

Article

From Dual Pathways to Emerging Triadic Convergence: A Bibliometric Analysis of Sustainable Finance, Digital Transformation, and Circular Economy—2015–2025

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Abstract

Sustainable finance has evolved rapidly in tandem with digital transformation and the circular economy; however, the simultaneous integration of these three domains remains fragmented. This study analyzes the intellectual structure of the field through a bibliometric analysis of a curated corpus of 2537 articles indexed in Scopus between 2015 and 2025, of which 2471 were classified into three thematic trajectories: sustainable finance combined with digital transformation (D1), sustainable finance combined with the circular economy (D2), and triadic convergence (D3). The classification followed a deductive, rule-based procedure, with documents independently coded by the two authors and discrepancies resolved by consensus. VOSviewer was used to construct networks of keyword co-occurrence, co-citation, and bibliographic coupling, identifying four thematic clusters. A complementary keyword-overlap projection was then used to articulate the deductive classification with the inductive clusters. The results reveal a rapidly expanding field, geographically concentrated in China, in which the dyadic trajectories anchor predominantly in a single conceptual cluster, while triadic convergence (D3), which appears only in 2021 and accounts for 2.7% of the classified corpus, is the only trajectory whose documents distribute across three clusters simultaneously. This pattern provides empirical support for interpreting triadic convergence as an emerging frontier rather than a consolidated stream. The findings are interpreted under the lens of *economicità*, an Italian accounting concept that frames sustainability as a condition for the firm's long-term economic equilibrium.

Keywords: sustainable finance; ESG; digital transformation; fintech; circular economy; green finance; bibliometric analysis; triadic convergence



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1. Introduction

Sustainable finance has established itself as one of the most dynamic fields in contemporary financial research, driven by the growing incorporation of Environmental, Social, and Governance (ESG) criteria into (i) investment decisions ([Nurhayati et al., 2025](#)), (ii) financing ([Rahmiyati et al., 2025](#)), (iii) corporate disclosure ([Amarna et al., 2024](#)), and (iv) financial regulation ([Habib et al., 2025](#)); this expansion has strengthened the academic and practical legitimacy of the field ([Shalhoob, 2025](#); [Tian et al., 2025](#)). However, it has also brought to light significant conceptual and methodological tensions ([Ali et al., 2025](#)). The evidence on the effects of ESG practices and sustainable finance instruments on financial performance, the cost of capital, and value creation remains mixed and depends

on the institutional, sectoral, and methodological context (Serafeim, 2015; Bassen et al., 2006; De Lucia et al., 2020; Bătae et al., 2021). Furthermore, the proliferation of green instruments, sustainability reports, and disclosure frameworks has intensified debates regarding comparability, materiality, impact measurement, and the risk of greenwashing (Hammoudeh et al., 2020; Macchiavello & Siri, 2022; Saraswati et al., 2025).

This discussion has been shaped by two structural transformations. The first is the digitization of the financial system, driven by fintech, artificial intelligence, blockchain, and advanced analytics—technologies that promise to reduce information asymmetries, improve traceability, and expand ESG assessment capabilities (Huynh et al., 2020; Huang et al., 2023; N. Kumar et al., 2021; S. Kumar et al., 2025). The second is the circular economy, presented as a way to reorient value creation toward long-term horizons through resource reuse, remanufacturing, and material efficiency (Hens et al., 2018; Karaman et al., 2020; Madaleno et al., 2022; Russell & Nasr, 2023). However, the literature often assumes that both transformations integrate naturally with sustainable finance, when in reality their empirical and conceptual articulation remains uneven.

The available evidence suggests that the relationship between sustainable finance and digital transformation has developed to a greater extent than the relationship between sustainable finance and the circular economy (Safi et al., 2024; Shan et al., 2023; Osei et al., 2025). Various studies have examined the role of digitalization in ESG assessment, the development of green financial instruments, climate risk management, and the efficiency of sustainable markets (De Lucia et al., 2020; Huang et al., 2023; Taghizadeh-Hesary & Yoshino, 2019). Likewise, the literature has shown that technologies such as blockchain, artificial intelligence, and digital platforms can improve the traceability of value chains, the verification of environmental information, and the transparency of corporate reporting (Asif et al., 2023; De Giovanni, 2023; Saidu et al., 2025). However, these advances focus primarily on partial convergences. The simultaneous integration of sustainable finance, digital transformation, and the circular economy remains less developed and has not yet been fully systematized.

