a bibliometric review and policy perspective

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Received: 31 July 2025 / Accepted: 3 March 2026

Abstract
This paper presents a bibliometric analysis to explore existing research on climate risk in the banking sector. The review synthesises key drivers, transmission channels, and theoretical frameworks, identifying how climate risks propagate through the financial system. Drawing on 226 peer-reviewed articles, the study maps the evolution of the field and identifies five major thematic clusters: climate finance regulation, risk assessment, bank lending behavior, climate risk management and climate corporate governance. After identifying the most important contributions in the field and how the literature has evolved, we observe that research on climate finance regulation and risk assessment is well-developed, whereas other areas require further investigation. These findings suggest future research directions for scholars and offer policy-relevant insights.

Keywords Climate risk · Transition and physical risks · Banking sector · Financial regulation · Bibliometric review

Introduction

Climate change is one of the most pressing and unprecedented challenges of the twenty-first century, with intensifying extreme weather events and surging carbon emissions reshaping environmental and socioeconomic dynamics [1]. According to the Intergovernmental Panel on Climate Change [2], approximately 3.5 billion people live in areas highly vulnerable to climate change. Climate-related events, such as floods, droughts, and heatwaves have led to mounting economic damages. A notable example is the number of floods across Europe, which caused at least €18 billion in property damage and 335 deaths in 2024.[1] These events highlight a growing exposure of businesses and infrastructures to climate risks. When companies suffer economic disruptions, their ability to repay debt weakens, leading to deteriorating credit portfolio quality and increased default risks.

Climate change affects financial stability through two primary channels: physical risks, stemming from acute and chronic climate hazards such as hurricanes, floods, wildfires, and rising sea levels [3–5], and transition risks, arising from policy, technological, and market adjustments linked to the shift toward a low-carbon economy [6]. These risks propagate through the financial system, affecting asset valuations, credit conditions, and liquidity [7, 8]. Because of their exposure to affected sectors and their central role in credit intermediation, banks are particularly vulnerable to these risks.

In response, international frameworks such as the 2015 Paris Agreement and institutions including the Basel Committee on Banking Supervision [9], the European Central Bank [10], and the Financial Stability Board [11] have

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[1] In 2024, storms and flooding affected an estimated 413,000 people, resulting in the loss of at least 335 lives. Damage from storms and flooding across Europe during the year is estimated to have cost at least €18 billion.
https://climate.copernicus.eu/esotc/2024/flooding.

Published online: 11 April 2026

launched initiatives to strengthen climate-related financial oversight. In parallel, forums like the Network for Greening the Financial System (NGFS) and the Task Force on Climate-Related Financial Risks (TFCR) have enhanced coordination among regulators and financial actors. These initiatives have progressively encouraged banks and supervisors to integrate climate-related risks into prudential frameworks, disclosure practices, stress-testing exercises, and risk-management systems, thereby accelerating the development of an academic literature that examines both the conceptual foundations and the practical implications of climate-related financial risk.

Given the growing complexity and severity of climate-related risks and their relevance for banking stability, it is essential to understand the underlying drivers, transmission mechanisms, and methodological approaches used to assess their impact on the banking sector as well as to estimate future risk exposures through forward-looking tools such as scenario analysis and climate stress testing.

While the impact of climate risk on the financial system has received increasing attention from scholars, few review studies offer a comprehensive summary. Existing reviews have typically focused on related but distinct areas of literature, including environmental risk management by financial institutions and supervisors [12], the integration of climate-related risks into macroeconomic models [13], the effects of climate risk on specific asset classes such as equities [14], the pricing of financial assets [15], structural changes in the real economy and their impact on financial stability [16], and on the Central Bank's approach to climate risk [17].

To provide a clearer overview of the existing review studies and the specific aspects they address, Table 1 summarises their main characteristics, including research aims, methodological approaches and findings. This structured comparison highlights how current surveys tend to focus on selected dimensions of climate risks rather than offering a comprehensive synthesis.

Moreover, even if the existing reviews differ substantially in scope, they are similar in methodology. Indeed, most of them adopt a narrative approach. This leaves space for a bibliometric analysis examining climate risk in the banking sector. Indeed, this study aims to systematically map the existing climate risk literature, identifying key research strands and prospects for future investigation, with particular emphasis on the main research hotspots, i.e. regulatory challenges, assessment metrics, and risk management, and on how these themes have evolved over time. Additionally, it seeks to determine if there are any gaps in geographical coverage. To facilitate this, our review is structured around the subsequent research questions:

RQ1 What are the most important contributions and the key themes in the scientific literature on climate risk in the banking sector?

RQ2 How has academic research on climate risk in the banking sector evolved over time?

RQ3 What are the main challenges highlighted in the scientific literature on climate risk in the banking sector?

To address these questions, we adopt a bibliometric analysis [17, 18] of research articles published up until July 2025, which goes beyond traditional narrative or systematic reviews by offering a structured, data-driven map of the field. Beyond synthesising existing knowledge, bibliometric techniques enable the detection of patterns that are often difficult to identify through qualitative analysis. Through performance analysis, science mapping, and cluster analysis, we are able to reveal overlooked or emerging themes and highlight theoretical and methodological imbalances. We also identify geographical and temporal gaps and uncover network structures. By bringing these structural dimensions to light, the bibliometric analysis exposes areas where evidence remains thin or fragmented, thereby strengthening the basis for proposing future research and supporting more targeted policy discussions.

The rest of the paper is structured as follows: Sect. "Understanding climate risk in the banking system" outlines the theoretical background; Sect. "Methodology" details the methodology; Sect. "Results" presents the bibliometric results; Sect. "Discussion" discusses the findings; Sect. "Conclusion" concludes with implications, future research directions and limitations.

Understanding climate risk in the banking system

Drivers, transmission channels and theoretical frameworks

Climate change presents a complex array of risks for the banking sector, primarily transmitted through two drivers: physical risks and transition risks. These risks pose a direct threat to the stability of the broader financial system [7, 8, 19, 20].

Physical risks arise from acute events such as hurricanes, floods, and wildfires, as well as chronic changes like sea level rise, biodiversity loss, and pollution [14, 21–23].

These events can damage physical infrastructure, disrupt economic activity, and impair borrowers' repayment capacity. Banks may suffer losses through multiple mechanisms

Table 1 Overview of existing review studies on climate-related financial risks

Author	Year	Journal	Aim of the review	Methodology	Implications & findings
Breitenstein et al.	2021	Journal of Economic Surveys	Examines foundational research on environmental risk and its effects on financial performance, along with current environmental risk management practices and assessment or hedging tools	Systematic Literature Review	Environmental risks negatively affect financial performance, while awareness and assessment of climate-related financial risks increased significantly between 2011 and 2018
Giglio et al.	2021	Annual Review of Financial Economics	Reviews literature on climate change–financial market interactions, approaches to incorporating climate risk into macrofinance models, empirical evidence on climate risk pricing across asset classes, and portfolio strategies to hedge climate risk	Literature Review	Financial economics researchers have recently begun studying how climate change affects financial markets, making significant progress in modeling climate–economy–asset price links and showing that climate risk is already priced into markets
Semieniuk et al.	2021	WIREs Climate Change	Focuses on developing a coherent framework to explain the drivers, transmission channels, and impacts of phasing out carbon-intensive industries on the financial system and the broader economy, while also reviewing transition-risk policies and identifying research implications	Literature Review	High-carbon industries may quickly become uncompetitive due to shifts in climate policies, low-carbon technologies, consumer preferences, or expectations, causing their physical assets to lose revenue-generating capacity and potentially become stranded if unexpected
Venturini	2022	International Review of Financial Analysis	Reviews how climate change could be considered an additional source of market risk. Discuss the types of data needed to analyse the climate risk drivers that shape the dynamics of the equity market	Literature Review	Climate risk assessment by investors often lacks a basis in fundamental information, and since climate finance research is still emerging, more studies are needed to integrate meteorological insights and explore how firms can adapt to climate risks
Campiglio et al.	2023	Journal of Economic Surveys	Develop a critical review of the empirical and theoretical literature concerning the impact of climate-related risks on the price of financial assets	Literature Review	Investors respond to climate risks, affecting asset prices, firms' cost of capital, and financial risk assessments, but markets likely underprice these risks. Forward-looking methods show climate risks can significantly impact asset prices, though further research is needed to identify the drivers of financial instability
Carè et al.	2024	International Review of Economics and Finance	Describe and analyze the research hotspots and evolution trends in the central banking approach to climate risks	Bibliometric Analysis	Climate risk research is split between theoretical (44%) and empirical (56%) approaches. Most authors (92%) have published only once, indicating no established core of researchers, and the field is heavily influenced by funding and institutional support

Source: Authors' elaboration

[10]: (i) the bank's operations may be disrupted due to physical damage to its property, branches and data centers as a result of extreme weather events, (ii) severe physical events may lead to shifts in market expectations and could result in sudden repricing, higher volatility and losses in asset values on some markets, (iii) the probabilities of default (PD) and loss given default (LGD) of exposures within sectors or regions vulnerable to physical risk may be impacted, for example, through lower collateral valuations in real estate portfolios due to heightened exposure to climate-related hazards such as flooding.

Transition risks, on the other hand, originate from structural shifts toward a low-carbon economy. These include changes in regulatory frameworks (e.g., carbon taxes, emissions targets), technological advancements, and evolving market preferences [24, 25]. These dynamics can generate stranded assets and shifts in sectoral capital allocation [6, 26]. For banks, transition risks materialize through [10]: (i) changing consumer sentiment regarding climate issues that can lead to reputation and liability risk for the bank as a result of scandals caused by the financing of environmentally controversial activities, (ii) transition risk drivers may generate an abrupt repricing of securities and derivatives, for example, for products associated with industries affected by asset stranding, (iii) energy efficiency standards may trigger substantial adaptation costs and lower corporate profitability, which may lead to a higher PD as well as lower collateral values.

After considering the drivers and transmission channels of climate risk, it is important to examine the theoretical

frameworks that underlie the discussion. A theoretical perspective helps explain why banks should be concerned with their borrowers' behavior, stakeholder expectations, market sentiment, and risk management practices, particularly in light of evolving regulatory frameworks. In this section, we provide an overview of the key theories that, in our view, emerge from the literature: (i) *signalling theory; (ii) institutional theory; (iii) risk management theory; (iv) agency theory,* and *(v) uncertainty theory*.

The literature based on *signalling theory* [27–29] suggests that firms with high Corporate Social Responsibility (CSR) commitment generate a credible signal to attract more socially responsible consumers. These firms are also viewed as attractive borrowers by banks, which, to mitigate reputational risk, tend to favor lending to low-emitting firms [30–32]. From the perspective of asymmetric information theory, borrowers operating in high carbon emissions are considered riskier prompting banks to invest in more extensive screening and monitoring efforts [33–35].

Firms with higher carbon emissions are typically perceived as riskier by lenders, which can be reflected in higher debt financing costs (Jung et al. [36]). However, consistent with credit rationing theory, banks may prefer to restrict or deny credit to such high-risk borrowers rather than increase interest rates, in order to mitigate problems of adverse selection and the heightened likelihood of default [37]. As a result, carbon emissions have become a key determinant component in credit allocation decisions, directly influencing the composition of banks' loan portfolios. In this context, signalling theory offers a useful framework to understand how banks may leverage their lending policies, such as prioritizing low-carbon borrowers or offering preferential terms for green loans as a way to signal environmental commitment to stakeholders and the broader market (e.g., via GHG thresholds or ESG credit scoring).

Moving to *institutional theory,* it suggests that a company's survival depends on its acceptance by the society in which it operates [38, 39]. Institutional factors refer to norms, rules, values, beliefs, politics, public pressures and stakeholder expectations that force, discourage or encourage certain behavioural patterns and are crucial drivers of country-level differences. Differences in institutional contexts, such as the level of national economic development and socio-cultural system [40, 41], inevitably influence expectations on the level and quality of banks' climate commitment. Additionally, a well-established institutional environment can strengthen the perceptions of responsible business conduct [42, 43], and a country's culture can impact the ethical behaviours of the companies based there [44–47]. Meanwhile, banks are increasingly participating in voluntary initiatives to reinforce environmental criteria in their business (e.g., the Equator Principles). Responsible behaviours change across countries, and this affects the climate risk exposure [48, 49]. Institutional theory complements this by explaining how regulatory pressures and normative expectations (e.g., Equator Principles, TCFD guidelines) drive banks in certain contexts to adopt environmental rules and embed them in internal governance.

According to the *risk management theory*, a restrictive and selective lending process reduces banks' credit and portfolio risk [50]. A lower portfolio risk also implies a lower default risk of the bank, because of more stable income streams. Proactively adjusting lending portfolios to align with evolving climate policies and societal expectations allows banks to anticipate structural shifts and minimize future adjustment costs.

To support risk mitigation, European regulatory frameworks, such as the Basel Accords, have established capital requirements to cover market and credit risks. However, while Basel III strengthens financial institutions' resilience to short-term shocks, it has been criticized for insufficiently addressing the long-term nature of climate-related financial risks [51]. Supporting this theory, some studies have shown that banks which effectively manage climate risk within their lending portfolios, by reducing their exposure to borrowers in countries vulnerable to physical risks and to sectors exposed to transition risks, experience lower levels of credit risk [52, 53]. This underscores the importance of integrating climate risk into credit assessment and portfolio allocation to enhance long-term financial resilience.

Building on the above theories, *agency theory* provides additional insight into the challenges posed by climate risk in lending relationships as borrowers and lenders often have misaligned incentives regarding exposure to climate-related risks [54]. In such cases, banks bear the downside risks of lending to firms exposed to climate risks, but they do not share any potential benefits. Agency problems may also emerge when climate change impairs the value of collateral, such as physical assets, thereby reducing the likelihood of full debt repayment. For instance, if climate shocks negatively affect firm performance and asset values, pushing a borrower toward financial distress, managers may be incentivized to take riskier operational decisions. In this scenario, the increase in volatility raises the value of the managers' implicit put option, while their downside payoff is limited, effectively leaving them with nothing to lose. These behaviors can significantly increase credit risk for banks.

Finally, the *theory of uncertainty* explains how the unpredictable nature of climate impacts introduces significant informational risk into lending relationships. Climate-related uncertainty makes it difficult for banks to anticipate all future contingencies, rendering loan contracts inherently incomplete [55, 56]. This incompleteness exposes lenders to post-contractual opportunism and impairs their ability

to safeguard welfare. The theory incorporates information asymmetry, with the ambiguity surrounding the timing of climate risk. In response, lenders demand greater control rights such as stricter non-price loan terms, to compensate for what market-based price mechanisms alone cannot resolve. These complex challenges require a comprehensive and adaptive approach, an area where banks hold structural and institutional advantages. The unpredictable nature, scope, and timing of climate risk make it virtually impossible for lenders to write complete contracts that account for all potential scenarios.

The role of climate policy uncertainty and banking regulation

The theories discussed above emphasize the role of uncertainty stemming from climate risk. On one hand, in contexts of uncertainty and information asymmetry, policymakers can intervene to correct market failures. On the other hand, however, the introduction of new climate-related policies, especially in the wake of the Paris Agreement of 2015, has itself become a source of uncertainty for financial market participants. This phenomenon is known as climate policy uncertainty, which refers to the unpredictability surrounding the content, timing, and enforcement of climate policies. Addressing climate policy uncertainty is a necessary first step before analysing the impact of banking regulation, because these two forces interact closely in shaping how climate risk is perceived, priced, and managed within the financial system.

While regulatory frameworks determine the formal boundaries within which banks must operate, policy uncertainty affects how confidently banks and borrowers can make long-term financial decisions. Together, they influence banks' incentives, constraints, and strategic behavior in responding to climate risk. In pursuing their policy objectives, governments continually adjust climate-related measures in response to domestic and international developments, which can itself generate economic policy uncertainty. New climate-transition directives can create economic-policy uncertainty as well. For example, with the signing of the Paris Agreement and the introduction of green-credit policies, central banks and regulators have increased their demand for climate risk management, which has improved banks' ability to price climate risk and has ultimately changed banks' credit provision and risk preferences [57, 58].

