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The Evolution of Environmental, Social, and Governance (ESG) and Risk and Its Implications for Sustainable Finance: A Systematic Literature Review

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ABSTRACT

Recent literature addressing ESG and risk has increased by 70% since mid-2022, reflecting a growing interest in sustainable finance. Guided by the PRISMA flow diagram, this paper employs a hybrid systematic review methodology, combining bibliometric analysis with content analysis, to provide a comprehensive overview of the evolution of ESG and risk within the broader sustainable finance discourse. Our findings identify sustainability as a central theme within the ESG and risk literature, with a recent shift towards governance structure and performance evaluation. Furthermore, through Latent Dirichlet Allocation-based topic modeling, we delineate six key subtopic areas that collectively underscore ESG's role in resilience, risk management, and value creation. These findings demonstrate the importance of integrating sustainability into corporate decision-making and highlight ESG's potential to shape sustainable finance as an evolving and dynamic field for research.

1 | Introduction

1.1 | Background

The topic of sustainable finance has garnered increasing attention from practitioners and policymakers, who recognize the critical role of Environmental, Social, and Governance (ESG) activities in advancing corporate success and creating value for all stakeholders (e.g., Bostwick et al. 2015; Business Roundtable 2019; Delevingne et al. 2020; Harrison et al. 2019). The literature on ESG practices highlights three principal theoretical perspectives: risk, information, and strategy. The risk perspective emphasizes ESG's role in mitigating risks and preserving corporate value. The information and strategy perspectives focus on how ESG enables access to resources, enhances competitive advantage, and drives long-term value creation (Wang et al. 2023). Fundamentally, the strategic value of ESG practices lies in their capacity to foster sustainable growth, enhances risk management, and aligns organizational objectives with the evolving expectations of stakeholders.

Empirical research further reinforces the strategic importance of ESG. Studies have shown that organizations with high ESG ratings often outperform their peers financially, enjoy lower capital costs, and exhibit greater resilience during economic downturns (Chen et al. 2023; Eccles and Klimenko 2019; Wheatley 2022; Wong and Neher 2024). Furthermore, strong ESG practices attract investors, businesses, and customers who prioritize ethical and sustainable business practices (e.g., Kandpal et al. 2024). Governments are increasingly mandating ESG reporting, reinforcing its relevance in regulatory and strategic contexts (e.g., Mendenhal and Sutter 2024). By integrating ESG into their strategic frameworks, organizations can differentiate themselves in competitive markets, attract top talent, and align with global sustainability goals (e.g., Gannon and Hieker 2022; Markopoulos and Ramonda 2022).

This comprehensive approach not only enhances corporate reputation but also positions firms as proactive leaders in addressing pressing societal and environmental challenges. Hence, adopting ESG can be a key driver of sustainable success and competitive advantage in today's complex business landscape.

This study examines the thematic evolution of ESG and risk-related research, addressing the substantial growth in the literature over recent years. While prior systematic reviews (e.g., De Giuli et al. 2024) have contributed valuable insights, they have not provided a detailed account of thematic development or conceptual progression. To bridge this gap, we employed a bibliometric approach including co-citation-based clustering and keyword-based thematic evolution. In addition to the approach commonly used in bibliometric analysis, we analyzed metadata from the citation database Web of Science to gain a better understanding of emerging research trends. Our analysis included multiple topics, Keyword Plus (a unique value of Web of Science), micro, meso, and macro level citation topics, and research areas. Specifically, we extracted the keywords "ESG" and "risk." To address the reliability and credibility of the study, we applied the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) framework to guide the inclusion of relevant records for bibliometric analysis (PRISMA 2021). Furthermore, to enhance thematic clarity, our study applied cosine-similarity matching between Latent Dirichlet Allocation (LDA)-generated topic vectors and the full text of 234 documents. This process enabled the ranking of the most representative papers per topic, improving both narrative coherence and topic relevance.

1.2 | Initiatives Addressing ESG, Risk and Sustainable Finance

Existing literature reviews addressing ESG, risk and sustainable finance have experienced rapid growth, although in a fragmented and narrowly focused manner. For instance, Gallucci et al. (2022) conducted a portfolio-oriented study that revealed ESG and risks are a heterogeneous conceptualization of ESG risk (Gallucci et al. 2022). Similarly, De Giuli et al. (2024) performed a comprehensive review of 589 records, yet their findings also reflect inconsistencies in ESG-risk taxonomy. These studies show that the thematic structure of the academic literature remains weakly integrated, emphasizing the need for broader market and sector coverage.

Singhania and Gupta (2024), in their meta-analysis, emphasized the importance of distinguishing between systematic and idiosyncratic risk channels, advocating for the inclusion of contextual factors in ESG risk assessments. Kapil and Rawal (2023). Jin (2024) highlighted the role of systematic ESG risk as a priced factor that can be used to segregate firms based on their exposure. Collectively, these reviews highlight the importance of addressing sectoral heterogeneity, refining risk metrics, and developing industry-specific yet standardized definitions of ESG. Methodologically, the literature reflects a diverse range of approaches, including bibliometrics (De Giuli et al. 2024), meta-analysis (Singhania and Gupta 2024), a systematic review along with bibliometrics (Kapil and Rawal 2023), and a systematic literature review with a conceptual framework (da Cunha et al. 2025). Despite these efforts, persistent challenges remain, such as limited standardization (Gallucci et al. 2022), regional bias or indicator inconsistency (da Cunha et al. 2025), and limited or specific samples (De Giuli et al. 2024; de Leite Almeida et al. 2024; Monfort et al. 2025).

Similarly, several reviews have focused on sustainable finance. Luo et al. (2022) covered publications from 2000 to 2021. Kashi and Shah (2023) emphasized the role of banks, macroprudential policy, and risk profiling. Cunha et al. (2021) explored sustainable finance and investment, noting the limited literature to support societal and environmental impacts. Singhania et al. (2024) conducted review on sustainable finance with attention to climate risk. Methodologically, bibliometrics has emerged as the most commonly practiced approach across these studies (Ahmad et al. 2025; Peng et al. 2025).

In exploring reviews that addressed ESG, risk, and sustainable finance, prior work has covered themes such as integrity and greenwashing (Dempere et al. 2024), risk transmission and connectedness between green and conventional assets (Tettamanzi et al. 2024), and the role of regulation and AI-enabled measurement approaches (Lim 2024; Zairis et al. 2024). The predominant methodologies used in these studies include systematic literature reviews (Marti et al. 2024; Jayaram and Singh 2025; Zairis et al. 2024), scoping reviews (Dempere et al. 2024), and bibliometrics (Peng et al. 2025). Future work is still needed because the integration of a clear ESG-risk taxonomy remains limited (Zairis et al. 2024), some datasets are outdated, terminating in 2020 (Jayaram and Singh 2025), and there is a pressing need for robust countermeasures against greenwashing in sustainable finance.

Conceptually, the existing review initiatives have focused on (1) the origins and fundamentals of social responsible investment and ESG, (2) drivers of social responsible investment (SRI) and ESG performance, (3) stakeholder and shareholder engagement, and (4) institutional and regulatory roles. However, the implications derived from several systematic reviews so far have largely centered on performance. At the same time, critical dimensions, such as field diversity, risk channels, connectedness, and measurement standardization, remain comparatively underexplored, as shown in the Table 1.

In terms of methodology, bibliometrics has emerged as the most widely adopted approach in the relevant literature. Bibliometric is "the use of statistics to analysize publishing trends and highlight relationships between published works" (Ninkov et al. 2022, 173). Its popularity is primarily due to its capacity to uncover leading nodes, such as authors, articles, journals, institutions, and keywords, as shown in Table 1. However, bibliometric techniques have notable limitations. They are usually hard to identify the novel gaps and interdisciplinary linkages (Rafols et al. 2012), are slow to reflect the emerging themes in the literature (Anwar et al. 2019), and rely on high citation counts, which do not always reflect the depth and quality of scholarly arguments (Bornmann and Daniel 2008). On the other hand, LDA, as a topic modeling approach, utilizes text mining without a predefined taxonomy. LDA can uncover hidden topics in the text through data-driven modeling (Blei et al. 2003), which can help to address limitations of the bibliometric approach. As reported

TABLE 1 | Recent reviews' initiatives addressing ESG, risk, and in relation to sustainable finance.

Review (year)	Domain	Method	Focus	Limitations
De Giuli et al. (2024)	ESG + Risk	Bibliometric + SLR	ESG–risk; highlights fragmentation, no clear ESG-risk taxonomy	Researchers' work offered weak thematic connectedness
Gallucci et al. (2022)	ESG in portfolios	SLR	Portfolio-level evidence, heterogeneous ESG-risk conceptualizations/metrics	Lack of systematization across studies
Kapil and Rawal (2023)	Sustainable investment/ESG	Bibliometric + SLR	Organizes themes including cost/risk mitigation and greenwashing	Calls for integrative mapping of controversies and themes
Peng et al. (2025)	Sustainable finance connectedness	Bibliometric	Clusters on green bonds, tech, climate risk and spillovers	Systemic transmission under-specified
Tettamanzi et al. (2024)	EU Taxonomy	Critical review	Regulatory framing, implementation frictions	Real-world risk/performance impacts under-tested
Luo et al. (2022)	Sustainable finance (field)	Bibliometric	Hotspots since 2015, green bonds, climate finance	Breadth > depth; definitional inconsistency

in Table 1, the bibliometric approach alone reveals weak thematic connectedness and integrative mapping. Still, none of the methodological approaches are immune to limitations. There are also arguments that LDA is limited to offering meaning to topic-related keywords, as it only offers "a bag of words," with weak interpretability. To enhance the interpretive robustness of the LDA output, we conducted additional cosine-similarity matching. This approach involved comparing each topic vector, consisting of a list of keywords identified through LDA-based topic modeling, with the text of all 234 identified documents. This method helped to rank the most representative and relevant papers for each topic, thereby improving the narrative coherence and representativeness of the identified topics. This integrative approach offers a novel methodological contribution to this study.