This situation challenges bibliometric research and the conceptual delineation of the field. Although sustainable finance, digitalization, and circularity are often framed as convergent, the literature follows distinct trajectories: one linking sustainable finance and digital transformation, another addressing sustainable finance and the circular economy, and a smaller subset integrating all three domains. Thus, distinguishing dual articulation from genuine triadic convergence is essential to avoid methodological confusion between corpus construction criteria and empirical evidence of convergence.

To the best of our knowledge, there is still no systematic bibliometric mapping that clearly distinguishes these trajectories within the field. Existing reviews have generally focused on green finance and ESG (Muganyi et al., 2021; G. Zhou et al., 2022; Raman et al., 2025), on digitalization and machine learning applied to financial contexts (Huynh et al., 2020; S. Kumar et al., 2025), or on the circular economy and corporate sustainability (Hens et al., 2018; Karaman et al., 2020). In contrast, a structural characterization of the space where these trends intersect is still lacking. This gap is particularly relevant in the context of the Special Issue “The Future of Sustainable Finance: Digital and Circular Synergies of the Journal of Risk and Financial Management”, whose editorial focus presupposes a convergence whose true extent still requires empirical verification.

In this study, sustainable finance serves as the central theme of the analysis, while digital transformation and the circular economy are viewed as two complementary analytical trajectories. Consequently, the corpus is not defined as an exclusive set of triadic convergence documents, but rather as a broad space of dual convergence in which each document must link sustainable finance with at least one of the two trajectories: digital or circular.

Within this corpus, we then examine the subset of works that simultaneously integrate all three domains. This strategy allows us to assess whether triadic convergence constitutes a consolidated stream or, conversely, an emerging frontier within a still-fragmented field.

From a theoretical standpoint, this research draws on the concept of *economicità* developed within the Italian tradition of *economia aziendale* (Onida, 1971), which conceives of sustainability not as an external constraint on profitability, but as a condition for the firm's long-term economic equilibrium. This perspective is relevant to the present study because it allows for the articulation of the three domains analyzed without reducing them to equivalent dimensions. Sustainable finance provides the logic of capital allocation; digital transformation expands capabilities for measuring, verifying, and processing information; and the circular economy extends value creation toward less linear and more resource-efficient production models. Taken together, these elements allow us to interpret the triadic convergence not as a given premise, but as a possible emerging configuration of financial sustainability, technological innovation, and long-term value creation.

The theoretical expectation of a synergistic relationship among the three domains rests on three complementary mechanisms. First, digital transformation lowers the information and verification costs that have historically constrained sustainable finance, enabling more granular monitoring of environmental performance and reducing the information asymmetries associated with greenwashing. Second, the circular economy reconfigures the real-side activities that sustainable finance ultimately funds, creating financeable assets and projects whose viability depends on resource efficiency rather than linear throughput. Third, the digital and circular trajectories are themselves mutually reinforcing, since technologies for traceability and data integration are frequently a precondition for credible circular business models. From the standpoint of economic equilibrium, the simultaneous articulation of these mechanisms is what would distinguish a genuine triadic configuration from the mere coexistence of separate agendas. Yet the empirical literature has largely examined these relationships in pairs—sustainable finance with digital transformation, or sustainable finance with the circular economy—while studies addressing the three domains jointly remain scarce, which is precisely the gap this study seeks to characterize.

In this context, this study analyzes the intellectual structure of the literature on sustainable finance between 2015 and 2025, identifying its relationship with two complementary analytical trajectories, digital transformation and the circular economy, and assessing, within that framework, the extent to which the two converge simultaneously. To this end, a bibliometric analysis is conducted based on a refined corpus of 2537 articles indexed in Scopus. Of this set, 2471 documents were classified into trajectories D1, D2, and D3. The analysis examines patterns of scientific production, geographic distribution, primary sources, keyword co-occurrence, co-citation, bibliographic coupling, and thematic classification by trajectory.