Policy uncertainty operates through the following moderating mechanisms: first, an increase in policy uncertainty prompts banks to more fully identify the climate transition risk; second, increased policy uncertainty reduces the willingness of enterprises to invest [57], resulting in a decrease in the demand for bank loans. In an environment of increasing policy uncertainty, banks' business activities tend to become more cautious, leading them to conduct more comprehensive assessments of various client risks, including climate risk. Moreover, rising economic policy uncertainty increases banks' caution and risk aversion [58, 59], which in turn leads them to demand a higher risk premium. Consistent with the economic uncertainty concepts of Baker et al. [60], climate risk through physical and transition risk channels, affects both society and the economy and creates economic uncertainties. However, current mitigation action will have a material impact in the long-term, but the upcoming future state of the climate by 2050 is essentially determined by the GHG emissions of the last decades. This implies that the future trend of global climate change is relatively well-known in the medium term, which gives sufficient information for adaptation plans over that time horizon.

Turning to banking regulation, a key feature of macroprudential policy is that it empowers central banks and supervisory authorities to reduce the likelihood of instability ex ante, i.e. before market participants recognise the emergence of risk and adjust their behaviour. The macroprudential policymaker is forward-looking rather than backward-looking and has an incentive to prepare for worst-case scenarios.

Both the systemic magnitude and irreversibility of the threats associated with climate-related financial risk, and the radical uncertainty attached to them, justify the development of climate-related precautionary financial policy. Financial policies and regulation can be used to mitigate climate-related financial risk by supporting a rapid and smooth decarbonisation of economic activity through both direct measures and changing the incentive structures of financial institutions' and market players' decisions. This could involve penalising or even prohibiting financing and investing in economic activities that are incompatible with a transition to a below −2 °C warming path (e.g. fossil fuels), while supporting economic activities that are climate-desirable in terms of efficiency and renewability.

Indeed, central banks and financial regulators are increasingly regarded as a front-line defence against climate-related financial instability. Policymakers are incorporating climate risk into regulatory frameworks in order to safeguard financial stability. These interventions are likely to influence how banks manage climate risks and the role they will play in fostering the transition to a more sustainable economy.

Methodology

Bibliometric analysis

This study employs a bibliometric approach to analyse key contributions from journals, authors, institutions, and countries, and to identify research hotspots and emerging trends. This research technique's appeal lies in its ability to work across multiple disciplines and manage large datasets [18, 61]. Specifically, for an in-depth analysis, this study employs performance analysis, science mapping and cluster analysis [18, 62–64]. First, a performance analysis was conducted to elucidate the contributions of the research constituents (e.g., authors, articles, journals, institutions, and countries) in the domain of climate risks within the banking sector [18]. Next, science mapping techniques—such as citation, co-citation, and bibliographic coupling analysis—are applied to identify the relationships among research constituents [18]. Finally, cluster analysis is carried out to identify and categorize the key themes in the field of research by analysing keywords. Specifically, it is possible through a network visualization, in which a tag and a circle represent the elements (keywords), the size of which varies according to the element's importance.

More in depth, for the co-citation analysis, following established practice in bibliometric research [61, 65, 66], we applied a minimum citation threshold to focus on influential authors and to ensure the interpretability of the co-citation network. While prior studies adopt slightly different cut-off values depending on dataset size and research objectives, we selected a threshold of 10 citations as a balanced and conservative criterion. Bibliographic coupling analysis was conducted without imposing a minimum citation threshold, as this technique is particularly suitable for capturing recent and emerging research streams whose citation counts may still be low [66].

The use of bibliometric analysis often goes hand in hand with network visualization software, which ranges from entirely graphical user interface-based software such as VOSViewer[2] (van Eck and Waltman 2010) to command-based software such as Bibliometrix[3]package in R (Aria and Cuccurullo 2017). To carry out all our analysis, both software were used [67].

[2] VOSviewer is a software tool for creating and exploring maps based on network data. It explores co-authorship, co-occurrence, citation, bibliographic coupling, and co-citation links in one of three possible representations: network, overlay, or density visualization.

[3] Bibliometrix is a mapping analysis tool package that must be used within the R software environment.

Database and research protocol

The first step in a bibliometric analysis is the selection of an appropriate database. Web of Science and Scopus are the two most widely used platforms, and their differences have been extensively examined in the literature through direct coverage comparisons [68]. Overall, this evidence shows that Scopus indexes a larger number of journals, while Web of Science remains more selective in its coverage. Importantly, Scopus offers broader representation in the social sciences than Web of Science [68], which is particularly relevant for the interdisciplinary nature of climate-finance research. While combining the two databases may in some cases further increase coverage, the exclusive use of a single dataset is consistent with prior bibliometric studies in finance and climate risk research (e.g. [17, 18]) and ensures a transparent and replicable search strategy. Particular care was then taken in defining a comprehensive and coherent set of keywords in order to accurately identify the relevant research articles.

The choice of keywords is crucial in bibliometric analysis, as overly broad search strings can introduce substantial noise and dilute the dataset's conceptual focus. In this review, the search was carried out by selecting all the studies contained in the title, in the abstract or the keywords, the words "climate risk" AND "bank*", "transition risk" AND "bank*", "physical risk" AND "bank*" to ensure that the retrieved publications explicitly address climate-related risks as a distinct research domain within the banking sector. This targeted formulation allows us to capture work that directly engages with the core concepts used by regulators, supervisors, and the academic literature when discussing climate risks in banking.

In contrast, a much broader query, such as combining generic climate terms (e.g., "CO_2", "GHG") with banking- or credit-risk terminology, would retrieve a large volume of studies in environmental economics, macro-climate research, or sustainability finance that do not specifically analyse climate risks as defined in the regulatory and risk-management literature. For example, articles on carbon emissions or general climate-change impacts that discuss macroeconomic or environmental issues without providing a banking-sector risk perspective, thereby reducing the conceptual coherence of the dataset.

Thus, while broader search strings may capture adjacent themes, our more selective keyword strategy ensures conceptual precision and produces a cleaner, more interpretable bibliometric map of the literature that directly pertains to climate risks in banking.

After the selection of the keywords and queries, a set of inclusion and exclusion criteria were defined (Table 2) [17]. More in detail, to further refine the data collection procedure,

Table 2 Inclusion/exclusion criteria

Inclusion/exclusion	Criteria	Motivation
Inclusion	Only Scopus indexed research article	To limit the scope of the study to articles that have been selected and curated by the Scopus indexing system. This database is considered to be a reputable and widely used resource for academic and scholarly publications. Including only articles indexed in the Scopus can help ensure the quality and reliability of the sources used in the analysis and maintain consistency throughout the research process
	Articles from "all fields"	To ensure a comprehensive and broad coverage of literature. This approach allows to consider a wide range of perspectives, findings, and insights from various fields of study. It can be especially useful when addressing multidisciplinary or cross-cutting research questions that benefit from a holistic view of knowledge across different academic domains. Including articles from "all fields" acknowledges the potential contributions and relevance of research from different disciplines, enhancing the depth and breadth of the study or literature review
	Publication Type: only peer-reviewed journal articles	To prioritize articles that have been subject to this evaluation process. This approach helps maintain the quality and reliability of the sources used in the research or literature review. Peer-reviewed articles are generally considered to be more credible and authoritative sources of information in the academic community. Excluding nonpeer-reviewed sources, such as conference abstracts, preprints, or magazine articles, can help the researcher focus on articles that have undergone a rigorous evaluation and have a higher likelihood of providing accurate and trustworthy information for the study
	Language: only articles published in English	To limit the scope of the study to English-language publications. English serves as a common language in international collaborations and acts as a lingua franca in the academic community. By limiting the study to articles in English, the research can ensure relevance across a broader audience
Exclusion	Subject Relevance: exclude articles that are not directly related to the research topic or field of interest	To focus on articles that directly address the research question or align with the scope of the study. To exclude articles that are completely unrelated to the research topic or field of interest. Subject Relevance was measured considering: (i) Institutional scope mismatch; (ii) Sectoral misalignment; (iii) Conceptual false positives; (iv) Peripheral treatment of climate risk

Source: Authors' elaboration following Carè et al. [17]

as an inclusion criterion, data were collected from 'all fields' but were limited to only articles published in English [64, 69]. We selected only journal articles because this document type is regarded as "certified knowledge" [70–72] and is likely to have the strongest impact in the field [73].

After retrieving the initial set of 299 documents from Scopus, a manual purification process was conducted to ensure that the final corpus accurately reflects research on climate-related physical and transition risks in the banking sector. This step consisted of a systematic reading of each abstract to verify whether the article substantively addressed the research scope. Following this process, a total of 73 publications were excluded based on the following pre-defined exclusion criteria:

(i) Institutional scope mismatch: studies focusing on multilateral development banks or international financial institutions (e.g., World Bank, regional development banks), rather than commercial or retail banking institutions (43 articles excluded); (ii) Sectoral misalignment: studies in which climate risk was analyzed in sectors such as agriculture, energy, or land use, with banks appearing only as secondary actors or data providers (24 articles exluded); (iii) Conceptual false positives: publications in which the term "bank" referred to non-financial entities (e.g., river banks, seed banks, gene banks) (4 articles excluded); (iv) Peripheral treatment of climate risk: studies mentioning climate risk only tangentially, without a substantive focus on risk transmission, measurement, or management within the banking system (2 articles excluded).

To reduce subjectivity in the manual screening stage the same inclusion–exclusion rules were used for all records, and borderline cases were revisited to ensure that the criteria were interpreted uniformly across the entire dataset. Although the screening was conducted by a single author, decisions were based strictly on the stated conceptual boundaries of the study rather than on discretionary judgement.

It is important to note that restricting the search by subject area was not considered a reliable strategy. In bibliometric databases such as Scopus, articles are often classified according to the primary subject area of the journal rather than the specific content of the paper. As a result, studies that directly assess climate risks in banking may appear under broader or seemingly unrelated subject areas, depending on the journal's classification. Limiting the search by subject area could therefore have excluded relevant papers, reducing the completeness and representativeness of the dataset. By carefully screening abstracts instead, we ensured that all studies meeting the conceptual criteria were retained, regardless of the journal's assigned subject category.

Through this systematic screening, 73 papers were excluded because they did not meet the scope criteria, leaving a final, conceptually coherent sample of 226 studies published in 138 journals. This purification approach is fully consistent with standard practices in bibliometric research (e.g. [18, 66] and ensures that the resulting dataset captures genuine contributions to the literature on climate risks in banking.

Figure 1 summarises the four-stage screening process applied to the 299 records initially retrieved, resulting in a final dataset of 226 articles.

Results

The results are organized into two main sections: performance analysis and science mapping (Sect. "Performance analysis and science mapping"), and cluster analysis (Sect. "Cluster analysis"). Performance analysis and science mapping focus on specific units of analysis, including journals, authors, articles, countries and affiliations. Cluster analysis, on the other hand, identifies prevailing research themes through keyword analysis and examines their evolution over time using overlay analysis.

Performance analysis and science mapping

Table 3 presents the main statistics for our final sample of 226 articles. The authorship analysis shows that there are 40 single-authored and 186 multi-authored articles (with 2.87 co-authors per document on average); the high percentage of international co-authorships (30.09%) suggests a global community of academics involved in the issue, also notable by observing the authors' affiliations (Table 9). As we explore research funding, our investigation uncovers another important aspect. Specifically, our data show

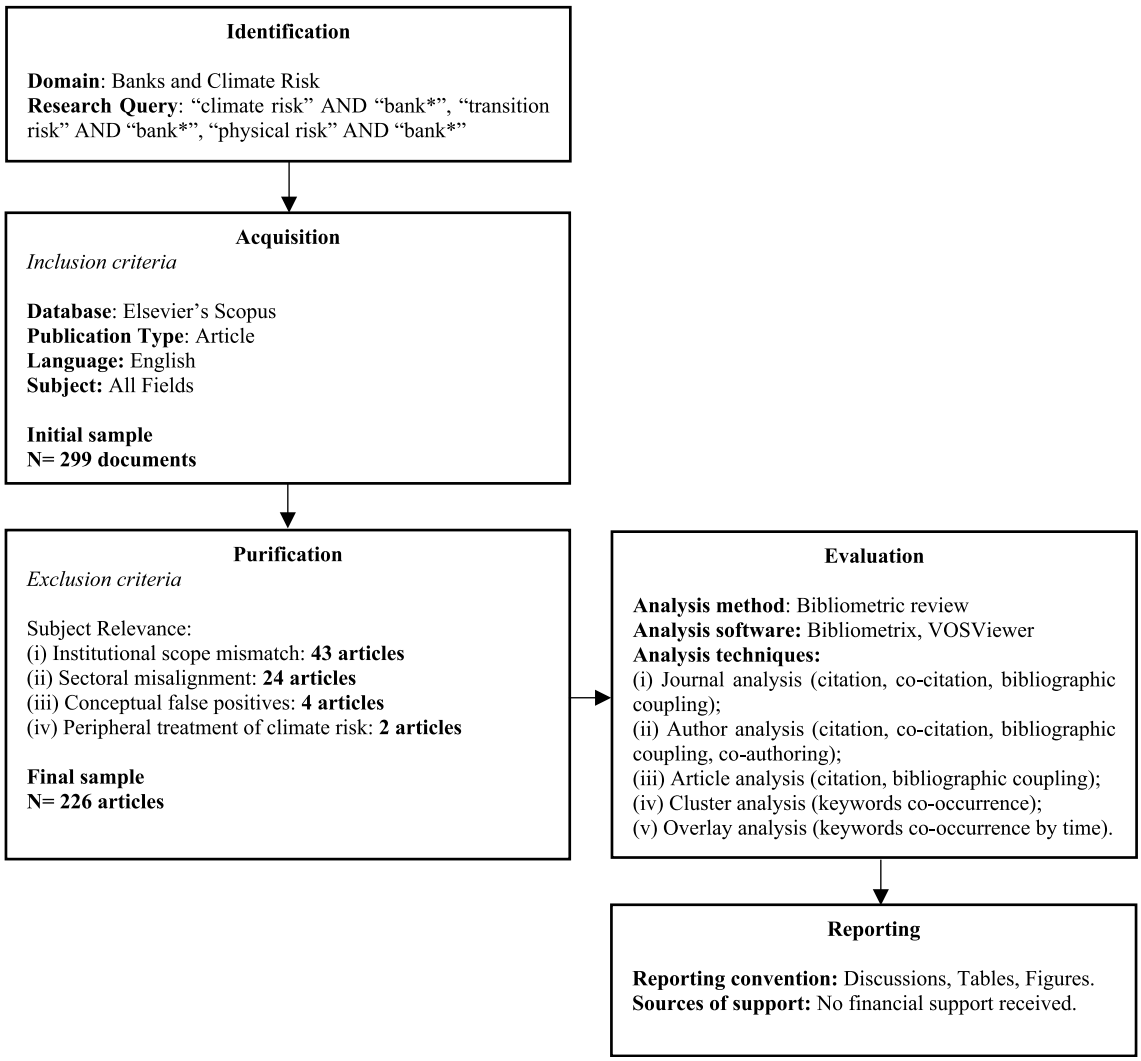

Fig. 1 Bibliometric search and screening protocol. Source: Authors' elaboration

Table 3 Bibliometric overview

Description	Results
Main information about data	
Timespan	2014:2025
Sources (journals, books, etc.)	138
Documents	226
Annual growth rate %	44.87
Document average age	1.73
Average citations per doc	17.38
Funding rate %	42.92
References	12,076
Document contents	
Keywords plus (ID)	395
Author's keywords (DE)	639
Authors	
Authors	568
Authors of single-authored docs	37
Authors collaboration	
Single-authored docs	40
Co-authors per doc	2.87
International co-authorships %	30.09
Document types	
Articles	226

Source: Bibliometrix output

that out of 226 studies in our sample, 97 receive funding. This information should be further analysed within the cluster analysis to determine whether funding influences the research directions. The resulting expansion in international co-authorship indicates growing convergence among academics, which may shape the field's evolution toward more harmonized risk-assessment frameworks and cross-country comparability.