It is stated in the literature that there are several risks associated with ESG practices, ranging from micro to meso and macro levels. Interestingly, ESG practices under strong corporate governance can facilitate firms to have sustainable finance and resilience. For instance, ESG can be planned strategically to deal with environmental and social risks, to offer strategic growth and stability in financial systems (Folqué et al. 2021). Similarly, the shareholders' demand for transparency and ethical conduct requires sustainable ESG-centric practices that address holistic risk assessment and deal with reputational risks. Moreover, ESG disclosure provides shareholders with a better picture to assess and understand a firm's alignment with the global Sustainable Development Goals (SDGs) (Avramov et al. 2022). ESG frameworks, systematic ESG risks, and performance metrics can help to minimize capital costs and maximize financial inclusivity to achieve and address sustainable finance (Folqué et al. 2021). Sound ESG practices mitigate idiosyncratic risks through efficient compliance and monitoring, facilitating an attractive environment for investors (Ziolo 2020). Thus, based on the above findings, the inter-connectedness between ESG risk and sustainable finance warrants further exploration of ESG risk-related literature, given its significance in the practice of sustainable finance.

Interestingly, a recent bibliometric study by De Giuli et al. (2024) performed author, journal, and keyword-based analyses, as well as an article co-citation-based performance analysis on a record count of 589 articles published between 1983 and 2022. However, the relevant literature addressing ESG and Risk has increased by 70% since the middle of 2022. Moreover, De Giuli et al. (2024) and Singhania and Gupta (2024) have suggested that future research should examine sustainability in the context of ESG and risk. While considering the argument of De Giuli et al. (2024) and Singhania and Gupta (2024), the authors also took a novel initiative to further examine the discussion sections of academic publications addressing sustainable finance in relation to ESG and risk. Therefore, the following research questions have been proposed:

RQ1. What are the thematic areas and intellectual progress in the academic literature on ESG and risk since the SDGs were announced in 2015?

RQ2. What are the prominent research directions and implications derived from the existing academic literature addressing sustainable finance in relation to ESG and risk?

In other words, it will be beneficial to explore what is implied and debated in the recent literature on the aspects of ESG and risk in the context of sustainable finance.

Philosophically, the studies in this paper can be framed within the perspective of system theory, where RQ1 focuses on input-oriented content relating to ESG and risk to uncover the structural and thematic knowledge of the field. In contrast, RQ2 adopts an output-oriented approach to analyze relevant studies, aiming to extract meaning and identify future research pathways within the field of sustainable finance. Accordingly, this dual-focus offers a novel approach to systematically trace the evolution and development of knowledge in sustainable finance in relation to ESG and risk. In the following sections, Study 1 and Study 2 will be presented to address RQ1 and RQ2, respectively.

2 | Study 1: A Systematic Review (Bibliometrics)

2.1 | Method

Bibliometrics facilitates a quantitative approach to exploring scientific literature to uncover patterns and the evolution of the knowledge domain (Narin et al. 1994). Further, it helps to underline the presence of knowledge and intellectual bases within the knowledge domain (Chen et al. 2008). During the evolution of any research domain, academics focus on specific gaps within the literature, leaving behind gaps that can only be seen through a multi-disciplinary lens (Kakaria et al. 2023). Along with providing a holistic view of the inter-disciplinary evolution of a particular knowledge domain, it also offers the opportunity to examine the role of vibrant nodes, which can be an author, research publication, journal, keywords, institution, or country.

2.1.1 | Materials and Data Extraction

As stated earlier, the purpose of Study 1 is to extend the argument raised by De Giuli et al. (2024). Clarivate Analytics' Web of Science was used to crawl metadata of publications. Specifically, journals indexed in the Science Citation Index, the Social Science Citation Index, and the Emerging Sources Citation Index was utilized. Similar to previous research (e.g., Perlines et al. 2022), this study used Web of Science for its detailed metadata, which is critical for bibliometric (citation) analysis. Moreover, the Journal Impact Factor (JIF) of cited references was calculated using data from the Web of Science database.

As shown in Figure 1, the PRISMA framework depicts three distinct stages of systematic review: (1) Identification, where 2144 records were identified, (2) Screening, where 618 records were excluded based on relevance and eligibility criteria, and (3) Included, where this final stage of systematic review resulted in 1008 records for Study 1, and 234 papers for Study 2 on ESG and Risk, focusing on sustainable finance as a research front.

2.1.2 | Analysis

The bibliometric analysis measures the role of each vibrant node within the intellectual structure of a certain research domain by measuring its impact (in terms of citations, co-citations, or co-occurrence) over time (Wei et al. 2015), which is one of the most frequently used approaches in mapping the cognitive structure of science (Erar 2002). The co-citation of nodes (articles, authors, and journals) provides a relational view, allowing the role of nodes within a specific knowledge domain to be observed. Small (1973) argued that, based on subject similarity, if two nodes are co-cited in a document, and if the frequency of their co-citation is high, it implies their relevance and relatedness to one another. Interestingly, within a certain knowledge domain, there is a chance to have multiple clusters (knowledge areas), where each cluster and its highly co-cited nodes possibly share the same theme (Chen et al. 2008). Moreover, the co-occurrence of nodes (keywords, institutions, or countries) helps to understand the relatedness between nodes and the possible role of nodes within a certain research domain (Lang et al. 2020).

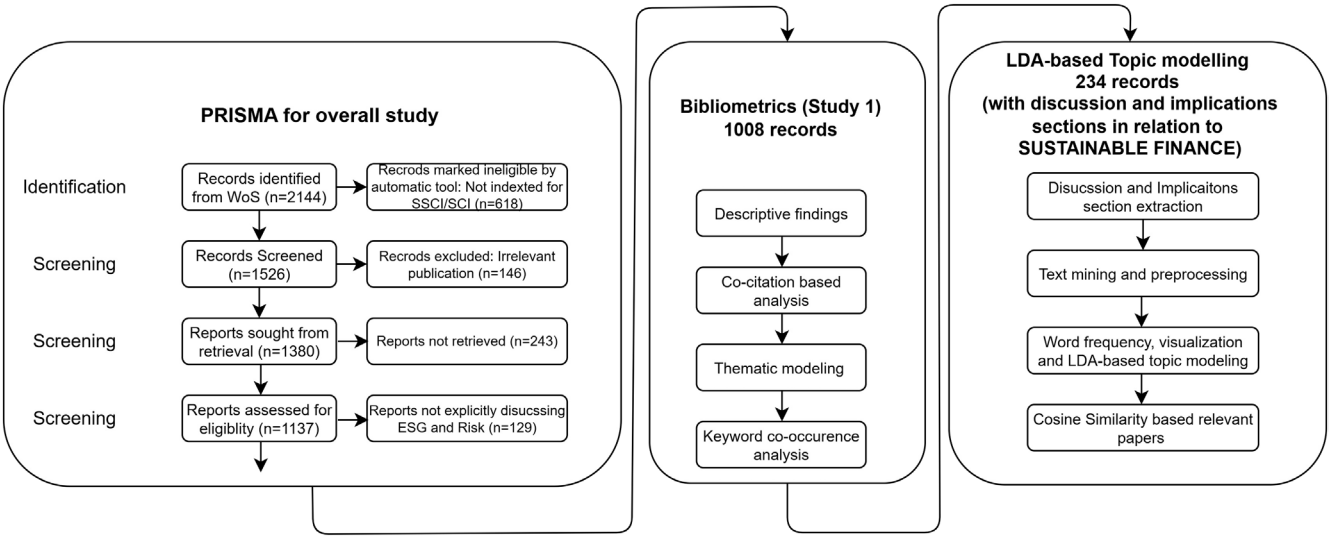

FIGURE 1 | PRISMA flow diagram to obtain Study 1 and Study 2 datasets (PRISMA 2021).

2.1.3 | Tools

To address the research question under Study 1, which is about offering a thematic view and the evolution of ESG and Risk-related literature, the authors employed two bibliometric tools, namely CiteSpace by Chen (2006) and Bibliometrix by Aria and Cuccurullo (2017). CiteSpace is a Java-based environment for co-citation/co-occurrence-based network analysis. It offers a high degree of customization and text mining capabilities, and provides insight, such as time-based trend analysis (Chen et al. 2008). In this study, CiteSpace was specifically used to perform co-citation analysis by (1) identifying leading publications based on their co-citation score and (2) the co-citation-based thematic view, which helps examine the intellectual structure of a certain research domain over time. To further understand the evolution of ESG and Risk-related literature, Bibliometrix (R-based environment) was used to perform keyword-based analysis. Specifically, the keyword-based thematic evolution analysis allows us to branch the dataset into multiple time slices, as it helps to understand how trends and priorities emerged, shifted, and prioritized over time, respectively. Moreover, it offers an environment to examine the trends within the research domain.

2.2 | Findings

2.2.1 | Descriptive Findings

In the current findings, the initial trace of ESG and Risk research can be observed in 2011, likely due to the aftermath of the financial crises (namely, the Global Financial Crisis [2007–2009], and the European Debt Crisis [2009–2010]). This prompted academic researchers to adopt a new lens for better understanding investors, shareholders, and governance. Specifically, more than 2400 authors contributed to 280 scholarly journals and produced more than 1000 academic research publications, with ESG and Risk as major research themes. Notably, the annual growth in this academic literature has been above 40% in recent years. Specifically, De Giuli et al. (2024) reported a total of 589 ESG and risk-related publications. However, they reported that the number of ESG and risk-related publications by the fourth quarter of 2024 is 1008, representing a 71% increase in publications during this time.

2.2.2 | Co-Citation Analysis

The co-citation analysis was performed using CiteSpace to examine the citation analysis in further detail. The most frequently co-cited research regarding co-citation-based analysis was by Albuquerque et al. (2019), which developed an industry equilibrium model to empirically explore the impact of CSR on firm risk and value. This study underscores the significant influence of advertising expenditures on CSR, enhancing consumer loyalty and reducing risk, particularly in industries with lower price elasticity of demand. The second most co-cited research, by Gillan et al. (2021), offered a review survey on ESG and CSR, emphasizing market characteristics, leadership, ownership structures, risk management, and overall performance. It highlights that ESG/CSR activities are more prominent in firms from developed economies with stronger legal protections. The third most co-cited work, by Pedersen et al. (2021), introduced an ESG-adjusted Capital Asset Pricing Model (CAPM) that includes environmental (e.g., carbon emissions), social (e.g., sin stocks), and governance factors into the investment process, as reported in the Table 2. The study found mixed results regarding the alignment of ESG factors with investor preferences and market expectations.

The fourth leading co-cited study by Broadstock et al. (2021) analyzed the impact of ESG performance on stock returns during the COVID-19 pandemic for Chinese listed firms. The study found that firms with higher ESG scores were more resilient, experiencing only a slight decline in stock prices, which suggests that ESG performance can serve as a risk mitigation tool. Lastly, the fifth leading research in co-citation analysis was done by Pástor et al. (2021), who examined the impact of sustainable investing on asset prices and corporate behavior. The study found that green assets generally generate lower returns, and positive shocks occur when demand for green products increases. This study concluded that ESG-related factors encourage firms to focus on sustainable investments and create a positive social impact.