The study makes a threefold contribution. First, it provides an updated characterization of the intellectual structure of the field. Second, it empirically distinguishes between dual pathways and triadic convergence. Third, it identifies research gaps and proposes a future agenda to advance the study of the integration of sustainable finance, digital transformation, and the circular economy.

The remainder of the article is organized as follows. Section 2 presents the methodology, including the information source, search strategy, selection criteria, thematic classification procedure, and bibliometric techniques used. Section 3 presents the results of the analysis. Section 4 discusses the findings in light of the existing literature and their academic, practical, and regulatory implications. Finally, Section 5 presents the conclusions, limitations, and future research directions.

2. Methodology

2.1. Methodological Design and Data Sources

This study employs a quantitative, descriptive, and exploratory bibliometric design aimed at analyzing the intellectual structure of the literature on sustainable finance in relation to two complementary analytical trajectories: digital transformation and the circular economy. Bibliometric analysis allows for the examination of the evolution, productivity, impact, and conceptual organization of a scientific field based on bibliographic metadata, citation relationships, co-authorship, keyword co-occurrence, co-citation, and bibliographic coupling (Aria & Cuccurullo, 2017; Donthu et al., 2021; Zupic & Čater, 2015).

The information source used was Scopus, selected for its extensive coverage of peer-reviewed journals in fields directly related to the subject of study, such as business, accounting, economics, finance, environmental sciences, energy, social sciences, computer science, and decision sciences. The use of a single database enhances the traceability of the study and reduces problems arising from metadata heterogeneity and duplication across different databases (Falagas et al., 2008; Singh et al., 2021).

The period analyzed covers the years 2015–2025. This time frame was selected because 2015 marks an institutional turning point for research on sustainability, climate finance, and the circular economy, particularly following the Paris Agreement and the strengthening of regulatory and business agendas related to the sustainable transition. Furthermore, this period allows us to capture the recent expansion of technologies such as fintech, artificial intelligence, blockchain, big data, and advanced analytics in the financial and sustainability sectors.

2.2. Search Strategy and Selection Criteria

The search strategy was designed based on a dual-convergence approach. Under this approach, sustainable finance serves as the mandatory thematic focus of the corpus, while each document was required to link this focus to at least one of two complementary themes: digital transformation or the circular economy. In general terms, the Boolean logic adopted was as follows:

Sustainable Finance and (Digital Transformation or Circular Economy)

This formulation does not assume that all documents in the corpus simultaneously encompass all three domains; rather, it defines a broad analytical framework within which sustainable finance can be linked to the digital trajectory, the circular trajectory, or both. Triadic convergence is subsequently examined as a specific subset of the corpus.

The search was conducted in Scopus on 20 February 2026, using institutional access. The metadata was exported, including information on title, abstract, keywords, authors, affiliations, source, citations, and references. The search was performed using the title, abstract, and keywords fields. To this end, three sets of thematic terms were identified, which are presented in Table 1.

Based on these three categories, the comprehensive search equation used in Scopus was organized in a structured manner, as shown in Table 2.

In addition, inclusion and exclusion criteria were established to ensure the formal and thematic consistency of the corpus. These criteria are presented in Table 3.

Table 1. Thematic categories and terms used in the search.

Categories	Subject Area	Search Terms
1	Sustainable finance	“sustainable finance”, “green finance”, “ESG”, “environmental social governance”, “green accounting”, “climate finance”, “climate risk”, “responsible investment”, “sustainability reporting”, “green bond*”, “sustainability-linked”
2	Digital Transformation	“digital transformation”, “digitalization”, “fintech”, “financial technology”, “blockchain”, “artificial intelligence”, “machine learning”, “big data”, “data analytics”, “distributed ledger”, “predictive analytics”, “algorithm*”, “cloud computing”, “internet of things”, “IoT”, “smart contracts”
3	Circular economy	“circular economy”, “circular finance”, “circular business model*”, “closed-loop”, “resource efficiency”, “sustainable value chain*”, “sustainable production”, “eco-innovation”, “sustainable supply chain finance”, “green supply chain”

Note. The asterisk (*) is the Scopus truncation operator: it retrieves all word forms derived from the indicated root. For example, “green bond*” retrieves “green bond” and “green bonds”; “algorithm*” retrieves “algorithm”, “algorithms”, and “algorithmic”.