Figure 2 illustrates a significant surge in academic interest in this topic beginning in 2021. This acceleration is not merely a reflection of academic interest but appears closely tied to major regulatory and policy milestones, such as the implementation of the EU Sustainable Finance Disclosure Regulation (SFRD) (2021), the release of supervisory climate-stress-test exercises by the ECB [10] and Bank of England (2022) and the Basel Committee climate risk measurement framework (BCBS [74]). Simultaneously, a series of extreme climate events and increasing geopolitical tensions reinforced the view that climate and financial stability risks are connected. These developments collectively stimulated data availability and generated demand for empirical and methodological contributions.

Journal analysis

The journal analysis provides further insight into the disciplinary structure and maturity of the field. The 226 articles in our sample are distributed across 138 different sources and indicate that research on climate-related banking risk is not confined to a single disciplinary niche but spans finance, economics and environmental science. The citation analysis (see Table 4) reveals that the highest number of citations is from the *Journal of Financial Stability* (567), followed by *Nature Climate Change* (547), *Ecological Economics* (501), *Journal of Corporate Finance* (369) and *Climate Policy* (185). The citation patterns show that journals traditionally associated with financial stability and banking (*Journal of Financial Stability*, *Journal of Corporate Finance*) are among the most influential sources, suggesting that the topic has entered the core agenda of the finance discipline. At the same time, the prominence of interdisciplinary journals such as *Nature Climate Change, Ecological Economics,* and *Climate Policy* highlights the subject's cross-cutting nature and reflects the integration of environmental perspectives into financial risk analysis. This multidisciplinary approach shows that climate risk research is moving from being a niche area to becoming a core part of mainstream research, rooted in empirical finance and financial regulation.

Co-citation patterns reinforce this view. Among the most cited sources, we find *Journal of Financial Economics* (157) followed by *Journal of Financial Stability* (149) and *Nature Climate Change* (131). Finance journals are among the most frequently cited sources, suggesting that the field draws heavily on established theoretical and empirical tools from mainstream finance.

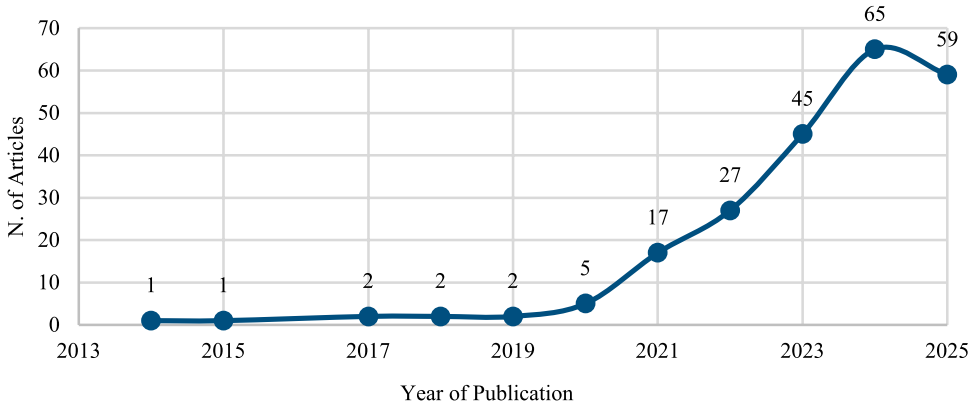

Fig. 2 Production over time. Source: Authors' elaboration

Table 4 Comparison of citation, co-citation and bibliographic coupling of journals

Citation analysis		Co-citation analysis			Bibligraphic coupling analysis			
Source	Papers	TC	Source	TC	Link strenght	Source	Link strength
Journal of financial stability	11	567	Journal of Financial Economics	157	5780	Journal of Financial Stability	1680
Nature climate change	1	547	Journal of Financial Stability	149	5324	International Review of Financial Analysis	1473
Ecological economics	4	501	Nature Climate Change	131	3885	Climate Policy	765
Journal of corporate finance	3	369	Journal of Corporate Finance	81	3812	Research in International Business and Finance	674
Climate policy	5	185	Review of Financial Studies	115	3537	Ecological Economics	639
Journal of banking and finance	2	164	Ecological Economics	110	3479	Journal of International Money and Finance	573
International review of financial analysis	12	159	Journal of Banking & Finance	91	3396	Finance Research Letters	569
Strategic management journal	1	123	Energy Economics	82	3113	Journal of Economic Surveys	532
Technological forecasting and social change	3	85	International Review of Financial Analysis	74	2820	International Review of Economics and Finance	473
Finance research letters	10	75	Journal of Finance	78	2584	Journal of Financial Regulation and Compliance	416
Journal of international money and finance	3	64	Finance Research Letters	57	1936	Journal of Cleaner Production	377
Review of economic dynamics	1	59	Management Science	44	1915	Journal of Corporate Finance	354
Journal of financial regulation and compliance	2	51	American Economic Review	51	1890	Annual Review of Financial Economics	340
Journal of environmental management	2	49	Climate Policy	60	1861	Journal of Sustainable Finance and Investment	335
Sustainability (Switzerland)	4	45	Journal of Cleaner Production	48	1809	Journal of Business Finance and Accounting	316
Economic change and restructuring	3	38	Journal of Financial Intermediation	36	1582	Latin American Journal of Central Banking	303
China and world economy	1	37	Ecological Economics	59	1488	Climatic Change	296
Global finance journal	2	35	Sustainability	69	1478	Risk Analysis	275
Business strategy and the environment	2	33	Business Strategy and The Environment	45	1447	Journal of Banking and Finance	262
Research in international business and finance	6	33	Research in International Business and Finance	36	1406	British Journal of Management	260

Source: Authors' elaboration

The bibliographic-coupling analysis also reveals a clear set of core outlets. The journals with the highest total link strength are *Journal of Financial Stability* (1680), *International Review of Financial Analysis* (1473), *Climate Policy* (765), *Research in International Business and Finance* (674), and *Ecological Economics* (639). These journals can therefore be considered the sources of reference or the "roots" of the literature on the subject. Strong bibliographic linkages with *Climate Policy* and *Ecological Economics* also reveal a sustained connection to environmental science. The coexistence of high-ranked finance and environmental journals within the citation network reflects both the growing credibility of climate risk research within the finance community and the continued need for an interdisciplinary approach for understanding transition and physical risks.

The distribution of publications across journals further indicates a field that is expanding but still heterogeneous. While many high-ranked journals publish a significant number of studies, numerous works are still found in lower-ranked journals. This indicates that although climate risk in banking is gaining recognition in top finance journals, the field is still consolidating. There are opportunities for greater integration into leading finance and economics publications as empirical evidence and methodologies advance.

Author analysis

The sample of articles considered highlights 586 authors across 226 publications (Table 5). The most cited author is Battiston Stefano (Professor of Economic Policy, University of Venice Ca' Foscari) with 780 citations, followed by Monasterolo Irene (Professor of Climate Finance at Utrecht University's School of Economics) with 739 citations. This result reflects their scholarly impact, as citation counts

Table 5 Comparison of citation, co-citation and bibliographic coupling of authors

Citation analysis			Co-citation analysis				Bibligraphic coupling analysis		
Author	Papers	TC	Author	TC	Link strenght	Cluster	Author	Link strength	Cluster
Battiston, S	5	780	Monasterolo, I	256	16,981	4	Monasterolo, I	686	2
Monasterolo, I	5	739	Battiston, S	260	16,695	4	Chenet, H	618	3
Mandel, A	1	547	Dafermos, Y	148	10,681	2	Ryan-Collins, J	618	1
Schütze, F	1	547	Campiglio, E	120	8888	2	Svartzman, R	606	3
Visentin, G	1	547	Bolton, P	111	7666	2	Guter-Sandu, A	519	2
Volz, U	2	326	Volz, U	102	6665	2	Haas, A	519	2
Dikau, S	1	324	Mandel, A	86	6431	2	Murau, S	519	2
Javadi, S	1	257	Ryan-Collins, J	80	5767	2	Bolton, P	507	3
Masum, A. A	1	257	Nikolaidi, M	74	5303	2	Despres, M	507	3
Chenet, H	2	211	Monnin, P	73	5353	2	Curcio, D	494	1
Ryan-Collins, J	2	211	Sautner, Z	69	5180	1	Gianfrancesco, I	494	1
Van Lerven, F	1	160	Tanaka, M	72	5111	2	Vioto, D	494	1
Alessi, L	3	156	Ongena, S	78	4940	1	Guo, K	490	1
Escobar-Farfán, Luis O.L	1	149	Stroebel, J	67	4905	1	Ji, Q	490	1
Martinez-Jaramillo, S	1	149	Visentin, G	73	4787	4	Zhang, D	490	1
Roncoroni, A	1	149	Svartzman, R	62	4528	2	Li, S	467	1
Dunz, N	2	146	Schutze, F	68	4403	2	Battiston, S	437	2
De Greiff, K	1	133	D'orazio, P	51	4098	2	Liu, X	419	1
Ehlers, T	1	133	Samama, F	56	3938	2	Berner, R	402	4
Packer, F	1	133	Mirza, N	63	3786	3	Jung, H	402	4
Huang, H. H	1	123	Umar, M	61	3766	3	Dunz, N	397	2
Kerstein, J	1	123	De Greiff, K	47	3585	1	Lucey, B	386	1

Source: Authors' elaboration

capture how frequently an author's work is referenced by subsequent studies.

While citation analysis emphasizes visibility and accumulated impact, it does not capture the relational structure of knowledge development. To address this limitation, author co-citation analysis is employed [66, 75] (Fig.3). Applying this method reveals that Battiston S. and Monasterolo I. are frequently co-cited, suggesting that subsequent studies often jointly rely on their models, frameworks, and empirical findings. Additional co-citation patterns emerge around a broader network of scholars, including Dafermos Y., Campiglio E., and Bolton P., who form a large interconnected cluster. Other distinct co-citation networks are also identified. One cluster centers on Sautner Z., Ongena S., and Stroebel J., another network includes Mirza N. and Umar M.

To further uncover active contributors at the research frontier, the study applies bibliographic coupling analysis, which links authors whose publications cite similar references. Unlike co-citation, which is backward-looking and reflects established intellectual influence, bibliographic coupling is forward-looking, capturing contemporary thematic proximity and ongoing research trajectories. Through this approach, coupled authors are Monasterolo I., Guter-Sandu A., Haas, A., while another cluster is composed by Chenet H., Svartzman, R. and Bolton, P. Moreover, co-author analysis is particularly suitable for studying scientific collaboration. This method can analyze co-authorship patterns among contributing scientists and produce a social network that makes up the research field. Co-author analysis identifies the social network among researchers [66, 76]. The main reason behind conducting this analysis was to recognize those scholars who are actively contributing together to this research field [65]. For this analysis, the minimum document scale was limited to one [65, 77].

Figure 4 illustrates the co-authorship network, revealing five well-defined collaboration clusters comprising a total of 20 researchers actively publishing on banks and climate risk. The structure of the network highlights both strong institutional collaboration and cross-institutional knowledge exchange, particularly among European academic institutions, policy-oriented research centers, and international financial organizations. Overall, the co-authorship network reveals a research field that is both institutionally concentrated and internationally connected, with European universities and policy institutions playing a dominant role. Table 6 provides details of these authors.

Key articles and central contributions in the literature

The growth of scientific production in the last 10 years confirms the growing attention to the risks associated with climate change. For the 226 articles included in the reference

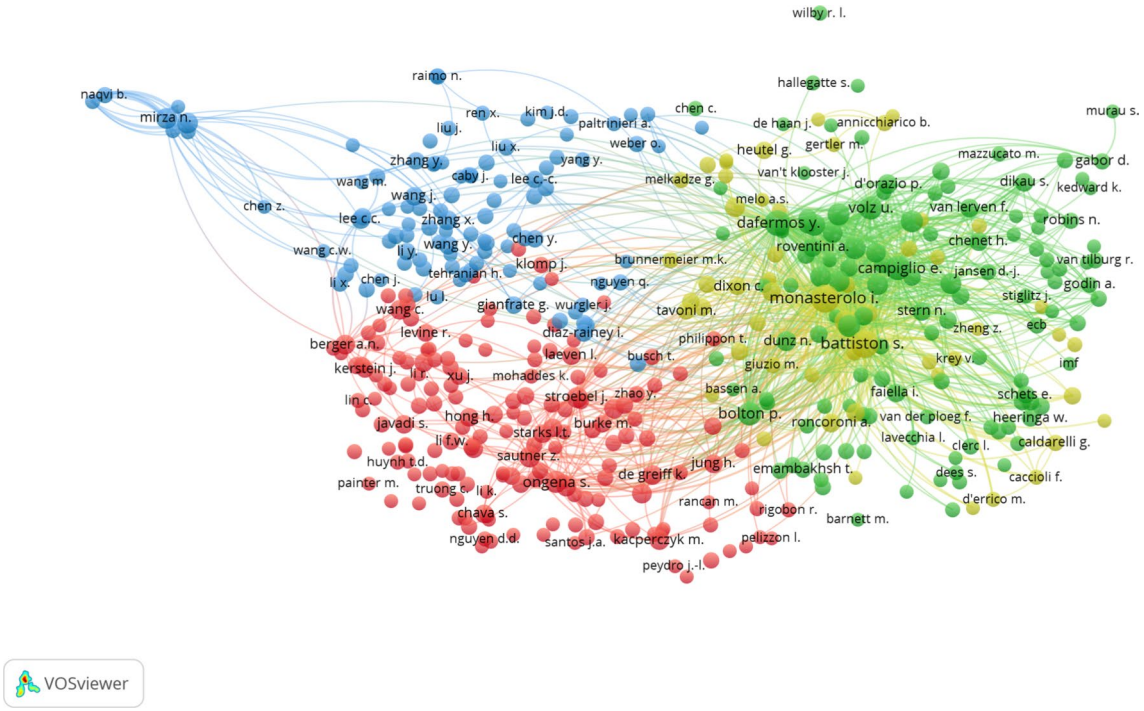

Fig. 3 Co-citation network. Source: Authors' elaboration

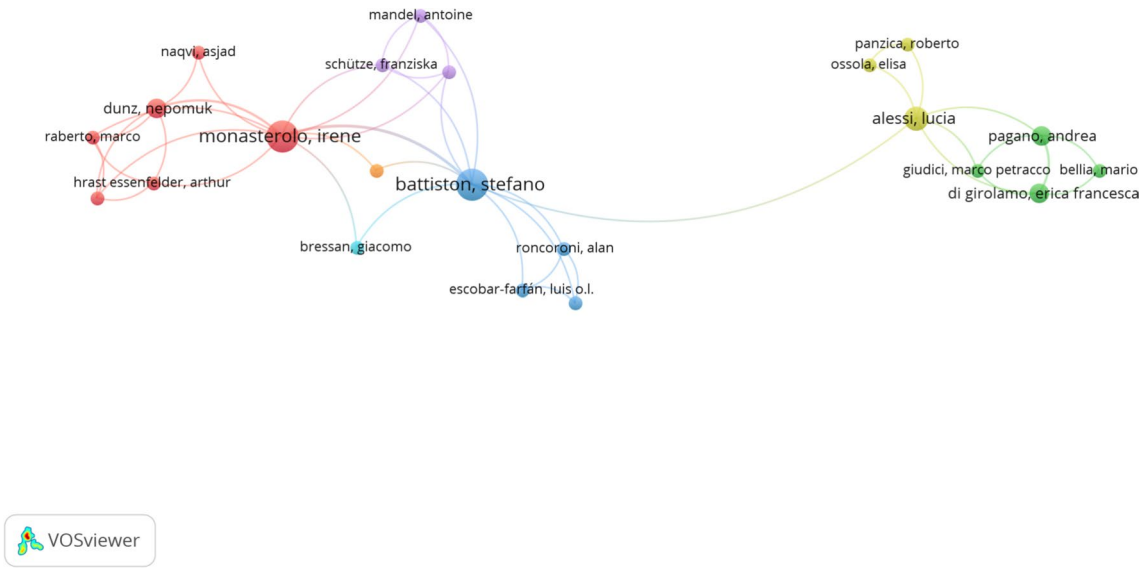

Fig. 4 Co-author network analysis. Source: Authors' elaboration. This figure presents the result of the co-authorship identification process. Each point represents one author and links represent co-authorships

sample, an average number of citations per article is identified equal to 17.38. The co-citation analysis identifies the main theoretical references that led to the development of the topic.