2.2.3 | Articles Co-Citation-Based Thematic View

To perform the article's co-citation-based thematic view (cluster analysis) of the crawled academic literature, we performed a minimum weight spanning tree as an algorithm to explore a

TABLE 2 | Leading co-citation-based publication.

Co-citation count	Author	Paper title	Journal
125	Albuquerque et al. (2019)	Corporate social responsibility and firm risk: Theory and empirical evidence	*Management Science*
122	Gillan et al. (2021)	Firms and social responsibility: A review of ESG and CSR research in corporate finance	*Journal of Corporate Finance*
119	Pedersen et al. (2021)	Responsible investing: The ESG-efficient frontier	*Journal of Financial Economics*
117	Broadstock et al. (2021)	The role of ESG performance during times of financial crisis: Evidence from COVID-19 in China	*Finance Research Letters*
100	Pástor et al. (2021)	Sustainable investing in equilibrium	*Journal of Financial Economics*

unidirectional graph. The article's co-citation-based cluster analysis reported a modularity score of 0.7169, a weight means silhouette score of 0.895, and a harmonic mean of 0.796. Therefore, it can be reported that the proposed clusters are clear in structure, each is distinguishable, and the balance has been achieved in terms of recall and precision. To keep the contribution of this research initiative unique, we examined the thematic view of the clusters that evolved in the post-COVID-19 era in detail.

The leading cluster was noted with the caption "#0 using machine learning." The contributing literature in this cluster includes Lucarelli and Severini (2024), who analyses the complexities and inconsistencies surrounding ESG ratings. The study argues that the current state of ESG rating is insufficiently developed and fragmented, rendering it a "black box" for evaluating sustainability, as the ongoing pursuit of comprehensive ESG evaluation remains unclear. Moreover, the work by Awijen et al. (2024) examined the effects of transition and physical climate risks on ESG stock prices. The study indicates that both physical and transitional climate risks are critical factors in predicting ESG stock prices, as integrating climate risk variables significantly improves the models' accuracy.

The second cluster is noted with the title of "#1 systematic ESG risk." The leading research work noted in the literature included Chang et al. (2022), who conducted a systematic review of ESG and CSR practices while mapping how they affect firm value and investment returns. Their work suggests that ESG-related efforts can positively affect firm value, such as motivating employees, strengthening total quality management, planning for long-term growth, increasing investors' returns, and decreasing financing costs by reducing risk and increasing stock prices. Another leading work in this cluster is the work of Kräussl et al. (2024). They examined ESG investment while focusing on investors' beliefs and perceptions. The study discusses how investors pursue ESG strategies for better returns, the challenges related to greenwashing, the inconsistency of ESG ratings, and their impact on ESG scoring as a financial metric.

The third-largest cluster observed with the title "#2 economic policy uncertainty" underlined the possible interaction of government initiatives, corporate decision-making, ESG performance, and related risks. Among the most visible research contributions in this cluster are Liu and Xu's (2024) work that investigated the effect of ESG ratings as informal environmental regulations on the green innovation activities of Chinese new energy companies. The study suggests that ESG ratings significantly improve green innovations with heterogeneity in these effects, where state-owned enterprises, larger firms, and those with higher levels of digitization benefit more from ESG-driven green innovation. The fourth vibrant cluster is noted as "#3 Idiosyncratic Risk," It includes the contribution of Wang et al. (2023), who examined the mechanisms through which ESG practices affect corporate value creation based on external (macro), industry-specific (meso), and organizational (micro) factors. The study indicates that ESG practices can reduce risk, enhance information transparency, and create a competitive edge, thereby increasing firm value. Indirectly, the emphasis on firm-level risk mitigation strategy highlights the essence of idiosyncratic risk management strategy. The fifth co-citation-based cluster, as shown in Figure 2, is noted as a "#4 environmental sustainability." The leading work within this cluster was that of Folqué et al. (2021), who examined the impact of different sustainable investment (SI) strategies on ESG risk management. The study indicates that funds relying solely on negative screening strategies exhibit higher ESG risk scores and worse carbon risk scores when compared to those using more advanced SI strategies to support the global transition to a low-carbon economy. Moreover, the contribution by Lueg et al. (2019) investigated the relationship between sustainability disclosure and company risk. The study reveals that sustainability disclosure reduces systematic risk in subsequent periods. It suggests using sustainability disclosure to manage and communicate risk to stakeholders. Specifically, both research works raise concerns about the actual value of ESG in terms of effectiveness.

2.2.4 | Keyword-Based Thematic Evolution

Bibliometrics were used to perform keyword-based thematic evolution, as it offers a temporal evolution of literature based on keyword analysis (Wu et al. 2022). The findings conclude that risk, performance, impact, governance, responsibility, management, disclosure, cost, and investment are dominant aspects in the literature. Moreover, terms like "sustainability," "investors," "shareholder value," and "emerging markets" contributed to connecting multiple research fronts in the literature. Interestingly, in 2024, keywords such as "law," "geopolitical risks," "irresponsibility," "economic policy uncertainty," "green investment," and "gold" emerged in the literature on ESG and Risk. In other words, the literature is evolving and incorporating multidisciplinary perspectives more rapidly.

As shown in Figure 3, the time spans for the analyses were determined by the respective bibliometric tools. For example, the co-citation analysis from 2005 to 2024 reflects the earliest co-cited works on ESG and Risk to appear in our dataset, indicating the foundational literature. In contrast, the keyword evolution analysis (2011–2024) results from automatic time frame selection by Bibliometrix, depending on when the key terms appeared and developed within the metadata, corresponding to an increasing academic interest in ESG-related keywords after the global financial crisis (2007–2009), and the European Debt Crisis (2009–2010). In terms of theoretical foundations, ESG and Risk-related literature up until the pandemic crisis was primarily dominated by CSR, focusing on the ethical and social aspects of business practices. However, uncertainty and prospect theory have been vibrant areas of research in recent years. Moreover, regarding ESG-related factors, the first decade emphasized risk management, the regulatory framework, and the validation of ESG practices on empirical grounds. Recently, however, the focus has shifted toward governance structure and performance evaluation, which also covers related attributes, such as attitudes, price, and efficiency. Furthermore, current trends lead to the exploration of emerging markets, where investment-related decisions, corporate governance, and stock returns have become key concerns.

3 | Study 2: LDA-Based Topic Modeling

Study 1 underlined sustainability as one of the key factors within the ESG and Risk literature. Based on the insights gained, Study 2 focuses on sustainability-centric factors as key

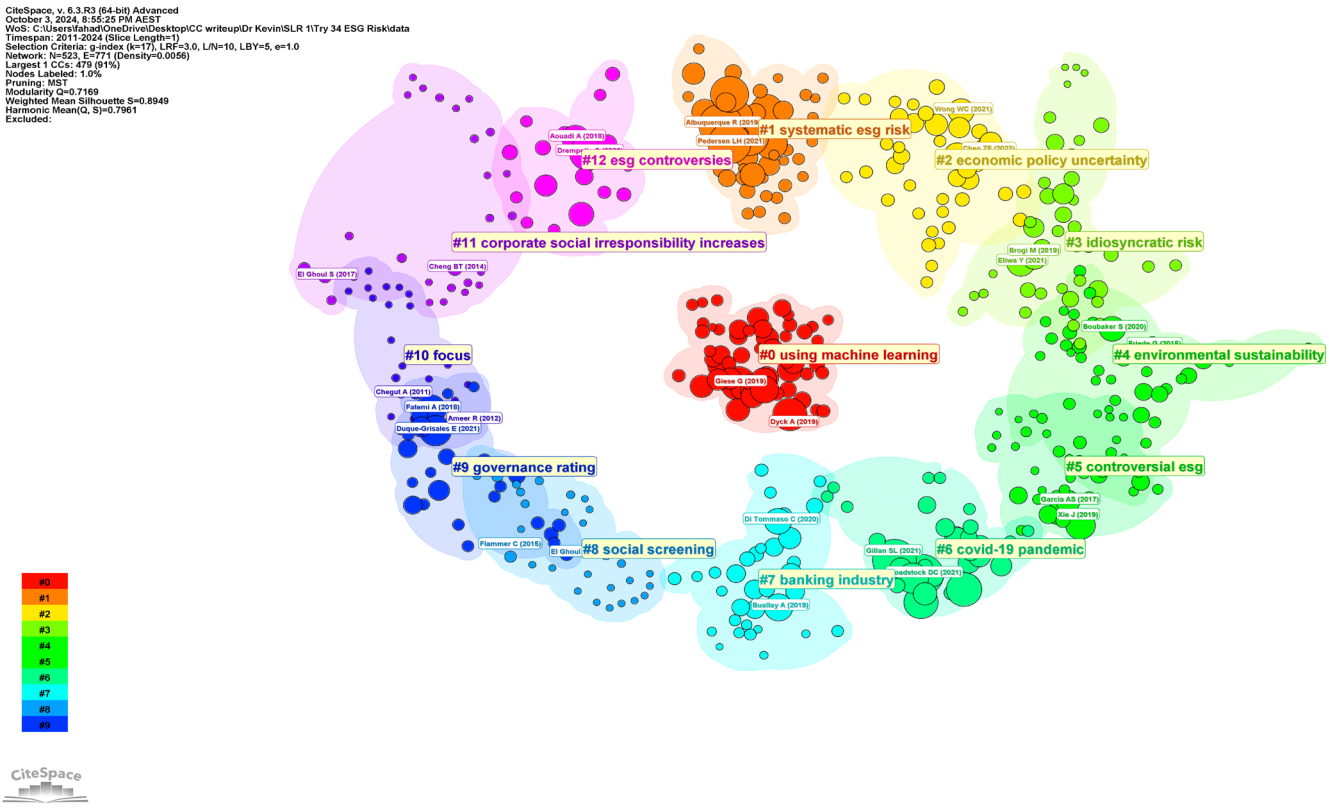

FIGURE 2 | Co-citation-based thematic view (intellectual structure of literature addressing ESG and Risk from 2005 to 2024).