Table 2. Structure of the search equation applied in Scopus.

Component	Contents
Search field	TITLE-ABS-KEY
Section A: Sustainable Finance	(“sustainable finance” OR “green finance” OR “ESG” OR “environmental social governance” OR “green accounting” OR “climate finance” OR “climate risk” OR “responsible investment” OR “sustainability reporting” OR “green bond*” OR “sustainability-linked”)
Primary logical operator	AND
Block B: Complementary Pathways	((“digital transformation” OR “digitalization” OR “fintech” OR “financial technology” OR “blockchain” OR “artificial intelligence” OR “machine learning” OR “big data” OR “data analytics” OR “distributed ledger” OR “predictive analytics” OR “algorithm*” OR “cloud computing” OR “internet of things” OR “IoT” OR “smart contracts”) OR (“circular economy” OR “circular finance” OR “circular business model*” OR “closed-loop” OR “resource efficiency” OR “sustainable value chain*” OR “sustainable production” OR “eco-innovation” OR “sustainable supply chain finance” OR “green supply chain”))
Time restriction	PUBYEAR > 2014 AND PUBYEAR < 2026
Summary equation	TITLE-ABS-KEY[(Sustainable Finance terms) AND ((Digital Transformation terms) OR (Circular Economy terms))] AND PUBYEAR > 2014 AND PUBYEAR < 2026

Note. The asterisk (*) is the Scopus truncation operator, which retrieves all word forms derived from the indicated root.

Table 3. Inclusion and exclusion criteria.

Criterion	Inclusion	Exclusion
Database	Documents indexed in Scopus	Documents not indexed in Scopus
Document type	Peer-reviewed journal articles	Editorials, notes, letters, corrections, books, book chapters, and conference proceedings
Period	Publications between 2015 and 2025	Publications outside the specified period
Language	English	Languages other than English
Subject areas	Business, Management and Accounting; Economics, Econometrics and Finance; Environmental Science; Computer Science; Social Sciences; Energy; Decision Sciences	Areas unrelated to the subject of study
Thematic relevance	Studies related to finance, banking, accounting, financial markets, sustainability, ESG, regulation, or corporate disclosure	Documents that are purely technical or engineering in nature, with no financial, regulatory, accounting, or sustainability aspects

2.3. Corpus Cleaning Process and PRISMA Flowchart

The corpus selection process followed a methodology informed by PRISMA, adapted to the context of bibliometric research. In this study, PRISMA was used as a transparency framework to document the stages of identification, screening, eligibility assessment, and inclusion of the bibliographic corpus, rather than as a clinical protocol for a systematic review in the strict sense (Page et al., 2021).

The initial search in Scopus yielded 2837 articles after applying the document type filter. Subsequently, the language filter reduced the set to 2768 records. Next, applying the filter for selected subject areas reduced the corpus to 2539 documents. Finally, a process to remove duplicates was carried out using the DOI as the primary criterion and, additionally, matching the normalized title, first author, and year of publication, resulting in a cleaned corpus of 2537 articles, as shown in Figure 1.