Table 7 provides an overview of the most influential articles, classified by total citations, normalized citations and bibliographic coupling (link strength). Comparative analysis, using three different indicators, helps mitigate the individual biases of each. Total citations tend to reward older articles, while with normalized citations, articles that have had a greater impact, in terms of citations, are favoured compared to others published in the same year. Bibliographic coupling, in turn, identifies the relevance of articles within the citation network of the field.

The joint analysis of the three indicators improves the quality of the study and avoids the omission of significant

Table 6 Social network of authorship

#	Co-authorship network*	Author	Institution/university	Total publications	Total citations
1	A	Monasterolo I	Vienna University of Economics and Business	46	3138
2	A	Raberto, M	Università degli Studi di Genova	69	3100
3	A	Hrast Essenfelder, A	European Commission, Joint Research Centre	24	661
4	A	Naqvi, A	Vienna University of Economics and Business	18	497
5	A	Dunz, N	Vienna University of Economics and Business	6	240
6	A	Mazzocchetti A	Università Ca' Foscari Venezia	10	216
7	B	Pagano, A	European Commission, Joint Research Centre	27	718
8	B	Giudici, M.P	European Commission, Joint Research Centre	6	140
9	B	Bellia, M	European Commission, Joint Research Centre	8	36
10	B	Di Girolamo, E.F	European Commission, Joint Research Centre	3	21
11	C	Battiston, S	Università Ca' Foscari Venezia	99	7444
12	C	Martinez-Jaramillo, S	The World Bank	41	1251
13	C	Roncoroni, A	Zurich University	2	221
14	C	Escobar-Farfán, Luis O.L	Banco de Mexico	2	192
15	D	Alessi, L	European Commission, Joint Research Centre	29	1031
16	D	Panzica, R	Banco de Portugal	10	666
17	D	Ossola, E	Università degli Studi di Milano-Bicocca	10	432
18	E	Mandel, A	Ecole d'Économie de Paris	50	1682
19	E	Schütze, F	German Institute for Economic Research	9	1005
20	E	Visentin, G	ETH Zürich	4	712

Source: Authors' elaboration. Organised by the total number of citations for the cluster

*A: Red (Cluster 1); B: Green (Cluster 2); C: Blue (Cluster 3); D: Yellow (Cluster 4); E: Violet (Cluster 5)

Table 7 Identification of most influential Articles according to citations, normalized citations and bibliographic coupling

Citations		Normalized citations		Bibliographic coupling	
Articles	TC	Articles	NC	Articles	Link strength
Battiston S. et al. [26]	547	Aguila N. and Wullweber J., [78]	12.15	De Bandt O. et al. [79]	278
Dikau S. and Volz U. [80]	324	Korzeb Z. et al. [81]	8.68	Zhang D., et al. [82]	201
Javadi S. and Masum A.A. [83]	257	Anastasiou D. et al. [84]	8.68	Acharya V.V. et al. [85]	190
Chenet H. et al. [86]	160	Ehlers T. et al. [87]	6.30	Cheung H. et al. [88]	179
Roncoroni A. et al. [89]	149	Benincasa E. et al. [90]	5.97	Curcio D. et al. [91]	173
Ehlers T. et al. [87]	133	Huang H. et al. [92]	5.83	Carè R. et al. [17]	170
Huang H.H. et al. [92]	123	Erhemjamts O. et al. [93]	5.64	Svartzman R. et al. [94]	164
Dunz N. et al. [95]	115	Baek S, and Kang M. [96]	5.21	Dafermos Y. and Nikolaidi M. [97]	161
Alessi L. et al. [98]	109	Dou J. et al. [99]	5.21	Anastasiou D. et al. [84]	161
Huang B. et al. [100]	76	Zhang D. et al. [82]	4.48	Chenet H. et al. [86]	160

Source: Authors' elaboration

documents. The most relevant article for the total number of citations is the one published by Battiston et al. [26], in terms of normalized citations, the ranking sees the article by Aguila and Wullweber [84].

The articles most integrated into the debate, that is, which occupy the first five positions by bibliographic coupling index, are:

- De Bandt et al. [79], The effects of climate change-related risks on banks: A literature review, Journal of Economic Surveys,
- Zhang et al. [82], Climate impacts on the loan quality of Chinese regional commercial banks, Journal of International Money and Finance,
- Acharya et al. [85], Climate Stress Testing, Annual Review of Financial Economics,
- Cheung et al. [88], Barriers and enablers to sustainable finance: A case study of home loans in an Australian retail bank, Journal of Cleaner Production,
- Curcio et al. [91], Climate change and financial systemic risk: Evidence from US banks and insurers, Journal of Financial Stability.

Global distribution of research: countries and affiliations

Tables 8 and 9 provide an overview of the geographic and institutional distribution within the research domain. China emerges as the leading contributor, accounting for nearly

Table 8 Country production

Country	Freq
China	117
Italy	66
Usa	62
Uk	56
Germany	47
France	45
Australia	23
Canada	14
India	14
Poland	11

Source: Authors' elaboration

NOTE: Country Production measures the number of author appearances by country affiliations. In other words, each article is attributed to the countries of all its co-authors and is therefore counted as many times as there are authors

Table 9 Relevant affiliations

Affiliation	Articles
Southeast University	9
European Commission—Joint Research Centre	7
Notreported	7
Vienna University of Economics And Business	7
Ocean University of China	6
Statistics and Research	6
Central University of Finance And Economics	5
China University of Mining And Technology	5
Nanjing Agricultural University	5
National University of Singapore	5

Source: Authors' elaboration

half of the publications in the sample (117). This predominance reflects both the strategic prioritization of sustainable finance by Chinese regulatory authorities and the availability of large-scale, high-frequency datasets that facilitate empirical analysis. Moreover, government initiatives and funding schemes have incentivized academic output in climate finance, generating a strong domestic research ecosystem. European countries, while producing fewer total publications than China, show a notable presence (with Italy as leading single EU country) characterized by methodological diversity related to data availability and a focus on regulatory impacts. Research from the EU tends to integrate comparative cross-country analyses, examine the impact of policy instruments such as the European Green Deal, and climate-stress-test exercises. North America, particularly the US, contributes substantially to empirical and econometric analyses, often emphasizing market-driven mechanisms in climate risk assessment. By contrast, other regions, including Africa, Latin America, and much of South and Southeast Asia, are underrepresented. This imbalance suggests potential gaps in the literature: financial systems and regulatory responses in these regions remain largely unexplored, and country-specific vulnerabilities to both physical and transition risks are not systematically captured. The limited representation of emerging economies makes results difficult to generalise globally and may be biased towards major economies, emphasising the need for future research to expand geographically and include diverse institutional, climatic, and market contexts.

Cluster analysis

Cluster analysis was performed using the author's keywords co-occurrence with the software VOSViewer [17]. The results (Fig.5) revealed five distinct thematic areas, each represented by a cluster of keywords and topics. In detail, we identify the following research areas based on keywords co-occurences.

The first research area (blue cluster) relates *Climate regulatory frameworks.* This cluster forms the conceptual and regulatory core of the literature, indicating that early research, roughly 2020–2022, was primarily motivated by the mandates of central banks, the NGFS, and increasing policy attention to climate-related systemic risk. This cluster captures the macro-level concern that climate change may impair system-wide stability through both physical risk channels and regulatory stress (e.g., Paris Agreement). This cluster is the "policy backbone" from which more specialized empirical themes subsequently evolved.

The second research area (green cluster) concerns *Climate risk and bank lending.* This cluster focuses on how climate risks propagate through financial institutions (bank lending, bank risk, bank loan). Average publication years are concentrated around 2023–2024, showing that this theme is relatively new and fast-expanding. This cluster represents the transition from macro-level conceptual framing to quantitative assessment of financial fragility.

The third research area (red cluster) focuses on *Climate risk assessment.* Cluster 3 aggregates research examining policy-driven transition risk, including carbon taxation. The presence of *carbon tax* and *climate stress test* indicates that this cluster focuses on forward-looking risk quantification. Temporal metrics suggest this stream matured rapidly between 2022 and 2024, coinciding with: the ECB's climate stress test (2022), increased regulatory emphasis on transition pathways, global discussions on carbon taxation frameworks. Cluster 3 provides the analytical tools and policy context necessary to quantify physical and transition risk exposure.

The Fourth research area (yellow cluster) relates to *Climate risk management.* Cluster 4 is more managerial-governance–oriented. It covers the intersection between ESG integration, supervisory practices, and internal bank risk processes. The average publication year (~2023) indicates

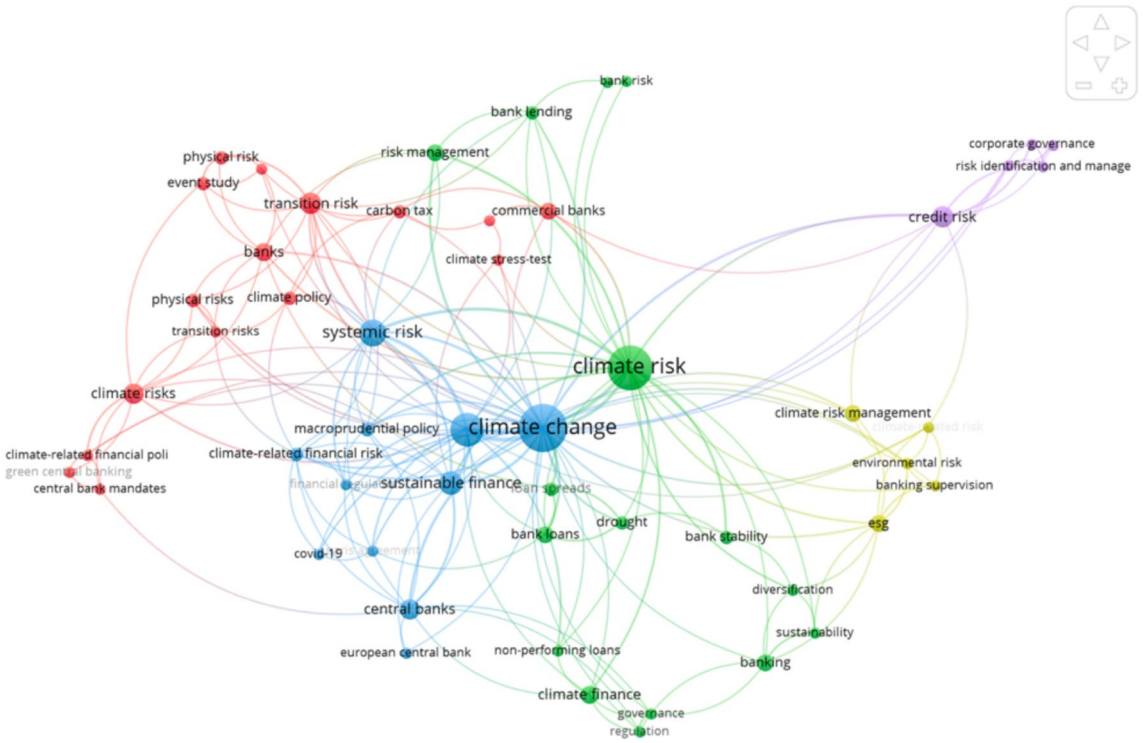

Fig. 5 Network diagram of the co-occurrence of keywords. Source: Authors' elaboration. Each node in a network represents a keyword. (1) The node size indicates the occurrence of the keyword, i.e. the number of times the keyword occurs. (2) The link between nodes represents the co-occurrence between keywords (i.e., keywords that occur together or occur together). (3) The thickness of the link between keywords indicates the number of times the keywords occur together). Each colour represents a thematic cluster, where the nodes and links in that cluster can be used to explain the topic coverage (cluster) of topics (nodes) and the relationships (links) between topics (nodes) that manifest under that theme (cluster). Extra: Following Paltrinieri et al. [76] and Migliavacca et al. [65], keywords with a minimum occurrence of 3 were selected (64 keywords meet the threshold),We excluded some keywords redundant and not relevant for create a thematic mapping (e.g. bank, banks, banking, India, China); Method: Lin/Log/modularity; Min. cluster size: 3 keywords

that this theme has gained relevance amid the EU Taxonomy rollout, increased disclosure requirements (CSRD), and global ESG standardization efforts. This cluster is the micro-level managerial counterpart to Cluster 1 and 2, focusing on how financial institutions internalize external regulatory pressures into governance, risk identification, and reporting frameworks.

The Fifth research area (violet cluster) examines *Climate risk and corporate governance.* Cluster 5 is centered on bank-level outcomes, especially: credit supply adjustments, loan pricing, and governance-risk interactions. The publication years (mostly 2022–2024) suggest a maturing empirical strand responding to growing availability of: climate-exposure datasets, borrower-level transition metrics, granular loan-portfolio information. Cluster 5 operationalizes climate risk into bank behavior, forming the empirical foundation for assessing climate risk premia in loan spreads and governance mechanisms shaping bank responses.

After identifying clusters based on the co-occurrence of keywords used by the author, we select the most cited articles among them. This approach allows us to compile Table 10 and analyse the contribution to the research field. We also evaluate the proportion of funded articles to determine whether funding influences the development of specific research areas. For instance, the most advanced field shows the highest percentage of funded studies, with Cluster 3 at 56% and Cluster 2 at 55%.

Moreover, Table 11 distinguishes between theoretical and empirical contributions. Overall the table highlights a strong dominance of empirical research though the balance between theoretical and empirical approaches varies across clusters. The first cluster shows a mixed methodological composition with both empirical and theoretical studies represented. This balance reflects the policy-driven nature of the topic where conceptual analysis is necessary to guide regulatory design. The second cluster is exclusively empirical data-driven and outcome-oriented. The third and fourth are also entirely empirical underscoring the centrality of measurement modeling and stress testing in climate finance research. This cluster displays a more balanced methodological profile combining empirical studies with theoretical analyses. Empirical papers in this cluster investigate how governance structures respond to climate risk while theoretical contributions (e.g.Turnbull and Habahbeh