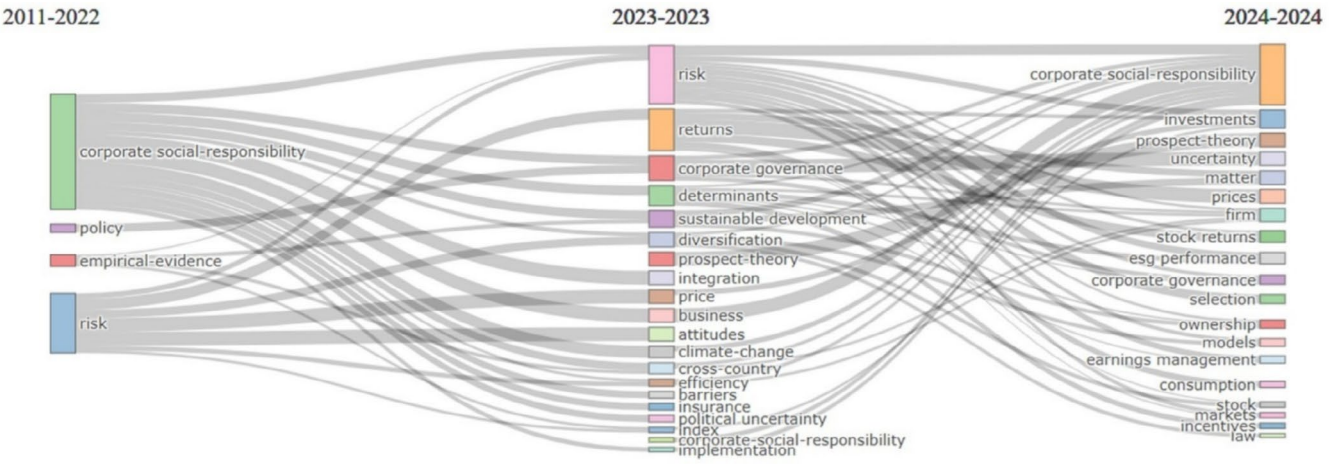

FIGURE 3 | Keyword-based thematic evolution of literature from 2011 to 2024.

concerns, identifying "sustainable finance" as a vibrant attribute linked to terms such as "corporate social responsibility," "climate change," and "green investments." The discussions and implications within this domain are examined here to add more depth to understanding ESG frameworks and risk management.

3.1 | Method

Based on the crawled data set of 1008 publications for Study 1, we further refined the dataset to examine the role and potential of sustainable finance in the context of ESG and Risk. To achieve this, this study considered 234 research publications out of 1008 on sustainable finance. After extracting the relevant information for Study 2, Python 3.11 was employed for text mining. Natural Language Processing (NLP) techniques were employed to uncover meaningful insights from unidirectional data. Systematically, it includes the process of pre-processing, standardizing, classifying text, and uncovering the pattern and LDA modeling (Xiao et al. 2021).

The preprocessing utilized tokenization, where text is broken down into words, with each word labeled as a token and

converted to lowercase (Elia et al. 2019). Spell correction was applied using TextBlob in Python. Additionally, stop-words, such as "the" and "in," were eliminated using the Natural Language Toolkit (NLTK), a suite of libraries in Python. Before topic modeling, part-of-speech (POS) tagging was carried out to categorize words from each sentence and assign the appropriate part of speech (e.g., noun, verb, adjective, etc.) to each tokenized word. In the final stage of text preprocessing, lemmatization was performed to convert nouns and adjectives into their base forms or lemmas (e.g., "ran," "running," and "runs" are lemmatizes to their base form "run").

We used the WordCloud (Oesper et al. 2011) library to find the top words in the data. Then, Python coding was applied to find the frequency of occurrence in the datasets. WorldCloud is an interactive Python library that creates visually appealing arrangements from words, where larger words have a higher frequency of events (Oesper et al. 2011). To find the words and their frequencies, we use Pandas (McKinney 2010).

The LDA facilitates assigning topics to each document (and sub-sets of documents) by utilizing probability distribution. It drives the possibility of proposing a thematic view (topic clustering) and text sorting facility based on extracted topics (Yu and Xiang 2023), as shown in Appendix A. This approach in the field of NLP has been widely used in the social sciences (Wu et al. 2023) and multi-disciplinary research (Yu and Xiang 2023). The authors used the LDAvis package, which offers an interactive environment to visualize LDA-based topic modeling. Through the LDAvis package, authors explored which aspects of "sustainable finance" have been researched in the context of ESG and Risk in the existing literature.

The output from pyLDAvis in Python, which includes a list of topic-based keywords for each topic, was exported into Excel format to facilitate further analysis. Given the limitation of the LDA-based topic modeling, with a restricted capacity for thematic insights (Rishu and Kukreja 2024), this study also used cosine similarity scores. Specifically, the cosine similarity helped to examine (a) the paper's TF–IDF vector (unigram–bigram features) and (b) a topic vector built from that topic's exported keywords. This technique is widely used in the textual analysis literature, allowing the assignment of scores for each topic, supported by a keyword corroboration statistic (percentage of the topic's keywords present in each document).

All operations were conducted in Python 3.11, which utilized well-acknowledged libraries, that is, NLTK (Nair and Thushara 2024), scikit-learn for TF–IDF and cosine similarity (Gupta et al. 2024), and pyLDAvis for topic modeling (Gencoglu et al. 2023). All scripts and files developed by the authors were exported and documented. To facilitate replication, all code generated in Python and outputs are listed in Supporting Information Appendix S1.

3.2 | Findings

3.2.1 | Descriptive Findings

Study 2 analyzed the implications sections of 234 selected studies that specifically discussed sustainable finance. The leading terms from the crawled literature included "market," "firm," "investment," "investor," "portfolio," "companies," "stakeholder," "sustainability," "rating," "score," "stock," "information green," "fund," and "corporation."

WordCloud was used to visualize the leading terms from the crawled content relating to the implications of sustainable finance, as shown in Figure 4. The semantic meaning of the content addressing sustainable finance within the literature on ESG and Risk can be used to identify leading adjectives, nouns, and verbs as terms.

This approach offers an overall understanding of the thematic structure of the content, as discussed by Nair and Thushara (2024). For instance, nouns usually indicate the core concept and the entities involved in the discussion. The verb describes the actions and processes involved in the evolution of the topic. The adjective provides a brief qualitative explanation of the nouns involved in the literature, as shown in Table 3. The prominent nouns in the crawled literature included "performance,"

FIGURE 4 | WordCloud, which contains leading words within the discussion and implications related to sustainable finance (within the context of ESG and Risk).

"investment," "portfolio," "stock," and "strategy." Besides this, the attributes, such as "financial," "sustainable," "social," "green," "future,", and "regulatory," were observed to have adjectives with high frequency. Moreover, leading verbs in the crawled literature included "invest," "promote," "incorporate," "greenwash," and "mitigate."

3.2.2 | Topic Modeling

As a topic modeling algorithm, LDA helps uncover the themes/topics within the collected dataset. LDA starts with the assumption that each document or record in the data set can potentially have more than one topic, and each of the topics can comprise multiple words (Gencoglu et al. 2023). LDA helps to understand how words within each topic are generated in a probabilistic fashion (Jin et al. 2023). To achieve LDA-suggested topic modeling, it is important to understand the role of document-to-topic distribution (alpha) and topic-to-word distribution (beta). The higher alpha scores indicate the diversity in the topics, and higher scores of beta indicate diversity within each topic (Taecharungroj 2021). These two controllers in LDA are usually used as hyperparameters to tailor the LDA-suggested model. To better understand the crawled data from the discussion and the implications of the literature, the authors performed topic-count identification, ranging from 2 to 30 topics, to determine the most appropriate topic resolution. This is one of the recommended approaches in the literature (Abdelmeguid et al. 2024), applying variation in hyperparameters to find the best scores of perplexity and coherence. Based on the best coherence and topic relevance score, the optimal number of topics is computed (Gencoglu et al. 2023).

An optimal number of topics are a crucial factor for topic modeling, as it helps to understand the pattern in the data. The procedure for selecting certain topics (n) involves assessing two factors: coherence and perplexity. Coherence refers to the degree of interpretability of the topics generated by LDA. A higher coherence indicates a higher ability to interpret the topic (Yuan et al. 2021). On the other hand, perplexity underpins the ability to predict by topic modeling. Specifically, a lower degree of perplexity indicates a higher ability to generalize and report (Qi et al. 2019). The findings concluded that $n = 6$ offers higher coherence than the other topic numbers. However, the perplexity was noted slightly higher as compared to $n = 4$. The trade-off is arguable, as it helps to achieve higher coherence. A similar approach has also been adopted in the existing literature while performing LDA-based topic modeling (Röder et al. 2015). Thus, $n = 6$ was selected as the best possible topic, balancing the degree of coherence and perplexity with the challenge of human interpretability.

Topic 1 in Table 4 summarizes the impact of ESG on financial performance in equity markets. Specifically, it emphasizes the role of asset allocation in corporate sustainability. The related papers highlight links between ESG and firms' growth, asset pricing, and financial returns. Most of the papers covering Topic 1 use panel data, Fama–MacBeth cross-sections, and factor models (CAPM/Carhart) to examine empirical relationships with financial metrics, and generally find that stronger ESG is associated with lower risk/cost of capital and, in some contexts, higher value; effects vary by ESG pillar and market context (Bertelli and Torricelli 2024; Rojo-Suárez and Alonso-Conde 2024). However, Bannier et al. (2023) find mixed or limited ESG impact on the firm's performance in India. Collectively, these studies highlight the strategic role of ESG in financial decision-making and corporate growth.

Papers related to Topic 2 highlight the strategic role of ESG in alleviating financial constraints. For instance, firms with higher ESG awareness often prioritize green innovation, reflecting a shift towards sustainable practices (Zhai et al. 2022). Green financial policies can help to increase profitability, enhance green crediting, and reduce the risk of financial constraints (Zhang 2023). A key mechanism in this process is the adoption of Task Force on Climate-Related Financial Disclosures (TCFD) style reporting, which plays a crucial role in mobilizing sustainable investment by reducing market friction and significantly influencing key stakeholders such as investors, insurers, and other macro-level institutions (Ngo et al. 2023). Regulatory bodies are increasingly

TABLE 3 | Leading nouns, verbs, and adjectives in the context of Study 2.

N	Noun	Freq	Verb	Freq	Adjective	Freq
1	Performance	549	Invest	109	Financial	315
2	Investment	401	Develop	100	Sustainable	305
3	Sustainability	290	Promote	75	Social	278
4	Portfolio	262	Examine	74	Environmental	256
5	Stock	221	Integrate	66	Corporate	256
6	Information	198	Investigate	66	Green	216
7	Policy	180	Incorporate	46	Future	129
8	Disclosure	176	Greenwash	34	Economic	122
9	Strategy	157	Mitigate	34	Responsible	85
10	Governance	148	Perform	33	Regulatory	79

Abbreviations: Freq = frequency; *N* = number.

TABLE 4 | LDA based on topic modeling.

Topic number	Unique aspects (LDA-based keywords)	LDA-based leading keywords (not complete list)	Cosine similarity-based relevant papers	Proportion
1	Asset allocation and corporate sustainability	Portfolio, score, model, market, return, stocks, uncertainty, data, asset, relationship, sustainability, value, impact	Bannier et al. (2023), Bertelli and Torricelli (2024), Gehricke et al. (2024), Narula et al. (2024), Rojo-Suárez and Alonso-Conde (2024)	36.0%
2	ESG strategies, disclosure, and policies	Social, corporate, information, development, strategic, cost, stakeholders, economic, capital, government, company, activity	Jiang et al. (2023), Ngo et al. (2023), Steuer and Tröger (2022), Tang (2022), Zhai et al. (2022), Zhang (2023)	25.5%
3	Green finance and greenwashing	Investment, investor, climate, index, decision, strategy, SRI, manager, change, crisis, responsible, concern, growth	Atz et al. (2023), Díaz-Peña et al. (2022), Dorfleitner and Utz (2024), Martini (2021), Schoenmaker and Schramade (2019)	24.4%
4	Carbon, energy and transition metrics	Energy, indicator, renewable, climate, accord, fossil, carbon, economy, transparency, regulatory, report, finance, valuation, compliance, clarity	Bagh et al. (2024), Bender et al. (2019), Bernardelli et al. (2022), Monaco (2023), Rodriguez-Rojas et al. (2022)	06.1%
5	Banking, bonds and credit	Bank, bond, rate, survival, calibrate, credit, sovereign, book, availability, agreement, ROE, foster, certify, network	Agnese and Giacomini (2023), Capelle-Blancard et al. (2019), Grishunin et al. (2023), Lian et al. (2023), Magale (2021)	04.0%
6	SRI funds, ETF screening	Fund, responsible, preference, investor, outperform, knowledge, ethical, paradigm, conventional, Russia, ETF	Aslan and Posch (2022), D'Apice et al. (2021), Díaz et al. (2024), El Ghoul et al. (2023), ElBannan (2024), Jørgensen and Plovst (2023), Valadkhani and O'Mahony (2025)	03.9%

advocating for such disclosures, as they have the potential to reallocate capital toward environmentally responsible activities. However, some scholars argue that such disclosures should be mandatory and publicly enforced, serving as a complement rather than a substitute for direct climate policy interventions (Steuer and Tröger 2022).

Topic 3-related literature explores the strategic role of green finance in promoting environmentally sustainable outcomes while acknowledging its limitations. In some cases, such initiatives can lead firms to signal change without real action (commonly referred to as greenwashing). In China, strict green policies have incentivized firms to adopt sustainable practices, but in competitive or high-emitting firms, these policies may result in symbolic disclosure (Díaz-Peña et al. 2022). Globally, firms are adopting TCFD or IFRS S2 to standardize climate reporting, thereby enhancing transparency and sustainable investment. However, their effectiveness during periods of economic crises is uncertain. For instance, higher-ESG portfolios have seen a higher degree of resilience and faster recovery during crises (Atz et al. 2023). However, ESG performance is not always robust across economic crises; evidence from EURO STOXX analyses suggests that ESG factors contributed to long-term performance and during COVID-19, but had a limited impact during the 2008 financial crisis (Bertelli and Torricelli 2024).

Research papers related to Topic 4 emphasized the strategic role of climate-aligned portfolios in mitigating and adapting to climate risk. These portfolios aim to reduce exposure to carbon-intensive assets and thereby mitigate "brown" revenues (Bender et al. 2019). In the process of transforming into green and sustainable investment practices, announcements of fossil-fuel divestment by large institutional investors have shown to have a negative impact on the stock prices of fossil-fuel companies (Monaco 2023). Similarly, financial institutions that continue to finance fossil-fuel projects tend to receive lower ESG ratings, reflecting stakeholder disapproval (Bernardelli et al. 2022). However, in China, where firms often have greater growth options, the impact of ESG is weaker (Bagh et al. 2024), suggesting that ESG strategies are not uniform across different markets. These findings suggest that ESG-related policies and strategies should be tailored to specific market conditions and firm characteristics to maximize their relevance and impact.

Topic 5 explores how bond investors perceive firms with high ESG ratings. Firms with higher ESG values are generally considered safer investments, which are reflected in lower yields (Capelle-Blancard et al. 2019). The literature suggests that firms with higher social and governance values tend to have lower default risk while environmental performance is less predictable (Capelle-Blancard et al. 2019). High ESG scores also indicate lower financial risk and increased transparency (Lian et al. 2023). In the context of EU bank bonds, issuers with higher ESG credentials, especially in governance and disclosure, are associated with lower issuance costs (Agnese and Giacomini 2023). Similarly, green bonds typically carry slightly lower yields, a phenomenon known as "greenium" (Grishunin et al. 2023).

The research papers identified under Topic 6 highlight the significance of socially responsible investment (SRI) and its implications for both investors and fund managers. Sustainability, particularly its ethical dimension, is increasingly integrated into investment decisions. Central to this topic are two main questions: (1) how SRI and ESG impact investment decisions (Aslan and Posch 2022; Valadkhani and O'Mahony 2025), and (2) the resilience gained by ESG in times of crisis (ElBannan 2024). Notably, it is suggested in the literature that firms that engage in sustainability disclosure tend to improve their credibility and performance (Díaz et al. 2024). This underlines the strategic role of SRI in fund management and its potential to outperform conventional investments.

The above-discussed six topics are shown in Figure 5 which provides a special lens through which to view the ESG and risk-related literature, signifying their role in resilience, risk management, and value creation. These findings underline prospects for integrating sustainability into decision-making and strengthen the key role ESG could play in developing sustainable finance as a research front. Findings from Study 2, therefore, provide a conceptual view of the ESG and Risk-related literature while underlining the role of sustainable finance as a research focus. Further, Study 2 was based on these findings from LDA-based topic modeling that identified six topics.

4 | Discussion

4.1 | Integrated View of Bibliometrics and LDA-Based Findings

Study 1 identified the vibrant research fronts in the ESG risk literature, which are evolving with a distinctive research focus. In contrast, Study 2 shows how the leading research fronts are heading towards the broader domain of sustainable finance. Through co-citation-based clusters analysis, Study 1 revealed six recurring thematic clusters: (i) systematic and idiosyncratic risk, (ii) policy, disclosure, and credibility, (iii) banking and credit channels; (iv) screening, ratings, and investor beliefs; (v) machine-learning/measurement; and (vi) market shock and controversies. These clusters included several exemplary contributions. For example, Lucarelli and Severini (2024) coined the term 'chimera' that complicates credible inference and syntheses of investor expectations, greenwashing tensions, and heterogeneous performance claims (Kräussl et al. 2024). Reviews linking ESG and CSR to the firm's core value emphasized the role of risk channels and the impact of disclosure and governance on the cost of capital (Chang et al. 2022). Sectoral and institutional transmission in the banking literature explored ESG drivers, incentives, and risk-taking behavior (Galletta and Mazzù 2023; La Torre et al. 2021). Disclosure-focused studies added micro-level evidence on how reporting impacts market dynamics (Li et al. 2024), while research on sustainability disclosure highlights its role in risk reduction strategy through improved information environments (Lueg et al. 2019). Measurement approaches are increasingly computational as machine learning is now used to forecast ESG indices and extract signals that traditional scores may have overlooked (Awijen et al. 2024).

Study 2 identified six LDA topics: (1) ESG and asset pricing in equity, (2) policy/disclosure and corporate strategy, (3) green-finance integration and greenwashing, (4) carbon and energy transition

FIGURE 5 | LDA-based topic modeling of sustainable finance-related discussion and implications in the context of ESGs and Risk.

metrics, (5) banking and bonds/credit spreads, and (6) SRI funds/ETFs and screening. The mapping from Study 1 to Study 2 shows clear transmission pathways. For instance, Study 1 underscored the importance of disclosure credibility and the rating channel (Li et al. 2024; Lucarelli and Severini 2024), as shown in Figure 6 below. These bridging mechanisms are also linked to Study 2, especially in the case of Topic 2, which captures how reporting and disclosure practices help shape corporate strategy.

Similarly, when Study 1 emphasized the role of SRI screening, which can potentially contribute to shaping investor beliefs (Kräussl et al. 2024), it finds a direct parallel in Study 2 under Topic 6, which illustrates how these beliefs materialize through ETF design and screening rules. The measurement cluster in Study 1, which underlined the role of machine learning (Awijen et al. 2024), also connects with Topics 1 and 6 in Study 2, as it has the potential to sharpen equity and fund-level signals. The banking and credit-focused cluster (Galletta and Mazzù 2023; La Torre et al. 2021) maps directly into Topic 5, where credit spreads and bank risk intermediation facilitate the transmission of ESG. Moreover, carbon, energy and transition-risk related themes in Study 1 (Folqué et al. 2021) correspond with Topic 4, which gives the quantitative foundation for the environmental pillar of ESG. These themes feed into Topics 1, 2, and 5, reinforcing their relevance across multiple dimensions of sustainable finance.