Table 10 Key contributions and thematic areas

Cluster (n. of articles)	Most cited articles (*Authors*) [Citations]	Words (occurrences)	Funding rate (%)
1. Climate finance and regulatory frameworks (23)	▪ Central bank mandates, sustainability objectives and the promotion of green finance (Dikau S. and Volz U. [80]) [324] ▪ Finance, climate-change and radical uncertainty: Towards a precautionary approach to financial policy (Chenet H.; Ryan-Collins J.; van Lerven F., [86]) [160] ▪ How can green differentiated capital requirements affect climate risks? A dynamic macrofinancial analysis (Dafermos Y.; Nikolaidi M., [97]) [71] ▪ Climate policy, financial frictions, and transition risk (Carattini S.; Heutel G.; Melkadze G., [101]) [59] ▪ Biodiversity loss and climate change interactions: financial stability implications for central banks and financial supervisors (Kedward K.; Ryan-Collins J.; Chenet H., [102]) [51]	Climate change (57), financial stability (35), central banks (12), macroprudential policy (7), financial regulation (4), paris agreement (3)	9 out of 23 (39%)
2. Climate risk and bank lending (20)	▪ The impact of climate change on the cost of bank loans (Javadi S.; Masum A.A., [83]) [257] ▪ Climate sentiments, transition risk, and financial stability in a stock-flow consistent model (Dunz N.; Naqvi A.; Monasterolo I., [95]) [115] ▪ Effect of climate-related risk on the costs of bank loans: Evidence from syndicated loan markets in emerging economies (Ho K.; Wong A., [103] [27] ▪ Climate impacts on the loan quality of Chinese regional commercial banks (Zhang D.; Wu Y.; Ji Q.; Guo K.; Lucey B., [82]) [27] ▪ Does climate change affect bank lending behavior? (Aslan C.; Bulut E.; Cepni O.; Yilmaz M.H., [104] [24]	Climate risk (46), bank lending (7) bank loans (6), non-performing loans (4), bank risk (3), loan spread (2), bank credit (1),	11 out of 20 (55%)
3. Climate risk assessment (64)	▪ Climate risk and financial stability in the network of banks and investment funds (Roncoroni A.; Battiston S.; Escobar-Farfán L.O.L.; Martinez-Jaramillo S., [89]) [149] ▪ The pricing of carbon risk in syndicated loans: Which risks are priced and why? (Ehlers T.; Packer F.; de Greiff K., [87]) [133] ▪ What greenium matters in the stock market? The role of greenhouse gas emissions and environmental disclosures (Alessi L.; Ossola E.; Panzica R., [98] [109] ▪ Climate transition risk and bank performance: Evidence from China (Li, S., & Pan, Z., [105]) [49] ▪ Climate transition risk in US loan portfolios: Are all banks the same? (Nguyen, Q., Diaz-Rainey, I., Kuruppuarachchi, D., McCarten, M., & Tan, E. K., [106]) [42]	Transition risk (24), carbon tax (8), physical risk (8), climate stress test (5)	36 out of 64 (56%)
4. Climate risk management (20)	▪ Firm climate risk, risk management, and bank loan financing (Huang H.H.; Kerstein J.; Wang C.; Wu F., [92]) [123] ▪ Climate risk, ESG performance, and ESG sentiment in US commercial banks (Erhemjamts O.; Huang K.; Tehranian H., [107] [34] ▪ ESG and FinTech funding in the EU (Giakoumelou A.; Salvi A.; Bekiros S.; Onorato G., [108] [20] ▪ Climate policy uncertainty and bank systemic risk: A creative destruction perspective. (Liu, Y., Wang, J., Wen, F., & Wu, C., 2024) [14] ▪ Banks' climate commitments and credit to carbon-intensive industries: new evidence for France (Mésonnier J.-S., [109])	ESG (7), climate risk management (5), environmental risk (3)	7 out of 20 (35%)
5. Climate risk and corporate governance (10)	▪ What are the banks doing in managing climate risk? Empirical evidence from a position map (Toma P.; Stefanelli V., [110]) [9] ▪ A framework to analyze the financial effects of climate change (Turnbull S.M.; Habahbeh L., [111] [5] ▪ Frontloading ESG risks and benefits into the capital charge to incentivise green financing (Ozdemir B., [112] [1] ▪ Climate on the Agenda: How Board Composition Drives Climate Change Disclosure in European Banks (Raimo N.; Fraccalvieri I.; Vitolla F.; Bussoli C., [113]) [0] ▪ Disentangling the S and the G in the European banking industry: The role of climate risk and opportunity awareness (Rega F.G.; Russo S.; Salerno D., [114]) [0]	Corporate governance (3), risk identification and management (2)	0 out of 11 (0%)

Source: Authors' elaboration

[111]; Ozdemir [112]) address conceptual questions related to incentive alignment.

First research area: climate regulatory frameworks

The blue cluster (*climate regulatory frameworks*) is characterised by keywords such as climate change, central banks, financial regulation, financial stability, macroprudential policy, and the Paris Agreement.

The earliest work in this area was published in 2021 by Dikau and Volz. They discussed central banks' roles in managing climate risks, noting few have explicit sustainability mandates. Most need to include climate risks in policies to maintain financial stability, as ignoring them is a duty failure. In 2021, Chenet et al. [86] suggest a proactive financial

Table 11 Key contributions and analysis type

Cluster	Article	Theoretical/empirical
1. Climate finance and regulatory frameworks (23)	Dikau S. and Volz U. [80]	Empirical
	Chenet H.; Ryan-Collins J.; van Lerven F. [86]	Theoretical
	Dafermos Y.; Nikolaidi M., [97]	Empirical
	Carattini S.; Heutel G.; Melkadze G., [101]	Empirical
	Kedward K.; Ryan-Collins J.; Chenet H., [102]	Theoretical
2. Climate risk and bank lending (20)	Javadi S.; Masum A.A., [83]	Empirical
	Dunz N.; Naqvi A.; Monasterolo I., [95]	Empirical
	Ho K.; Wong A., [103]	Empirical
	Zhang D.; Wu Y.; Ji Q.; Guo K.; Lucey B., [82]	Empirical
	Aslan C.; Bulut E.; Cepni O.; Yilmaz M.H., [104]	Empirical
3. Climate risk assessment (64)	Roncoroni A.; Battiston S.; Escobar-Farfán L.O.L.; Martinez-Jaramillo S., [89]	Empirical
	Ehlers T.; Packer F.; de Greiff K., [87]	Empirical
	Alessi L.; Ossola E.; Panzica R., [98]	Empirical
	Li, S., & Pan, Z., [105]	Empirical
	Nguyen, Q., Diaz-Rainey, I., Kuruppuarachchi, D., McCarten, M., & Tan, E. K., [106]	Empirical
4. Climate risk management (20)	Huang H.H.; Kerstein J.; Wang C.; Wu F., [92]	Empirical
	Erhemjamts O.; Huang K.; Tehranian H., [107]	Empirical
	Giakoumelou A.; Salvi A.; Bekiros S.; Onorato G., [108]	Empirical
	Liu, Y., Wang, J., Wen, F., & Wu, C., 2024	Empirical
	Mésonnier J.-S., [109]	Empirical
5. Climate risk and corporate governance (10)	Toma P.; Stefanelli V., [110]	Empirical
	Turnbull S.M.; Habahbeh L., [111]	Theoretical
	Ozdemir B., [112]	Theoretical
	Raimo N.; Fraccalvieri I.; Vitolla F.; Bussoli C., [113]	Empirical
	Rega F.G.; Russo S.; Salerno D., [114]	Empirical

Source: Authors' elaboration

policy to address climate risks, as market solutions are limited by uncertainty, aiming to guide markets toward a net-zero carbon future.

Dafermos and Nikolaidi [97] examined the impact of green differentiated capital requirements (GDCRs) on climate-related financial risks, finding that they can reduce global warming and physical financial risks, especially when implemented together or with green fiscal policies, while also generating transition risks that can be managed through policy combinations. Similarly, Carattini et al. [101] discusses the need for aggressive climate policy to meet the Paris Agreement's goals, which may trigger transition risk and potentially lead to a recession, and highlights the role of macroprudential policies in mitigating this risk by reducing banks' exposure to carbon-intensive assets, supporting economic growth, and ensuring that climate policies are not delayed due to transition risks.

Kedward et al. [102] argue for a more integrated approach to managing climate change and biodiversity loss financial risks, emphasising the importance of considering their interconnections and proposing a precautionary approach with coordination between central banks and government departments.

Within this research stream, a significant number of contributions underscore the importance of a clearly defined and forward-looking regulatory framework to steer the financial system toward climate neutrality. Central banks are actively engaged in this transition to preserve the resilience of the financial system in the face of climate-related disruptions.

Second research area: climate risk and bank lending

In the green cluster (*climate risk and bank lending*), the most relevant keywords are: climate risk, bank lending, bank credit, bank risk, bank loans, loan spread, and non-performing loans.

Javadi and Masum [83] discovered that companies with customers more exposed to climate risk face higher interest rates on their loans. This impact is particularly driven by the long-term loans of poorly rated firms. In addition to immediate effects, climate-related physical risks also seem to affect credit allocation.

Dunz et al. [95] suggest that the green supporting factor can promote green investments in the short term but may pose risks to bank stability.[4] To support the low-carbon transition without adversely affecting non-performing loans and

[4] The European Commission has proposed the revision of the micro-prudential banking framework, i.e., the introduction of a green supporting factor (GSF) aimed to lower capital requirements for green investments.

household budgets, implementing the Carbon Tax should be paired with redistribution policies. Additionally, they conclude that if banks adjust their credit conditions based on firms' carbon profiles before climate policies are introduced, it can help align investments with low-carbon goals and enhance financial stability.

Ho and Wong [103] analyse syndicated loans in emerging markets and borrowers' greenhouse gas emission data to see if and how banks incorporate climate transition risk into lending. Their results show that since the Paris Agreement, banks in these markets have begun to price in climate transition risk for loans to emissions-intensive sectors, possibly due to increased awareness. The size of this risk premium depends on the bank's environmental stance; green banks charge higher loan spreads to brown firms than other banks. Additionally, banks may enforce stricter contractual terms, like shorter loan tenors and collateral requirements, especially when credit risk is more uncertain.

Zhang et al. [82] investigate the impact of climate risk on the stability of regional commercial banks in China. They examine both physical and transitional risks and their potential to adversely affect loan quality. The sample for this study spans from 2010 to 2019 and includes 591 regional commercial banks in China. The analysis reveals a positive association between higher levels of climate risk and higher levels of non-performing loans. Additionally, banks react to transitional policies by modifying their portfolios, as evidenced by a quasi-natural experiment of green finance reform.

Aslan et al. [104] analyse how banks modify credit supply in regions with higher climate risks by using province-level data on air pollution and loan growth in Turkey after the 2015 Paris Agreement. The findings indicate that, following the agreement, banks restrict credit in more polluted provinces, suggesting that they take climate change risks into account when adjusting their credit practices. Additionally, the study reveals that the relationship between climate risk and credit provisioning is asymmetric, depending on the level of air pollution.

Third research area: climate risk assessment

In the red cluster (*climate risk assessment*), the most relevant keywords are: carbon tax, physical risk, transition risk, and climate stress test. Studies in this cluster employ diverse methodologies to quantify both transition and physical climate risks.

Roncoroni et al. [89] examine how climate-transition risk and market conditions affect financial stability. They extend the climate stress-test framework by including an ex-ante network valuation of assets that considers price volatility and endogenous recovery rates for interbank assets. Their analytical results, applied to a supervisory dataset under various climate and market scenarios, show that in a disorderly low-carbon transition, stronger market conditions enable more ambitious climate policies at the same financial risk level.

Ehlers et al. [87], combining syndicated loan data with carbon intensity data of borrowers across a wide range of industries, find a significant "carbon premium" since the Paris Agreement. The price of risk, however, appears to be relatively low given the material risks faced by some borrowers. Only carbon emissions directly caused by the firm (scope 1) are priced, and not the overall carbon footprint, including indirect emissions.

Alessi et al. [98] provide evidence of a risk premium associated with a firm's greenness, based on European individual stock returns. They define a priced 'greenness and transparency' factor based on companies' greenhouse gas emissions and the quality of their environmental disclosures and show that what is priced by the market is the combination of environmental performance and environmental transparency. Based on this factor, they offer a tool to assess the exposure of a portfolio to the risk associated with the low-carbon transition, and hedge against it.

Li and Pan [105] propose a climate transition risk measurement method for commercial banks and examine its impact on bank performance using data from 490 Chinese banks (2008–2019). The empirical findings show that climate transition risk hampers commercial banks' performance, and this effect is weaker as bank size increases. The Paris Agreement and rising Chinese economic policy uncertainty positively moderate this impact. Additionally, climate transition risk partly reduces bank performance by decreasing loan size.

Nguyen et al. [106] examine banks' exposure to climate transition risk using a bottom-up loan-level methodology incorporating climate stress test based on the Merton probability of default model and transition pathways from theIPCC. Specifically, they match machine learning predictions of corporate carbon footprints to syndicated loans initiated in 2010 –2018 and aggregate these to loan portfolios of the twenty largest banks in the U.S. Banks vary in their climate transition risk not only due to their exposure to the energy sectors but also due to borrowers' carbon emission profiles from other sectors. Banks generally lend a minimal amount to coal (0.4%) but hold a considerable exposure in oil and gas (8.6%) and electricity firms (4.6%) and thus have a large exposure to the energy sectors (13.5%). They note that the climate transition risk profile remained stable over time, except for temporary or permanent reductions in fossil-fuel exposure after the Paris Agreement.

Fourth research area: climate risk management

In the Yellow cluster (climate risk management), the most relevant keywords are: ESG, climate risk management, and environmental risk.

Huang et al. [92] estimate firm-level physical risk from climate change based on managerial evaluation and firms' exposure to climate hazard events and find that climate risk results in unfavorable corporate financing terms related to bank loans (higher interest paid, higher likelihood of being required to collateralize the loan, and greater number of covenant constraints). Firms that take measures aimed at managing climate risk, including corporate climate strategy and board-level governance, are able to mitigate the negative impact of climate risk on loan contracting. They further find that a higher climate risk level is associated with inferior financial performance and higher default probability, which potentially leads to more stringent loan terms.

Erhemjamtsa et al. [107] measure US commercial banks' exposure to and materiality of physical climate risk by examining branch-level data. The location-specific climate risk measure is positively associated with banks' ESG performance and negatively associated with stakeholders' sentiment regarding ESG issues. Furthermore, banks that experience climate risk shocks improve ESG performance and receive positive ESG sentiment. While negative sentiment due to climate risk exposure is associated with worsened financial performance, stronger ESG engagement mitigates this adverse effect.

Giakoumelou et al. [108] analyse European FinTech firms during funding rounds from 2014 to 2022 to investigate the relationship between sustainability profiles and valuations. They find that ESG reporting is positively related to the amount of capital raised, as investors weigh in physical and transition risks in information asymmetries. Lower levels of trust in the relatively young FinTech niche are confirmed by the signalling role of mere ESG disclosure, while finer shades of ESG actual performance, such as rankings and certifications examined in this paper, have no impact [115, 116] conduct an international study on the effect of climate policy uncertainty on the systemic risk of banks. They find that climate policy uncertainty is associated with lower bank systemic risk. This relation is more pronounced in countries with high innovation capacity, climate readiness, a greater number of systemically important banks, and a more competitive banking system. Findings alleviate the concern that climate transition risk may contribute to financial instability.

Mésonnier [109] examines whether and how banks' green commitments to address climate change are reflected in their credit allocation to carbon-intensive industries in France. The author uses data on bank credit exposures to 49 industries in France, merged with sector greenhouse gas emission intensities and a score for banks' self-reported climate commitments. He finds evidence that higher self-reported climate commitments by banks are associated with slower lending growth to large firms in the most carbon-intensive industries. However, lending to SMEs across more or less carbon-intensive industries remains unrelated to banks' commitments to green their business. These findings suggest that devising an appropriate carbon reporting framework for small firms is likely to enhance the decarbonization of bank lending.

Fifth research area: climate risk and corporate governance

In the violet cluster (climate risk and corporate governance), the most relevant keywords are: corporate governance, climate risk identification and management.

Toma and Stefanelli [110] aim to outline a map of the choices banks are making in reviewing their risk management processes. The strategic, organizational, and internal control frameworks are reviewed to assess their adaptation to climate risk exposure, as required by banking supervision. The analysis is based on survey data. The results highlight an overall picture in which the bank efforts at the level of strategy and external communication are far from optimal. The unfamiliarity of bank management with climate risk issues is linked to the lack of historical data and information on climate risk scenarios and trends.

Turnbull and Habahbeh [111] begin by assessing climate risk factors, then describe the expected frequency of climate events and the potential losses if they occur. They present a framework for analysing the financial impacts of climate events and derive an expression for the probability of default that includes these effects. The analysis is further extended to a multiperiod model that evaluates the financial and risk-management consequences of temporary risks. This information can be reported to senior management, directors, shareholders, and regulators.

Ozdemir [112] examines supervisory initiatives, such as integrating climate-related risks into risk and capital management frameworks, including the related Pillar III Financial Disclosures, and considers them necessary but still insufficient. The policy objective should be not only that the financial system remains resilient during the transition, but also that it facilitates the transition. This facilitation should emerge as the natural outcome of banks' profit maximising behaviour in a competitive marketplace.

Moreover, Raimo et al. [113] examined the level of climate change disclosure among European banks and identified the factors influencing the dissemination of such information through their official websites. In particular, drawing on agency theory, it investigates the role of board characteristics in shaping CCD practices. The findings,

based on a sample of 107 publicly listed European banks, reveal that board expertise, gender diversity, and size positively influence the level of climate change disclosure, whereas board independence has no significant effect. These results underscore the critical role of governance structures in fostering transparency and accountability in climate-related matters. Second, it highlights the strategic role of board characteristics in shaping CCD practices, offering new insights into how governance mechanisms influence transparency in addressing climate-related challenges.

The study of Rega et al. [114] focuses on climate risk and opportunity awareness for European banks in enhancing their environmental, social, and governance performances, proxied by diverse ESG scores and disentangling the effects on specific sub-scores more related to social and governance dimensions of sustainable development. The results highlight that climate risk and opportunity have been factored into banks' ESG scores, providing empirical evidence on the crucial role of banks' climate awareness in improving S and G strategies and practices.