Two critical implications emerge from the proposed bridge view of Studies 1 and 2. First, information quality is crucial, as it plays a critical role in shaping ESG ratings and market responses. When disclosure lacks credibility and standardization,

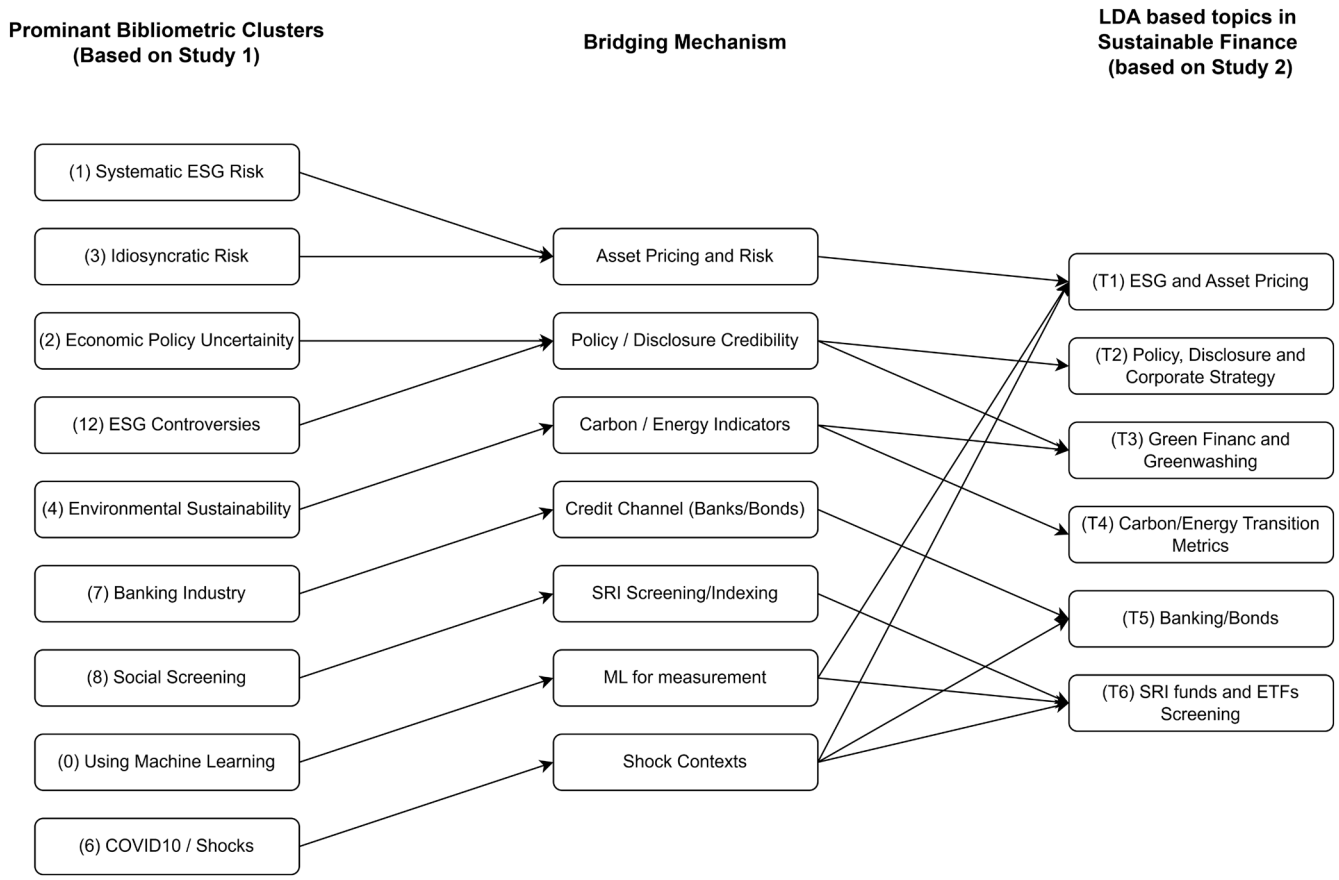

FIGURE 6 | Integrated view of bibliometrics and LDA-based findings.

information risk increases, and the market may react to noise, such as rumors, making it harder to identify and interpret fundamental information (Galletta and Mazzù 2023; Lucarelli and Severini 2024). In contrast, credible and standardized disclosure reduces information risk and promotes efficient integration of ESG information into equity and credit markets (Li et al. 2024; Lueg et al. 2019). Second, intermediation through banks and bond markets plays a strategic role in transforming ESG principles into tangible financing outcomes (Galletta and Mazzù 2023; Lueg et al. 2019). Meanwhile, funds and ETFs shape investor beliefs through their screening intensity and capital flows (Kräussl et al. 2024). Emerging technologies, such as machine learning and data science, further accelerate these processes by enhancing the timeliness and granularity of ESG-related signals (Awijen et al. 2024). In other words, both Studies 1 and 2 are mutually reinforcing: Study 1 identifies the inputs and architectural variables (i.e., credibility, measurement, intermediation, shocks) while Study 2 highlights the transformative expressions of those inputs (ranging from Topics 1 to 6) in sustainable finance.

4.2 | ESG, Risk and Sustainable Finance (As Conceptual Transmission Framework)

Building on the conceptual findings outlined above, how does Study 1 ESG and Risk help understand and formulate the view of Sustainable Finance? The authors proposed a three-stage transmission framework as shown in the Figure 7, that explains how ESG and Risk contribute to the development of sustainable finance as a research focus.

Stage 1 of the framework identifies key inputs, emphasizing the importance of information quality and contextual relevance. As literature argues, disclosure of high-quality reports reduces the degree of uncertainty (Li et al. 2024; Lueg et al. 2019). On the other hand, when different rating bodies produce divergent scores for the same firm, it increases informational noise and heightens the risk of greenwashing (Kräussl et al. 2024; Lucarelli and Severini 2024). The second crucial factor involves the application of machine learning and data science, which enhances real-time decision-making, improves investor confidence, and increases the attractiveness of ESG-related assets (Awijen et al. 2024). The third factor centers on contextual factors, particularly macro-level shocks such as COVID-19 and controversies. These events can amplify tail-risk perception and trigger non-financial signals that can influence market behavior (Galletta and Mazzù 2023; La Torre et al. 2021).

Stage 2 of the proposed framework outlines how the identified inputs are transmitted through economic mechanisms, emphasizing the credibility of ESG signals and their impact on the cash flows, discount rates, and covariances with price risks. It is argued in the literature that ESG/CSR-related risks are linked to firm valuation (Chang et al. 2022; Kräussl et al. 2024). Credible ESG information can also indirectly shape the trust and behavior of banks, bondholders who can re-price default

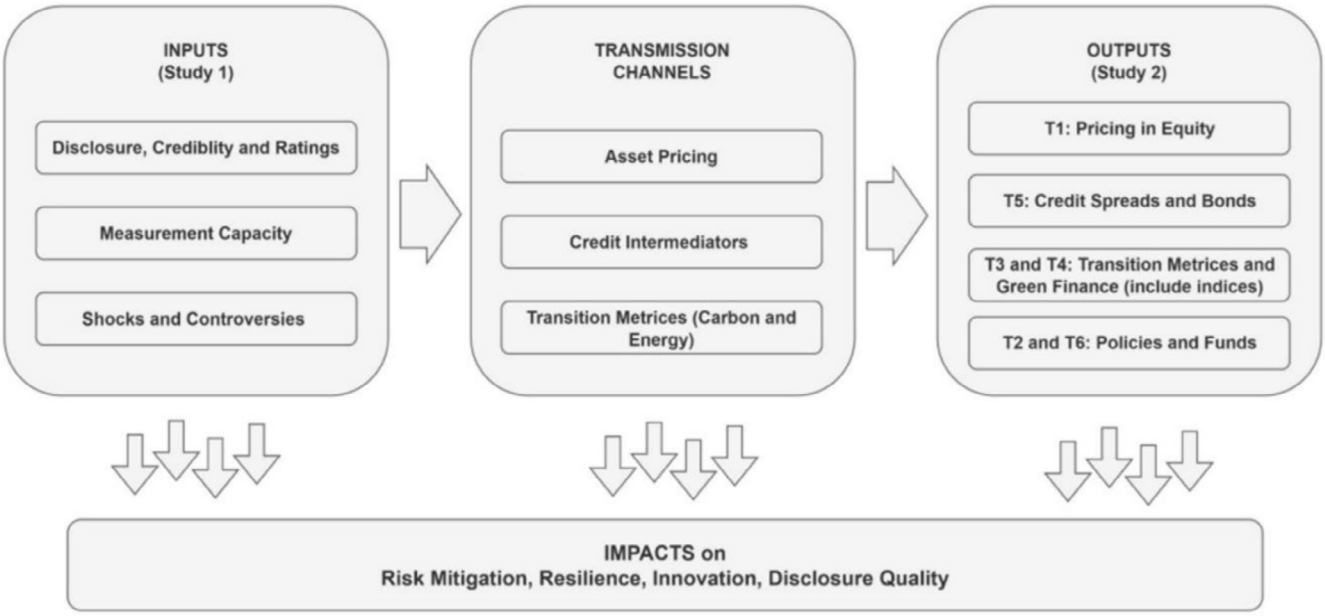

FIGURE 7 | Conceptual transmission framework (ESG and Risk → Sustainable Finance).

and funding risk accordingly, and respond more responsibly in the face of controversy-directed risk (La Torre et al. 2021). These inputs also drive the transmission metrics, such as carbon intensity, energy mix, ESG indicators, and related attributable data, which can help generate predictive insights into climate risk corporate strategies and pricing channels (Folqué et al. 2021).

Stage 3 focuses on the outcomes identified in Study 2, which employed the LDA technique to analyze sustainable finance in the context of ESG and Risk. Each of the topics identified represents a distinct outcome: (1) equity pricing, (2) policy/disclosure and corporate strategy, (3) green-finance and credibility (including greenwashing), (4) carbon, energy, and transition metrics, (5) banking and bonds, and (6) SRI funds, ETFs and screening.

Moreover, each stage illustrates how the proposed framework contributes to a deeper understanding of risk mitigation and resilience, innovation and disclosure quality in sustainable finance.

4.3 | Practical and Research Implications

The findings underscore that comparable and credible disclosure is crucial for mitigating information risk. This, in turn, facilitates effective pricing in equity and credit markets, thereby strengthening the validity of SRI screening claims. It is also posited in the existing literature that high-quality disclosure contributes to risk reduction. Thus, policies should prioritize the implementation and enforcement of transparency in ESG ratings, as it also reduces divergence-driven noise and improves market confidence (Lucarelli and Severini 2024). In the conceptual framework, banks and bond investors are identified as key transmission agents and amplifiers of ESG signals. ESG controversies increase risk-taking and funding costs (Galletta and Mazzù 2023). However, the use of credible transition matrices minimizes the spread and risk (Folqué et al. 2021). Moreover, by utilizing advanced systems, such as AI and ML, early warning systems for controversy control and screening can be implemented to support transition metrics alongside traditional credit factors. From a portfolio management perspective, the smart disclosure signals, when combined with inter-related carbon and energy indicators, offer a resilient and adaptive approach to address shocks. Moreover, the deployment of a machine-learning screening agent requires training and testing against controversial scenarios (Chang et al. 2022). In other words, such an agent can help monitor issuers in real-time and provide auditable decision trails, which can help foster investor confidence and belief in sustainable practices.