Overlay analysis

Cluster analysis is performed at a specific point in time to represent a static picture of the field at that moment. However, the analysis can investigate multiple time periods to capture the field's development. This longitudinal analysis can reveal how particular patterns within an intellectual structure emerge, grow, or fade away.

For this reason we performed an overlay analysis (Fig. 6) that shows how the topic has developed in the literature over time. This network analysis provides a visual representation of the interconnections between keywords and, at the same time, how these interconnections have shifted over time. The overlay analysis depicted in Fig. 6 allows examination of the temporal distribution of keywords within each cluster. The illustration uses a combination of colors to represent the timeline, with blue indicating the oldest keywords, moving through green and fading to yellow for the most recent topics. We can infer the evolution of specific research themes over time from the network map. While the regulation and the role of central banks open the research stream, the research interest evolved into risk management, the impact on credit risk and the need to measure both transition and physical risk. In Phase 1 (up to 2021), the field's foundational elements were established, mainly centred around Cluster 1 concepts. The emphasis was on conceptual risk frameworks and policy mandates. During Phase 2 (2021–2022), regulatory developments accelerated, with increased focus on macroprudential and systemic risk research (Clusters 1 & 2). Central banks and NGFS stress testing initiatives played a catalytic role, and transition risk tools started

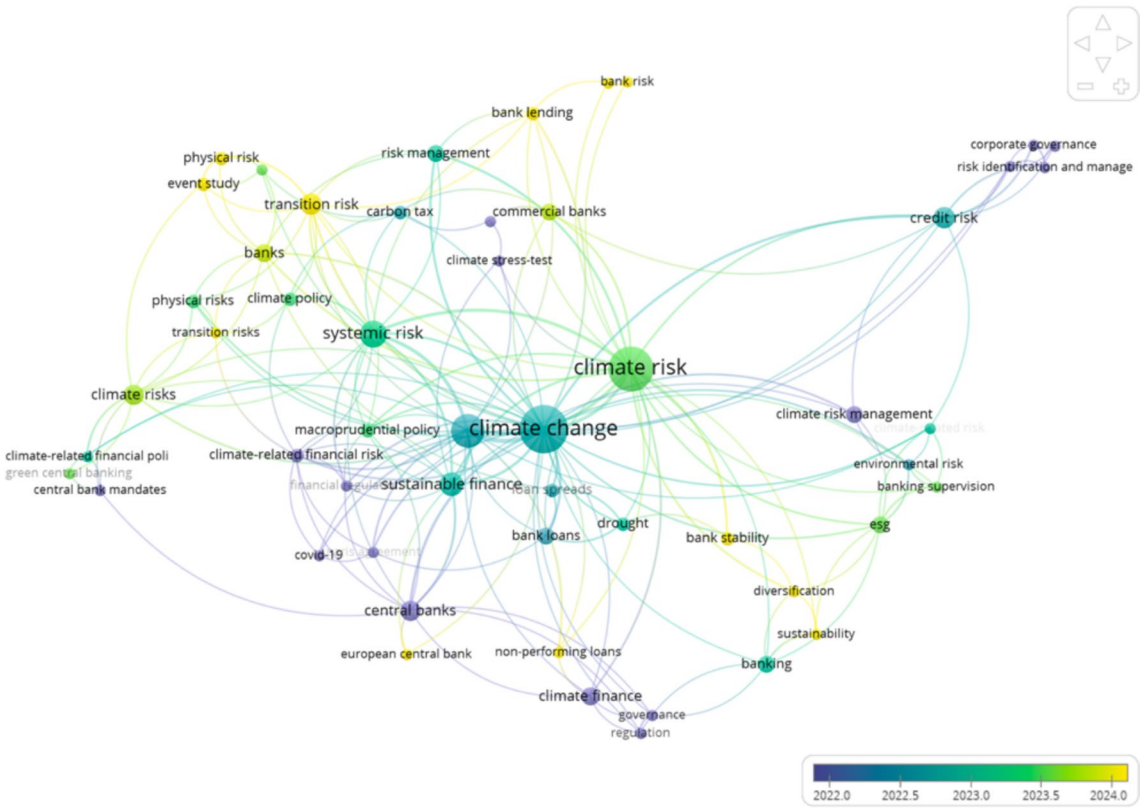

Fig. 6 Overlay diagram of the co-occurrence of keywords. Source: Authors' elaboration

to appear (Cluster 3). In Phase 3 (2023–2024), the focus shifted to bank-level empirical data and governance, with a rise in studies on loan-level risk, credit quality, and risk management (Clusters 4 & 5). ESG factors and supervisory frameworks became integral to risk assessments.

Discussion

The results of our bibliometric review enable the discussions about the current state of research, the challenges of existing approaches, and the potential aspects that need to be addressed in the future. The research design, which integrates performance analysis, science mapping, and cluster analysis, enabled us to answer the three research questions. Below, we provide a detailed discussion for each outlined research question.

RQ1 What are the most important contributions and the key themes in the scientific literature on climate risk in the banking sector?

The literature on climate risk in banking has been shaped by a core set of foundational studies that establish the field's priorities. Concerning the most significant contributions, based on citation analysis (Table 8), the top contribution (547 citations) is Battiston et al. [26], which introduces the network-based climate stress-test for Euro Area banks. This study is dominant not only because of its citation volume, but also because it reframes climate risk as a systemic exposure transmitted through financial interlinkages, rather than an idiosyncratic risk borne by individual institutions. It formalises the concepts of transition risk and stranded-asset exposure that are now standard in both academic and policy debate, and it provides the intellectual foundations for prudential climate stress testing and supervisory initiatives such as those developed by the NGFS and the ECB.

The second-most-cited study (324 citations) is Dikau and Volz [80], which examines how addressing climate-related risks and supporting mitigation and adaptation policies fit within central bank mandates. This paper plays a pivotal role because it provides the conceptual bridge between climate risk and financial-stability policy, clarifying the extent to which monetary and macroprudential authorities can and should incorporate climate considerations within their mandates. Its influence reflects the strong institutional dimension of the debate and illustrates how the academic literature and regulatory discourse have evolved in parallel.

The third major contribution (257 citations) is Javadi and Masum [83], who finds empirical evidence that firms in locations with higher exposure to climate change pay significantly higher spreads on their bank loans. This study is dominant because it operationalises the pricing-of-climate risk channel in bank lending, marking one of the first large-scale attempts to quantify how climate risk is transmitted through credit markets. The most commonly referenced contributions are located within the regulatory and climate risk assessment sub-field.

Even when highlighting the most influential works based on normalized citations the academic focus continues to be on regulation and risk evaluation. Korzeb et al. [81] examine how ESG activities influence banks' default risk while Anastasiou et al. [84] analyse the role of climate risk in discouraging loan applications among SMEs in the euro area, highlighting the potential for credit rationing among more exposed firms. Complementing these firm- and bank-level findings, De Bandt et al. [79] review recent empirical evidence on how climate-related risks affect banks, and Zhang et al. [82] study the impact of climate risk on the stability of regional commercial banks in China.

The dominance of regulatory and risk-assessment clusters has generated a research skew toward financial economics and regulation, with comparatively limited engagement from corporate governance and organizational behavior perspectives. Indeed, Cluster 5 (climate risk and corporate governance) remains relatively thin and fragmented, revealing a structural gap in the literature. A key implication of this pattern is that the analysis of internal governance mechanisms—including the role of boards, managerial incentives and risk culture—has received far less systematic attention. One reason for this imbalance is that the regulatory framework on internal governance and incentives is still evolving: while the EBA Guidelines on the Management of ESG Risks (EBA/GL/2025/01) and the ECB Draft Guide on Governance and Risk Culture [117] increasingly refer to boards, risk culture and remuneration as levers for managing ESG risks, prescriptive and harmonised requirements are not yet fully in place, which may partly explain the still-limited empirical evidence on these mechanisms. This regulatory incompleteness helps explain why empirical research on the interaction between remuneration incentives and banks' climate risk management remains scarce, particularly when compared with the far more developed literature on risk measurement and supervision. As the regulatory landscape becomes more explicit and standardised, the availability of comparable data and the clarity of incentive structures are likely to improve, opening a promising frontier for future research at the intersection of prudential regulation, corporate governance and sustainability.

RQ2 How has academic research on climate risk in the banking sector evolved over time?

The bibliometric evidence indicates that the field is undergoing multidimensional development. This trajectory in academic output is illustrated in Figs. 6 and 7, which visualise the research evolution over time. In the initial period (up to 2021), the most prominent contributions stemmed from the blue cluster, associated with regulatory and supervisory frameworks. This reflects the early dominance of policy-led discourse, particularly focusing on how central banks and financial supervisors were beginning to integrate climate considerations into prudential regulation. However, starting from 2021, the red cluster, representing literature on climate risk assessment, experienced an expansion. This thematic area, initially underrepresented, gradually came to overtake the regulatory discourse in both volume and influence. By 2023–2024, the red cluster dominates the landscape of climate risk in the banking sector, reflecting a broader academic effort to quantify transition and physical risks, often by incorporating climate-related variables into traditional risk metrics such as default probabilities and credit spreads. Taken together, Figs. 6 and 7 reveal a maturing research agenda, where the initial dominance of policy discussions (blue cluster) gives way to methodological assessments of climate risk (red cluster). This progression reflects the academic community's response to both regulatory demands and data availability, as financial institutions begin to disclose climate-relevant exposures more systematically.

By contrast, climate risk and corporate governance (violet cluster), remains comparatively small throughout the period, with only a modest increase in publications from 2022 onward. This late emergence is consistent with the fact that, until very recently, regulatory expectations regarding the integration of ESG and climate risk into internal governance mechanisms, including remuneration structures, had not yet been fully articulated. Although supervisors now increasingly emphasise the alignment of variable compensation with ESG-related objectives, clear and harmonised requirements in this area at the EU level are only beginning to take shape, with more prescriptive developments expected through the implementation of CRD VI and the related EBA remuneration guidelines. As a result, the governance-oriented literature has expanded more slowly than the risk-assessment and regulatory clusters, reflecting both data limitations and the still-evolving institutional framework. The gradual upward trend in the violet cluster from 2023 onwards suggests that, as regulatory guidance becomes more explicit, particularly on incentive systems, scholarly attention to governance-based levers of climate risk management is likely to intensify.

RQ3 What are the main challenges highlighted in the scientific literature on climate risk in the banking sector?

Despite substantial expansion, the literature consistently reveals structural challenges. By systematically extracting the limitations reported across documents in each thematic cluster (Table 12), five cross-cutting gaps emerge. First, climate regulatory work is constrained by regulatory asymmetry and persistent policy uncertainty, which weaken comparability and complicate transition-risk modelling. Second, bank-lending studies highlight a short-term bias in credit decisions, where environmental indicators increasingly appear in disclosures but do not translate into consistent risk-based pricing. Third, climate risk assessment faces the combined obstacles of scenario uncertainty and fragmented, non-standardized data, which restricts empirical robustness. Fourth, climate risk management research is hindered by opaque and inconsistently constructed ESG measures, raising concerns about greenwashing and limiting their value as risk proxies. Finally, governance-oriented studies remain narrow in scope, focusing on large banks and a limited set of board attributes, leaving internal managerial practices and smaller institutions largely unexplored.

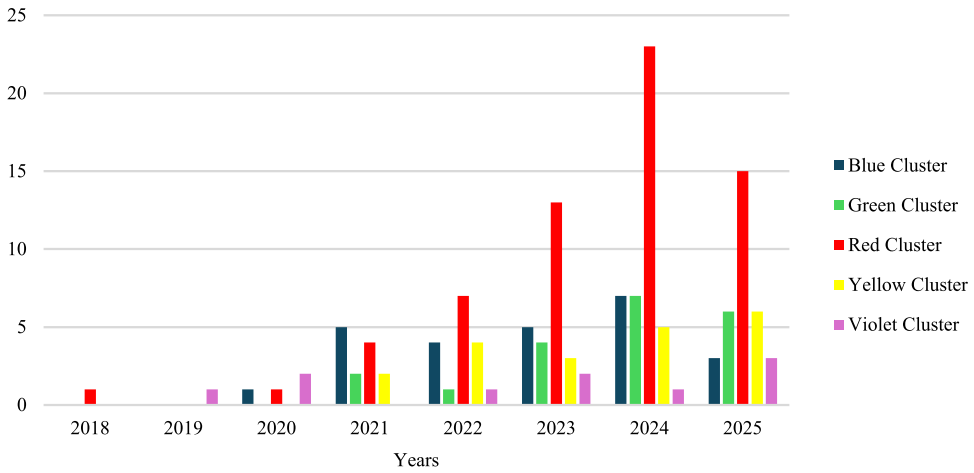

Fig. 7 Production by cluster over time. Source: Authors' elaboration

Table 12 Future research agenda

Theme (cluster)	Future research agenda	Author
Climate regulatory frameworks (Blue)	▪ Model interactions between climate policies to avoid systemic risk ▪ Analyze the dynamics of compound risks threatening financial stability ▪ Develop a harmonized international framework for climate-related prudential regulation tools ▪ Propose ways to include climate risk in SME banking ▪ Review bank governance to improve supervision schemes ▪ Extension of the precautionary financial policy (PFP) framework to other environmental challenges like biodiversity loss, water and air pollution, and natural resource depletion ▪ Deeper analyses of tools and policies related to climate-related financial risks (CRFR) ▪ Evaluations of which climate-related financial risks (CRFR) challenges are priorities for further data and modeling efforts to establish appropriate policy actions for different time horizons	Hidalgo-Oñate et al. [118] Chenet et al. [86]
Climate risk and bank lending (Green)	▪ Future research should develop more comprehensive and refined indicators of physical and transition climate risks that better capture the full range of climate-related challenges faced by banks in practice ▪ Further studies should use updated and enriched datasets to account for new roles, responsibilities, and structural changes in the Chinese banking sector arising from the country's dual carbon targets and ongoing green transition ▪ For future research, it would be interesting to separate climate risks into physical and transition risk parts using a more detailed measure of climate risks, which might allow distinguishing whether banking sector lending behavior changes according to the different types of climate risk exposure	Zhang et al. [82] Aslan et al. [104]
Climate risk assessment (Yellow)	▪ Future models could allow banks and other financial agents to anticipate shocks, rebalance their portfolios, and adjust interbank exposures over time, rather than treating financial contracts and contagion channels as fixed and exogenous ▪ Further work should incorporate agents' awareness of their own and others' reactions, particularly in fire-sale dynamics, to better capture endogenous price effects and systemic amplification mechanisms ▪ Extending sensitivity analysis to liquidity parameters would improve understanding of how varying market liquidity affects contagion and loss severity ▪ Future research should empirically estimate realistic probability distributions for idiosyncratic shocks to external asset prices, improving the accuracy of loss and default probability estimates ▪ Future research into the role of financial institutions in generating green jobs and services is needed so as to provide commercial banks with methods to offset the inhibitory effect of the climate transition risk on their performance. This future scope is particularly important for poorer countries ▪ Use broader firm data, improve credit-risk models (e.g., DCF, loan type/maturity), incorporate borrower default correlations and second-round losses, and model dynamic adaptation by banks and firms to climate transitions ▪ Given that the awareness of investors towards climate-related issues has clearly increased in recent years, it would make sense to estimate a model with a time-varying risk premium. This presents challenges in terms of estimation. Another interesting avenue relates to the drivers of the greenium, and in particular to the hypothesis that its negative sign could be driven by an increasing 'taste for green' among investors	Roncoroni et al. [89] Li and Pan [105] Nguyen et al. [106] Alessi et al. [98]
Climate risk management (Red)	▪ Examine the impact of firm-specific climate risk on equity issuance, public debt, and internal fund usage (e.g., dividends) beyond bank loans. Impact of ESG and climate-related risks reporting on bank performance and shareholder value ▪ Develop finer, economically informative firm-level climate risk metrics beyond CDP classifications and location-based exposure ▪ Investigate mechanisms in bank loan contracting, including the role of firm-provided "soft" information and climate risk dossiers in improving credit terms	Huang et al. [92] Erhemjamts et al. [107]
Climate risk and corporate governance (Violet)	▪ Study how banks can integrate climate risk into internal governance models, board-level strategies, and risk management processes ▪ Examine the impact of guidelines, prudential criteria, training, and knowledge-sharing on improving climate risk management, especially for smaller banks ▪ Conduct international comparisons of bank climate risk management to assess differences across regulatory and geographic contexts ▪ Include non-listed banks and banks outside Europe to capture diverse banking contexts and geographic differences in climate-related disclosure (CCD) ▪ Investigate additional board characteristics (e.g., age, tenure, diversity) affecting CCD practices ▪ Explore social media, sustainability reports, and other platforms beyond official websites ▪ Use interviews with sustainability officers or board members to understand internal motivations and strategies ▪ Examine biodiversity, human rights, and other ESG-related reporting in banks	Toma and Stefanelli [110] Raimo et al. [113]

Source: Authors' elaboration

The weak development of governance-oriented concepts implies that key internal levers of climate risk management remain underexplored. Remuneration systems, executive incentives, risk-committee design and ESG-linked compensation are virtually absent from existing clusters, partly reflecting the still-evolving supervisory expectations in this area.

Yet these mechanisms critically influence banks' and firms' risk appetites, climate-related disclosure quality and transition-risk exposure. A more balanced field would incorporate micro-level organizational theories to explain how climate risks are internalized, how managerial incentives shape exposure to transition or physical risks, and how governance failures may amplify systemic vulnerabilities. This represents a natural evolution of the literature once the initial wave of risk-assessment studies matures.

Taken together, these insights indicate that the field is in a risk-assessment phase, driven by regulatory imperatives and data availability, but is likely to shift toward a governance-integration phase as scholars begin examining how climate risks are created, transmitted, and mitigated within firms. Strengthening the governance cluster constitutes the most compelling avenue for future research and would meaningfully broaden the disciplinary foundations of climate-finance scholarship.

Conclusion

The present analysis goes beyond earlier bibliometric studies by integrating multiple strands of the climate–finance literature into a unified, empirically grounded thematic structure. Prior reviews have typically focused on individual domains and on narrative reviews, without examining how these domains interact or how their relative maturity varies across the field. By contrast, our bibliometric mapping reveals five thematically coherent clusters whose intellectual densities vary considerably. This comparative perspective allows us to articulate new insights into the evolution, disciplinary balance, and blind spots of climate-finance research.

Our results consistently show that the field remains intellectually anchored in risk-based and prudential approaches, whereas the analysis of internal governance mechanisms including remuneration structures, incentive design and risk culture is still at a comparatively early stage of development. This finding is fully consistent with the weak and late emergence of the "climate risk and corporate governance" cluster in our science-mapping results.

A first distinctive finding is the asymmetry between risk-oriented and governance-oriented scholarship. While the literature has made substantial progress in modelling transition and physical risks, transmission mechanisms, and policy instruments, work on internal governance mechanisms (e.g. executive incentives, risk committee structures, remuneration) remains thin and fragmented. This imbalance suggests that the field is still in an early "risk quantification" phase and has not yet fully integrated insights from corporate governance, organizational behavior, or contracting theory. These gaps are rarely highlighted in previous reviews and point to a clear disciplinary misalignment that warrants correction.

Second, our analysis shows that the bank lending channel is comparatively narrow, with most studies examining pricing responses to climate exposures but offering fewer insights into renegotiation, collateral requirements or cross-country heterogeneity in supervisory expectations. This underdevelopment suggests that micro-level corporate finance tools (e.g. loan-level datasets) can significantly advance the field.

Third, by combining bibliometric techniques with cluster-level qualitative synthesis, we reveal temporal dynamics that previous reviews do not emphasize: risk-assessment work accelerates after 2021, while governance papers rise only marginally. This highlights areas where research lags behind policy needs, particularly as central banks, banking supervisors, and corporate boards face increasing demands for climate-related decision-making.

Policy implications

The bibliometric analysis conducted in this review enables the identification of several policy-relevant insights that emerge across the five research clusters. While academic interest in climate risk and banking has grown considerably, the literature reveals persistent gaps in the translation of these insights into concrete regulatory action, institutional coordination, and operational frameworks.

First, the cluster on climate regulatory frameworks highlights the pressing need for enhanced coordination between central banks, supervisory authorities, and fiscal institutions. Given the systemic and nonlinear nature of climate-related financial risks, a precautionary approach to financial regulation is warranted. This implies going beyond traditional, backward-looking risk assessments and embracing tools capable of addressing deep uncertainty, including scenario-based macroprudential stress testing and forward-looking capital adequacy frameworks.

In relation to bank lending, the findings suggest that financial supervisors should foster an environment in which credit reallocation towards low-carbon sectors is both feasible and incentivized. Banks must be encouraged to differentiate borrowers based on their exposure to physical and transition risks, and to integrate environmental considerations into

their credit risk models beyond reputational concerns. Policymakers can play a role in strengthening disclosure obligations at the firm level, thereby improving the informational basis for climate-related credit decisions.

With regard to climate risk assessment, this review underscores the need for standardized metrics and forward-looking methodologies that can meaningfully capture firms' vulnerability to climate shocks. Existing approaches (whether based on emissions data, ESG ratings, or geographic risk indices) often lack comparability and transparency. Regulatory authorities could support convergence by issuing methodological guidance and promoting common reporting standards.

In the area of climate risk management, the literature reveals considerable variation in how banks operationalize their climate strategies. This suggests the need for regulatory guidance on how climate risk should be embedded into governance structures, internal control systems, and risk appetite statements. The increasing reliance on ESG scores for both compliance and strategic purposes raises additional challenges, particularly in light of concerns regarding rating divergence and greenwashing. Supervisors may consider setting minimum quality standards for the use of third-party ESG data in the credit process and encouraging independent verification mechanisms.

Finally, the cluster on climate risk and corporate governance points to the crucial role of board-level commitment and expertise in shaping banks' climate-related practices. Strong governance frameworks, including clear board responsibilities for sustainability and transparent disclosure of climate-related decisions, are essential to ensuring that environmental considerations are integrated into core banking operations. Regulatory authorities should promote board-level accountability and foster the development of climate-related governance competencies across the financial sector. Moreover, increased attention should be directed towards smaller and regionally oriented financial institutions, which may face unique governance and resource constraints in responding to climate risk.

Future research agenda

For future research avenues, we evaluated and summarised the research directions published in the articles in our sample. We selected the most influential articles based on bibliometric citation analysis. Subsequently, we analysed the content of these influential articles to identify unexplored future research directions for each cluster, and we verified to eliminate any repetitions. This method resulted in prospective research directions grouped into five main research streams (see Table 12).

A coherent research agenda emerges when these proposals are viewed collectively rather than in isolation. Across clusters, the most pressing transversal challenge concerns the absence of harmonised, decision-relevant measures of climate exposure. This limitation affects regulatory design, bank-lending analysis, risk assessment, risk management and governance alike. Strengthening the empirical foundations of climate-finance research, therefore, requires progress in developing standardised climate risk metrics, richer firm- and bank-level data, and clearer reporting practices.

A second overarching insight is that climate risk cannot be fully understood within a single analytical paradigm. The regulatory literature highlights the need for integrated policy frameworks, lending studies examine how climate shocks are transmitted through credit markets, and governance research increasingly emphasises internal organisational dynamics. Future work would benefit from combining these perspectives—for example, by investigating how regulatory expectations affect lending behaviour, or how governance structures condition the transmission of climate shocks through banks' balance sheets.

Several clusters also reveal systematically overlooked domains. Smaller and cooperative banks—despite their relevance for regional credit provision—remain underrepresented in the literature. Disclosure and ESG metrics continue to pose methodological challenges, raising identification concerns for empirical research. Moreover, the geographic concentration of studies in advanced economies points to the need for broader cross-country and emerging-market evidence, where climate vulnerability is often greatest but data availability remains limited.

Finally, a particularly important direction for future research concerns the internal governance of climate risk management in banks. While supervisory expectations on the integration of ESG and climate risk considerations into boards' oversight, risk culture and remuneration systems are only now becoming more explicit at the EU level, empirical evidence on how these mechanisms shape banks' risk-taking and transition strategies remains scarce. As regulatory guidance progressively consolidates, more granular data on incentive structures and governance practices are likely to become available, opening the way for a richer research agenda at the intersection of prudential regulation, corporate governance and sustainability.

Limitations

While bibliometric analysis effectively summarises and synthesises literature, it's important to acknowledge its limitations. For future research, exploring alternative bibliometric methodologies can provide additional insights and further enhance the analysis. Another significant limitation pertains

to our exclusive reliance on Scopus, which, while extensive, omits grey literature, relevant journals and working-paper series (e.g., NBER, CEPR, SSRN), potentially underrepresenting some research fields. Although we follow established bibliometric procedures, the screening and keyword selection process inevitably shapes the dataset's boundaries. Furthermore, co-occurrence techniques identify patterns of scholarly focus but do not evaluate causality, research quality, or theoretical innovation. These methods should be supplemented with qualitative analysis and expert evaluation. Finally, bibliometric clusters approximate, but do not fully replicate, conceptual research areas. In conclusion, while bibliometric analysis has its limitations, it remains a valuable tool for knowledge creation and research evaluation, benefiting various fields, including business research.

Funding Open access funding provided by Università degli Studi di Milano within the CRUI-CARE Agreement. This research did not receive any specific grant from funding agencies in the public, commercial, or not-forprofit sectors.

Declarations

Conflict of interest None.

References

1. Krogstrup, S., & Oman, W. (2019). *Macroeconomic and financial policies for climate change mitigation: A review of the literature*.
2. IPCC. 2022. Climate Change 2022: Impacts, Adaptation, and Vulnerability. *Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change*. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, p. 3056
3. Calabrese, R., T. Dombrowski, A. Mandel, R. K. Pace, and L. Zanin. 2024. Impacts of extreme weather events on mortgage risks and their evolution under climate change: A case study on Florida. *European Journal of Operational Research* 314 (1): 377–392.
4. Feyen, E. H., Utz, R. J., Zuccardi Huertas, I. E., Bogdan, O., & Moon, J. (2020). *Macro-financial aspects of climate change*. World Bank Policy Research Working Paper, (9109).
5. Mandel, A., T. Tiggeloven, D. Lincke, E. Koks, P. Ward, and J. Hinkel. 2021. Risks on global financial stability induced by climate change: The case of flood risks. *Climatic Change* 166 (1): 4.
6. Caldecott, B., A. Clark, K. Koskelo, E. Mulholland, and C. Hickey. 2021. Stranded assets: Environmental drivers, societal challenges, and supervisory responses. *Annual Review of Environment and Resources* 46 (1): 417–447.
7. Carney, M. 2015. Breaking the tragedy of the horizon–climate change and financial stability. *Speech Given at Lloyd's of London* 29:220–230.
8. NGFS. (2020). *Guide for Supervisors—Integrating climate-related and environmental risks in prudential supervision*. Network for Greening the Financial System, Paris, France.
9. Basel Committee on Banking Supervision. (2020). *Climate-related financial risks: A survey on current initiatives*.
10. European Central Bank (ECB). (2020). *Guide on climate-related and environmental risks*.
11. Financial Stability Board (FSB). (2020). *The implications of climate change for financial stability*.
12. Breitenstein, M., D. K. Nguyen, and T. Walther. 2021. Environmental hazards and risk management in the financial sector: A systematic literature review. *Journal of Economic Surveys* 35 (2): 512–538.
13. Giglio, S., B. Kelly, and J. Stroebel. 2021. Climate finance. *Annual Review of Financial Economics* 13:15–36.
14. Venturini, A. 2022. Climate change, risk factors and stock returns: A review of the literature. *International Review of Financial Analysis* 79 : Article 101934.
15. Campiglio, E., L. Daumas, P. Monnin, and A. von Jagow. 2023. Climate-related risks in financial assets. *Journal of Economic Surveys* 37 (3): 950–992.
16. Semieniuk, G., E. Campiglio, J. F. Mercure, U. Volz, and N. R. Edwards. 2021. Low-carbon transition risks for finance. *Wiley Interdisciplinary Reviews: Climate Change* 12 (1) : e678.
17. Carè, R., R. Fatima, and N. Lèvy. 2024. Assessing the evolution of banking reputation literature: A bibliometric analysis. *International Journal of Bank Marketing* 42 (5): 1059–1091.
18. Donthu, N., S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim. 2021. How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research* 133:285–296.
19. Cevik, S., and J. T. Jalles. 2022. This changes everything: Climate shocks and sovereign bonds∗. *Energy Economics* 107 : 105856.
20. Dafermos, Y., M. Nikolaidi, and G. Galanis. 2018. Climate change, financial stability and monetary policy. *Ecological Economics* 152:219–234.
21. Adom, P. K., and S. Amoani. 2021. The role of climate adaptation readiness in economic growth and climate change relationship: An analysis of the output/income and productivity/institution channels. *Journal of Environmental Management* 293 : 112923.
22. Lee, C., C. Wang, B. T. Thinh, and Z. Xu. 2022. Climate risk and bank liquidity creation: International evidence. *International Review of Financial Analysis* 82 : Article 102198.
23. Tol, R. S. J. 2009. The economic effects of climate change. *Journal of Economic Perspectives* 23 (2): 29–51.
24. Diaz-Rainey, I., S. A. Gehricke, H. Roberts, and R. Zhang. 2021. Trump vs. Paris: The impact of climate policy on U.S. listed oil and gas firm returns and volatility. *International Review of Financial Analysis* 76 : 101746.
25. Reboredo, J. C., and A. Ugolini. 2022. Climate transition risk, profitability and stock prices. *International Review of Financial Analysis* 83 : Article 102271.
26. Battiston, S., A. Mandel, I. Monasterolo, F. Sch¨utze, and G. Visentin. 2017. A climate stress-test of the financial system. *Nature Climate Change* 7:283–288.
27. Bushman, R. M., and R. Wittenberg-Moerman. 2012. The role of bank reputation in "certifying" future performance implications of borrowers' accounting numbers. *Journal of Accounting Research* 50 (4): 883–930.