4.4 | Limitations and Future Work

This review initiative covers both the breadth of the academic literature by utilizing a bibliometric approach coupled with LDA-based topic modeling. The bibliometric analysis maps the broader landscape of the literature, and LDA-based topic modeling refines insights from relevant studies. However, two limitations remain. First, measurement bias may exist in LDA-based topic modeling due to its sensitivity to term frequency, which can result in under-representation of conceptually important but less frequently mentioned constructs. Second, selection dynamics can influence the outcome in the case of co-citation analysis, potentially skewing results toward established nodes, such as authors, journals, and papers, and overlooking emerging or less prominent trends within a certain period. Future work can triangulate the LDA-based topic modeling with hand-coded validation sets and domain ontologies, or by explicitly focusing on a specific policy or sector in existing literature. Furthermore, LLM-based topic modeling can also be performed alongside LDA while keeping human-in-the-loop validation, which will help to mitigate hallucinations and reduce label drift (to avoid any inconsistent topic labels).

5 | Conclusion

This study provides a systematic review of how ESG and risk research have developed, along with their growing integration into sustainable finance. Using bibliometric analysis and LDA-based topic modeling within a PRISMA-guided framework, the analysis shows an increasing merging of ESG, risk management, and financial performance discussions. The results highlight six main thematic areas, from ESG-focused asset pricing and disclosure practices to green finance, transition risk metrics, and socially responsible investment strategies, each demonstrating ESG's strategic importance in boosting resilience, reducing risks, and generating long-term value. Since the post-crisis period, ESG scholarship has become more complex, shifting towards governance structures, the credibility of disclosure, and data-driven measurement. This development underscores the move from a mainly ethical orientation rooted in CSR to a more empirical, performance- and governance-oriented approach.

The three-stage framework presented here enhances theory by mapping the transmission of ESG signals, from informational inputs and credibility factors to financial market intermediation and sustainability outcomes, thereby linking micro-level disclosure practices with macro-level financial transformation. Empirically, the study highlights that credible, standardized ESG disclosure reduces informational asymmetries, boosts investor confidence, and supports the efficient pricing of risk in equity and credit markets. Practically, these findings underscore the significance of transparent ESG governance and data-driven technologies in creating resilient financial ecosystems. For policymakers and regulators, the evidence stresses the importance of harmonized reporting standards and effective enforcement strategies to prevent greenwashing and promote accountability.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** Appendix.

Appendix A

The readable LDA-based topic details are shown in Figures A1–A6.

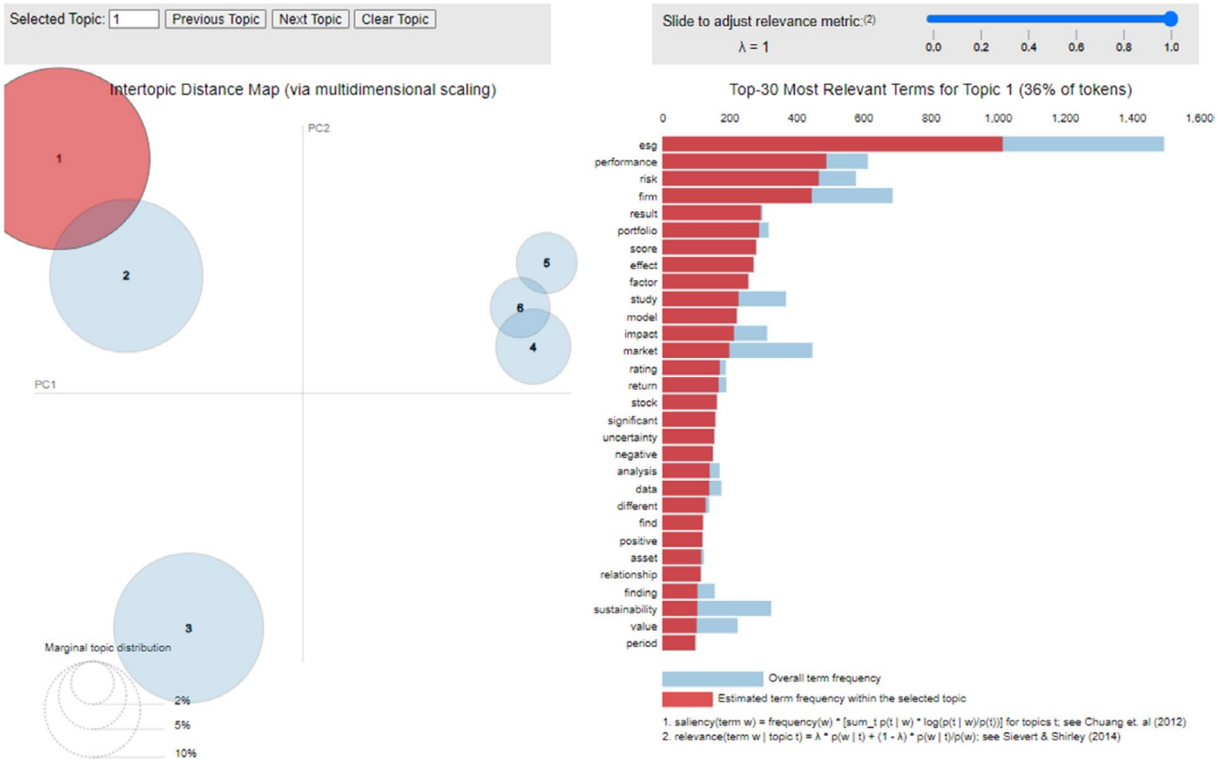

FIGURE A1 | Topic 1 LDA based output.

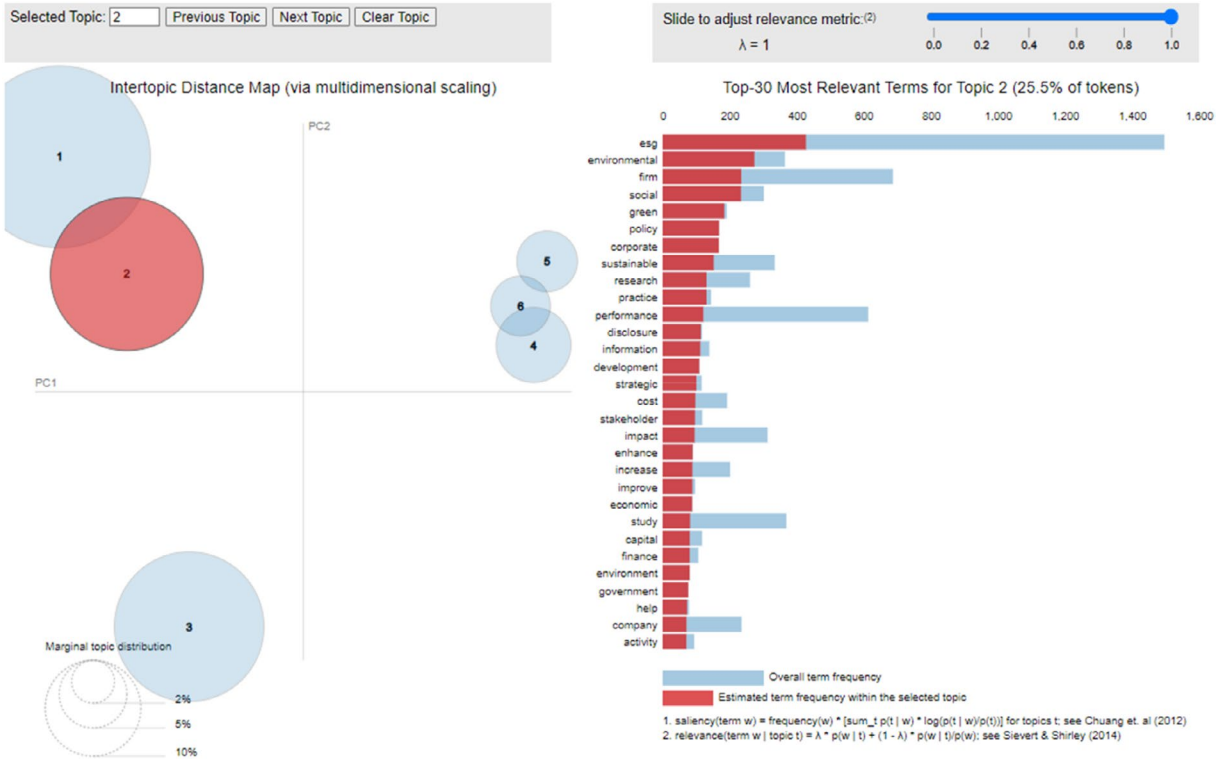

FIGURE A2 | Topic 2 LDA based output.

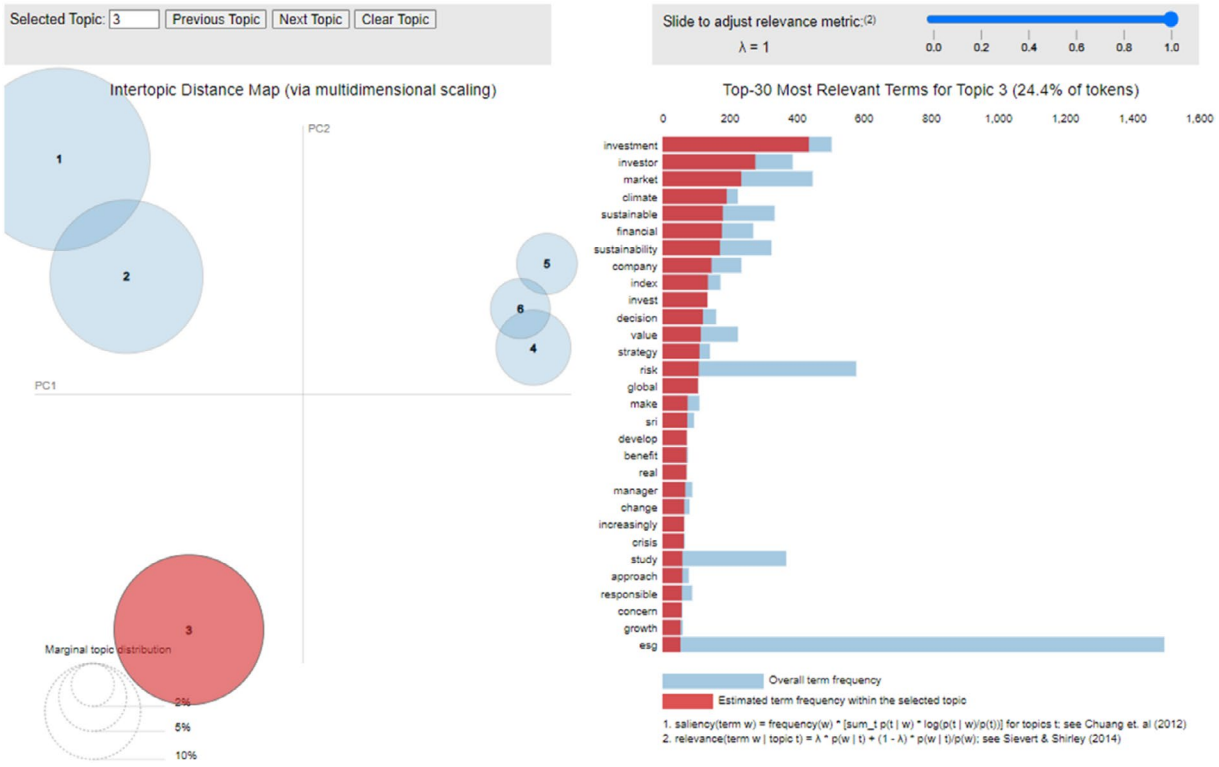

FIGURE A3 | Topic 3 LDA based output.