28. Campbell, T. S., and W. A. Kracaw. 1980. Information production, market signalling, and the theory of financial intermediation. *The Journal of Finance* 35 (4): 863–882.
29. Stiglitz, J. E. 2000. The contributions of the economics of information to twentieth century economics. *The Quarterly Journal of Economics* 115 (4): 1441–1478.
30. Chemmanur, T. J., and P. Fulghieri. 1994. Investment bank reputation, information production, and financial intermediation. *The Journal of Finance* 49 (1): 57–79.
31. Gopalan, R., V. Nanda, and V. Yerramilli. 2011. Does poor performance damage the reputation of financial intermediaries? Evidence from the loan syndication market. *The Journal of Finance* 66 (6): 2083–2120.
32. Herbohn, K., R. Gao, and P. Clarkson. 2019. Evidence on whether banks consider carbon risk in their lending decisions. *Journal of Business Ethics* 158 (1): 155–175. https://doi.org/10.1007/s10551-017-3711-3.
33. Balachandran, B., and J. H. Nguyen. 2018. Does carbon risk matter in firm dividend policy? Evidence from a quasi-natural experiment in an imputation environment. *Journal of Banking & Finance* 96:249–267.
34. Bolton, P., & Kacperczyk, M. T. (2021). *Carbon disclosure and the cost of capital*. Available at SSRN p. 3755613.
35. Nguyen, J. H., and H. V. Phan. 2020. Carbon risk and corporate capital structure. *Journal of Corporate Finance* 64 : 101713.
36. Jung, J., Herbohn, K., & Clarkson, P. (2018). Carbon risk, carbon risk awareness and the cost of debt financing. *Journal of Business Ethics*, 150(4): 1151–1171.
37. Safiullah, M., M. N. Kabir, and M. D. Miah. 2021. Carbon emissions and credit ratings. *Energy Economics* 100 : 105330.
38. DiMaggio, P. J., and W. W. Powell. 1983. The iron cage revisited: Institutional isomorphism and collective rationality in organizational fields. *American Sociological Review* 48 (2): 147–160.
39. Meyer, J. W., and B. Rowan. 1977. Institutionalized organizations: Formal structure as myth and ceremony. *American Journal of Sociology* 83 (2): 340–363.
40. Baughn, C. C., N. L. Bodie, and J. C. McIntosh. 2007. Corporate social and environmental responsibility in Asian countries and other geographical regions. *Corporate Social Responsibility and Environmental Management* 14 (4): 189–205.
41. Jones, M. T. 1999. The institutional determinants of social responsibility. *Journal of Business Ethics* 20 (2): 163–179.
42. Li, R., and R. Ramanathan. 2020. Can environmental investments benefit environmental performance? The moderating roles of institutional environment and foreign direct investment. *Business Strategy and the Environment* 29 (8): 3385–3398.
43. Xie, X., Y. Jia, X. Meng, and C. Li. 2017. Corporate social responsibility, customer satisfaction, and financial performance: The moderating effect of the institutional environment in two transition economies. *Journal of Cleaner Production* 150:26–39.
44. Del Mar Miras-Rodriguez, M., J. A. Machuca, and B. Escobar-Pérez. 2018. Drivers that encourage environmental practices in manufacturing plants: A comparison of cultural environments. *Journal of Cleaner Production* 179:690–703.
45. Del Mar Miras-Rodríguez, M., A. Carrasco-Gallego, and B. Escobar-Pérez. 2015. Are socially responsible behaviors paid off equally? A cross-cultural analysis. *Corporate Social Responsibility and Environmental Management* 22 (4): 237–256.
46. Ringov, D., and M. Zollo. 2007. The impact of national culture on corporate social performance. *Corporate Governance: The International Journal of Business in Society* 7 (4): 476–485.
47. Waldman, D. A., M. Sully. de Luque, N. Washburn, R. J. House, B. Adetoun, A. Barrasa, M. de Sully Luque, M. Bobina, M. Bodur, Y.-J. Chen, S. Debbarma, P. Dorfman, R. R. Dzuvichu, I. Evcimen, P. Fu, M. Grachev, R. Gonzalez Duarte, V. Gupta, D. N. Den Hartog, A. H. B. de Hoogh, J. Howell, K.-Y. Jone, H. Kabasakal, E. Konrad, P. L. Koopman, R. Lang, C.-C. Lin, J. Liu, B. Martinez, A. E. Munley, N. Papalexandris, T. K. Peng, L. Prieto, N. Quigley, J. Rajasekar, F. G. Rodríguez, J. Steyrer, B. Tanure, H. Thierry, V. M. Thomas, P. T. van den Berg, C. P. M. Wilderom, and C. P. Wilderom. 2006. Cultural and leadership predictors of corporate social responsibility values of top management: A GLOBE study of 15 countries. *Journal of International Business Studies* 37 (6): 823–837.
48. Jamali, D., and R. Mirshak. 2007. Corporate social responsibility (CSR): Theory and practice in a developing country context. *Journal of Business Ethics* 72 (3): 243–262.
49. Scholtens, B., and F. C. Kang. 2013. Corporate social responsibility and earnings management: Evidence from Asian economies. *Corporate Social Responsibility and Environmental Management* 20 (2): 95–112.
50. Nandy, M., and S. Lodh. 2012. Do banks value the eco-friendliness of firms in their corporate lending decision? Some empirical evidence. *International Review of Financial Analysis* 25:83–93.
51. D'Orazio, P., and L. Popoyan. 2019. Fostering green investments and tackling climate-related financial risks:Which role for macroprudential policies? *Ecological Economics* 160:25–37.
52. Bellinvia, A., Venturelli, V., Brighi, P., & Algeri, C. (2025). *Weathering the storm: How climate risks shape bank credit risk in European banks*. Finance Research Letters, p. 107511.
53. Umar, M., et al. 2021. Carbon neutrality, bank lending, and credit risk: Evidence from the Eurozone. *Journal of Environmental Management* 296 : 113156.
54. Jensen, M. C., and W. H. Meckling. 2019. Theory of the firm: Managerial behavior, agency costs and ownership structure. In *Corporate governance*, 77–132. Gower.
55. Grossman, S. J., and O. D. Hart. 1986. The costs and benefits of ownership: A theory of vertical and lateral integration. *Journal of Political Economy* 94 (4): 691–719.
56. Klein, B., R. G. Crawford, and A. A. Alchian. 1978. Vertical integration, appropriable rents, and the competitive contracting process. *The Journal of Law and Economics* 21 (2): 297–326.
57. Gulen, H., and M. Ion. 2016. Policy uncertainty and corporate investment. *The Review of Financial Studies* 29 (3): 523–564.
58. Vural-Yavaş, Ç. 2020. Corporate risk-taking in developed countries: The influence of economic policy uncertainty and macroeconomic conditions. *Journal of Multinational Financial Management* 54 : 100616.
59. Ng, J., W. Saffar, and J. J. Zhang. 2020. Policy uncertainty and loan loss provisions in the banking industry. *Review of Accounting Studies* 25 (2): 726–777.
60. Baker, S. R., N. Bloom, and S. J. Davis. 2016. Measuring economic policy uncertainty. *The Quarterly Journal of Economics* 131 (4): 1593–1636.
61. Khan, A., J. W. Goodell, M. K. Hassan, and A. Paltrinieri. 2022. A bibliometric review of finance bibliometric papers. *Finance Research Letters* 47 : Article 102520.
62. Cobo, M. J., A. G. Lopez-Herrera, E. Herrera-Viedma, and F. Herrera. 2011. An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the fuzzy sets theory field. *Journal of Informetrics* 5 (1): 146–166.
63. Noyons, E., H. Moed, and A. V. Raan. 2006. Integrating research performance analysis and science mapping. *Scientometrics* 46 (3): 591–604.
64. Shashi, Centobelli, P., Cerchione, R., & Mittal, A. (2021). Managing sustainability in luxury industry to pursue circular economy strategies. *Business Strategy and the Environment*, *30*(1), 432–462.
65. Migliavacca, M., R. Patel, A. Paltrinieri, and J. W. Goodell. 2022. Mapping impact investing: A bibliometric analysis. *Journal of International Financial Markets, Institutions and Money* 81 : Article 101679.

66. Zupic, I., and T. ˇ Cater. 2015. Bibliometric methods in management and organization. *Organizational Research Methods* 18 (3): 429–472.
67. Arruda, H., E. R. Silva, M. Lessa, D. Proença Jr., and R. Bartholo. 2022. VOSviewer and bibliometrix. *Journal of the Medical Library Association: JMLA* 110 (3): 392.
68. Mongeon, P., and A. Paul-Hus. 2016. The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics* 106:213–228.
69. Tian, X., Y. Geng, J. Sarkis, and S. Zhong. 2018. Trends and features of embodied flows associated with international trade based on bibliometric analysis. *Resources, Conservation and Recycling* 131:148–157.
70. Chang, L., T. Watanabe, H. Xu, and J. Han. 2022. Knowledge mapping on Nepal's protected areas using CiteSpace and VOSviewer. *Land* 11 (7) : 1109.
71. Fernandez-Alles, M., and A. Ramos-Rodríguez. 2009. Intellectual structure of human resources management research: A bibliometric analysis of the journal human resource management, 1985–2005. *Journal of the American Society for Information Science and Technology* 60 (1): 161–175.
72. Ramos-Rodríguez, A.-R., and J. Ruíz-Navarro. 2004. Changes in the intellectual structure of strategic management research: A bibliometric study of the Strategic Management Journal, 1980–2000. *Strategic Management Journal* 25 (10): 981–1004.
73. Crossan, M. M., and M. Apaydin. 2010. A multi-dimensional framework of organizational innovation: A systematic review of the literature. *Journal of Management Studies* 47 (6): 1154–1191.
74. Basel Committee on Banking Supervision. (2021). *Climate-related risk drivers and their transmission channels*.
75. Small, H. 1973. Co-citation in the scientific literature: A new measure of the relationship between two documents. *Journal of the American Society for Information Science* 24 (4): 265–269.
76. Paltrinieri, A., M. K. Hassan, S. Bahoo, and A. Khan. 2019. A bibliometric review of sukuk literature. *International Review of Economics & Finance* 86:897–918.
77. Bahoo, S., I. Alon, and A. Paltrinieri. 2020. Sovereign wealth funds: Past, present and future. *International Review of Financial Analysis* 67 : 101418.
78. Aguila, N., & Wullweber, J. (2025). Legitimising green monetary policies: Market liberalism, layered central banking, and the ECB's ongoing discursive shift from environmental risks to price stability. *Journal of European Public Policy* 32(3): 665-696.
79. De Bandt, O., Kuntz, L. C., Pankratz, N., Pegoraro, F., Solheim, H., Sutton, G., Sutton, G., Takeyama, A., & Xia, F. D. (2024). The effects of climate change-related risks on banks: A literature review. *Journal of Economic Surveys*.
80. Dikau, S., and U. Volz. 2021. Central bank mandates, sustainability objectives and the promotion of green finance. *Ecological Economics* 184 : 107022.
81. Korzeb, Z., Karkowska, R., Matysek-Jędrych, A., & Niedziółka, P. (2025). How do ESG challenges affect default risk? An empirical analysis from the global banking sector perspective. *Studies in Economics and Finance* 42(1): 89-114.
82. Zhang, D., Y. Wu, Q. Ji, K. Guo, and B. Lucey. 2024. Climate impacts on the loan quality of Chinese regional commercial banks. *Journal of International Money and Finance* 140 : 102975.
83. Javadi, S., and A. A. Masum. 2021. The impact of climate change on the cost of bank loans. *Journal of Corporate Finance* 69 : 102019.
84. Anastasiou, D., Ballis, A., Kallandranis, C., & Lakhal, F. (2025). Analyzing the effects of climate risk on discouraged borrowers: Deciphering the contradictory forces. *Risk Analysis* 45(1): 223-239.
85. Acharya, V. V., R. Berner, R. Engle, H. Jung, J. Stroebel, X. Zeng, and Y. Zhao. 2023. Climate stress testing. *Annual Review of Financial Economics* 15 (1): 291–326.
86. Chenet, H., J. Ryan-Collins, and F. Van Lerven. 2021. Finance, climate-change and radical uncertainty: Towards a precautionary approach to financial policy. *Ecological Economics* 183 : 106957.
87. Ehlers, T., F. Packer, and K. de Greiff. 2022. The pricing of carbon risk in syndicated loans: Which risks are priced and why? *Journal of Banking & Finance* 136 (3) : 106180.
88. Cheung, H., A. Baumber, and P. J. Brown. 2022. Barriers and enablers to sustainable finance: A case study of home loans in an Australian retail bank. *Journal of Cleaner Production* 334 : 130211.
89. Roncoroni, A., S. Battiston, L. O. Escobar-Farfán, and S. Martinez-Jaramillo. 2021. Climate risk and financial stability in the network of banks and investment funds. *Journal of Financial Stability* 54 : 100870.
90. Benincasa, E., Betz, F., & Gattini, L. (2024). How do firms cope with losses from extreme weather events?. *Journal of Corporate Finance* 84: 102508.
91. Curcio, D., I. Gianfrancesco, and D. Vioto. 2023. Climate change and financial systemic risk: Evidence from US banks and insurers. *Journal of Financial Stability* 66:101132.
92. Huang, H. H., J. Kerstein, C. Wang, and F. Wu. 2022. Firm climate risk, risk management, and bank loan financing. *Strategic Management Journal* 43 (13): 2849–2880.
93. Erhemjamts, O., Huang, K., & Tehranian, H. (2024). Climate risk, ESG performance, and ESG sentiment in US commercial banks. *Global Finance Journal* 59: 100924.
94. Svartzman, R., P. Bolton, M. Despres, L. A. Pereira Da Silva, and F. Samama. 2021. Central banks, financial stability and policy coordination in the age of climate uncertainty: A three-layered analytical and operational framework. *Climate Policy* 21 (4): 563–580.
95. Dunz, N., A. Naqvi, and I. Monasterolo. 2021. Climate sentiments, transition risk, and financial stability in a stock-flow consistent model. *Journal of Financial Stability* 54 : 100872.
96. Baek, S., & Kang, M. (2025). Does ESG enhance asset quality and funding cost management in banking diversification?. *Finance Research Letters* 73: 106542.
97. Dafermos, Y., and M. Nikolaidi. 2021. How can green differentiated capital requirements affect climate risks? A dynamic macrofinancial analysis. *Journal of Financial Stability* 54 : 100871.
98. Alessi, L., Ossola, E., & Panzica, R. (2021). What greenium matters in the stock market? The role of greenhouse gas emissions and environmental disclosures. *Journal of Financial Stability* 54: 100869.
99. Dou, J., Mirza, N., Umar, M., & Horobet, A. (2025). ESG uncertainties and valuation implications: Evidence from the EU banking sector. *Research in International Business and Finance* 76: 102872.
100. Huang, B., Punzi, M. T., & Wu, Y. (2021). Do banks price environmental transition risks? Evidence from a quasi-natural experiment in China. *Journal of Corporate Finance* 69: 101983.
101. Carattini, S., G. Heutel, and G. Melkadze. 2023. Climate policy, financial frictions, and transition risk. *Review of Economic Dynamics* 51:778–794.
102. Kedward, K., J. Ryan-Collins, and H. Chenet. 2023. Biodiversity loss and climate change interactions: Financial stability implications for central banks and financial supervisors. *Climate Policy* 23 (6): 763–781.
103. Ho, K., & Wong, A. (2023). Effect of climate-related risk on the costs of bank loans: Evidence from syndicated loan markets in emerging economies. *Emerging Markets Review* 55: 100977.

104. Aslan, C., Bulut, E., Cepni, O., & Yilmaz, M. H. (2022). Does climate change affect bank lending behavior?. *Economics Letters* 220: 110859.
105. Li, S., and Z. Pan. 2022. Climate transition risk and bank performance: Evidence from China. *Journal of Environmental Management* 323 : 116275.
106. Nguyen, Q., I. Diaz-Rainey, D. Kuruppuarachchi, M. McCarten, and E. K. Tan. 2023. Climate transition risk in US loan portfolios: Are all banks the same? *International Review of Financial Analysis* 85 : 102401.
107. Erhemjamts, O., Huang, K., & Tehranian, H. (2024). Climate risk, ESG performance, and ESG sentiment in US commercial banks. *Global Finance Journal* 59: 100924.
108. Giakoumelou, A., Salvi, A., Bekiros, S., & Onorato, G. (2024). ESG and FinTech funding in the EU. *Research in International Business and Finance* 69: 102233.
109. Mésonnier, J. S. (2022). Banks' climate commitments and credit to carbon-intensive industries: New evidence for France. *Climate Policy* 22(3): 389-400.
110. Toma, P., and V. Stefanelli. 2022. What are the banks doing in managing climate risk? Empirical evidence from a position map. *Ecological Economics* 200 : 107530.
111. Turnbull, S., & Habahbeh, L. (2020). A framework to analyze the financial effects of climate change. *The Journal of Risk* 23(2): 105-146.
112. Ozdemir, B. (2023). Frontloading ESG risks and benefits into the capital charge to incentivise green financing. *Journal of Risk Management in Financial Institutions* 16(4): 427-448.
113. Raimo, N., I. Fraccalvieri, F. Vitolla, and C. Bussoli. 2025. Climate on the agenda: How board composition drives climate change disclosure in European banks. *Business Strategy and the Environment*. https://doi.org/10.1002/bse.4366.
114. Rega, F. G., Russo, S., & Salerno, D. (2025). Disentangling the S and the G in the European banking industry: The role of climate risk and opportunity awareness. *Research in International Business and Finance*, p. 102977.
115. Liu, Z., S. He, W. Men, and H. Sun. 2024. Impact of climate risk on financial stability: Cross-country evidence. *International Review of Financial Analysis* 92 : 103096.
116. Liu, Z., J. Li, and H. Sun. 2024. Climate transition risk and bank risk-taking: The role of digital transformation. *Finance Research Letters* 61 : 105028.
117. European Central Bank. (2024, July). *Draft guide on governance and risk culture*. https://www.bankingsupervision.europa.eu/framework/legal-framework/public-consultations/pdf/ssm.pubcon202407_draftguide.en.pdf
118. Hidalgo-Oñate, D., Fuertes-Fuertes, I., & Cabedo, J. D. (2023). Climate-related prudential regulation tools in the context of sustainable and responsible investment: a systematic review. *Climate Policy* 23(6): 704-721.

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