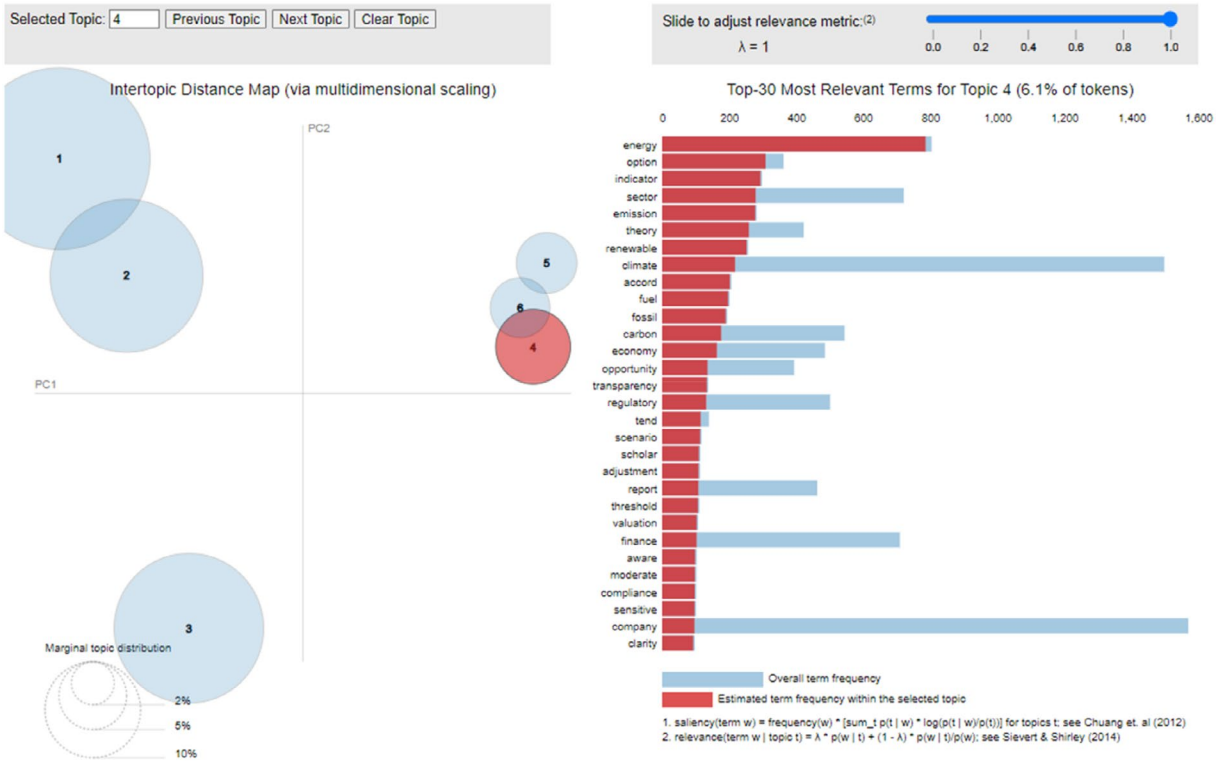

FIGURE A4 | Topic 4 LDA based output.

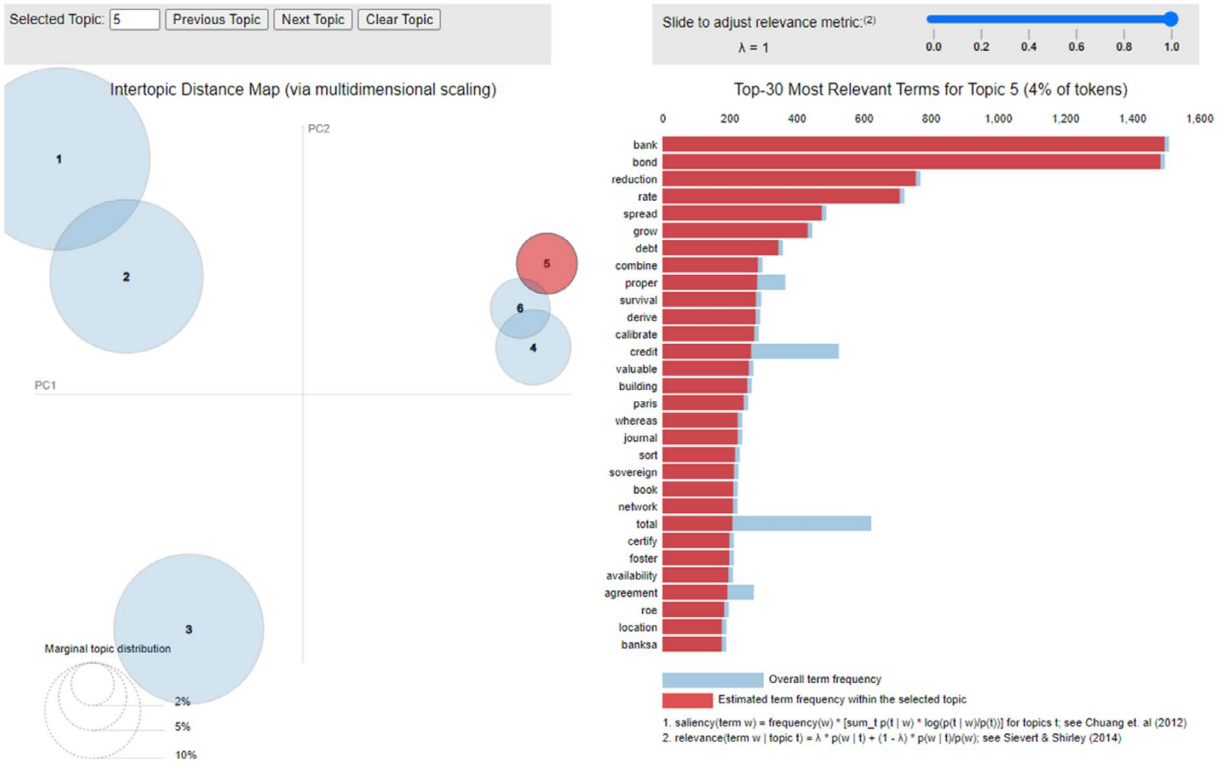

FIGURE A5 | Topic 5 LDA based output.

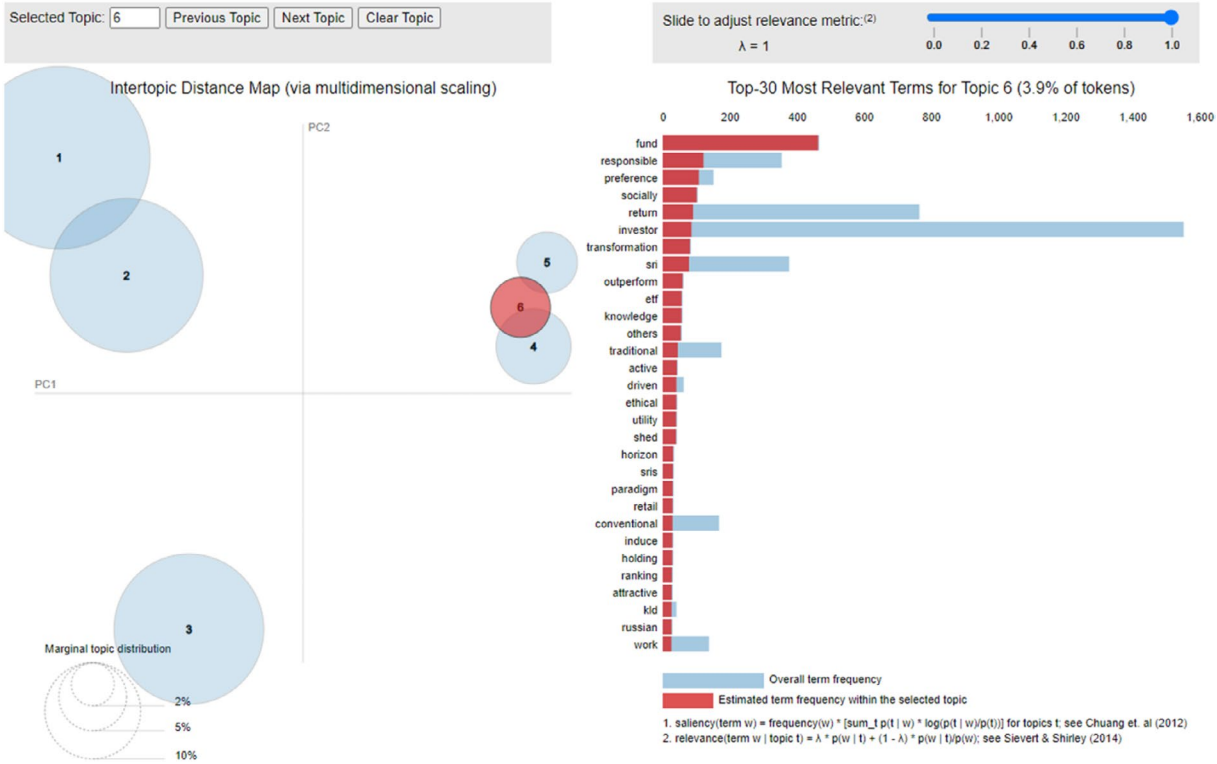

FIGURE A6 | Topic 6 LDA based output.