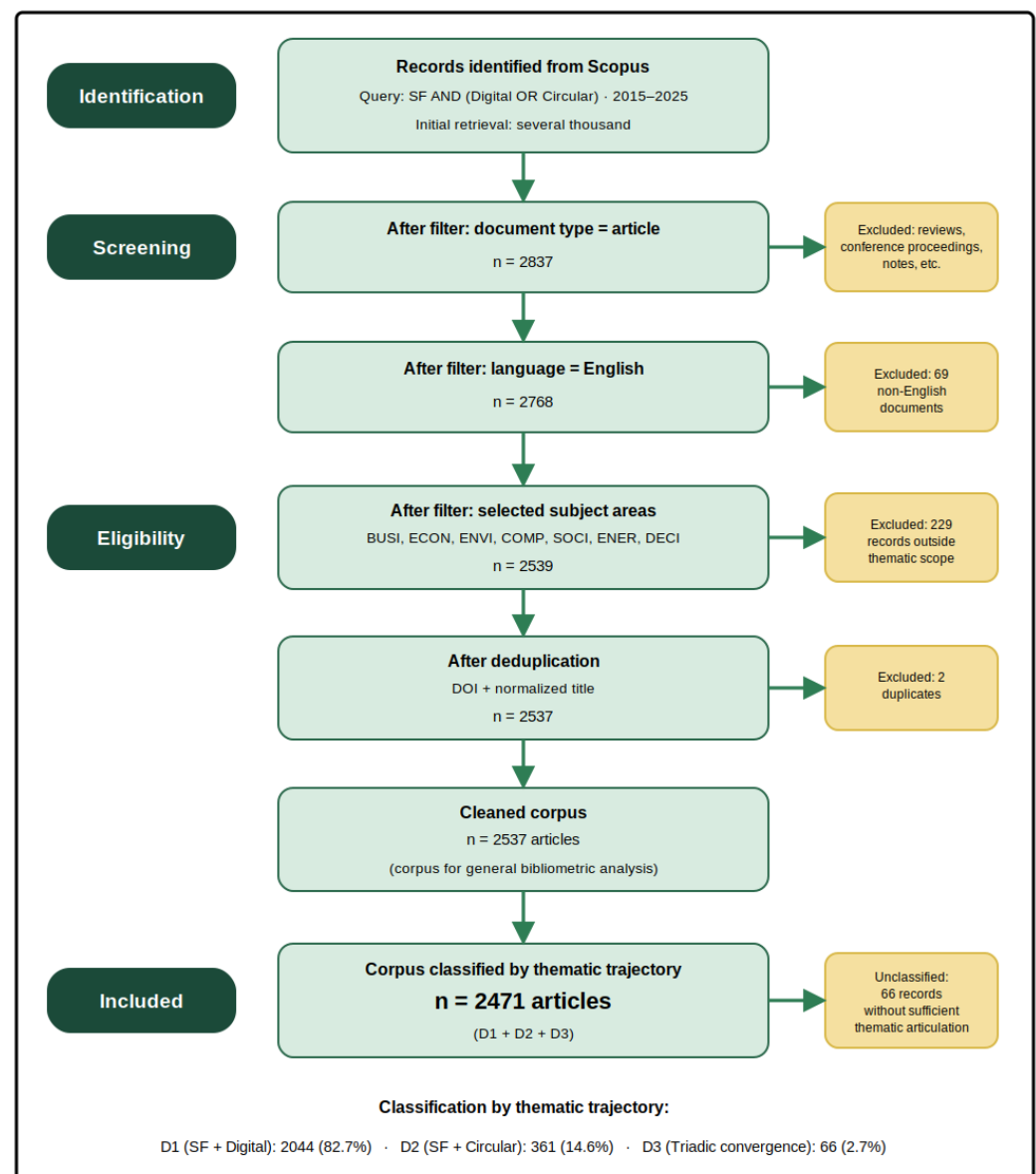


Figure 1. PRISMA-reported flowchart for the selection of the bibliometric corpus.

Consequently, the final corpus consisted of 2537 articles, which form the empirical basis for the bibliometric analysis and the classification by thematic pathways.

2.4. Bibliometric Techniques and Analytical Tools

The analysis combined scientific performance indicators with bibliometric mapping techniques. First, the study examined annual scientific output, citations received, the most productive sources, geographic distribution, author productivity, and international collaboration. Second, science mapping techniques were applied to identify conceptual and intellectual relationships within the corpus, including keyword co-occurrence, co-citation, and bibliographic coupling. These techniques allow for characterizing the evolution of a scientific field, its main thematic clusters, its intellectual foundations, and its active research fronts (Aria & Cuccurullo, 2017; Donthu et al., 2021; Zupic & Čater, 2015).

Figure 2 summarizes the analytical workflow applied to the corpus, showing the sequence of techniques used and their main outputs, from the descriptive characterization of the field to the theoretical interpretation under economicità.

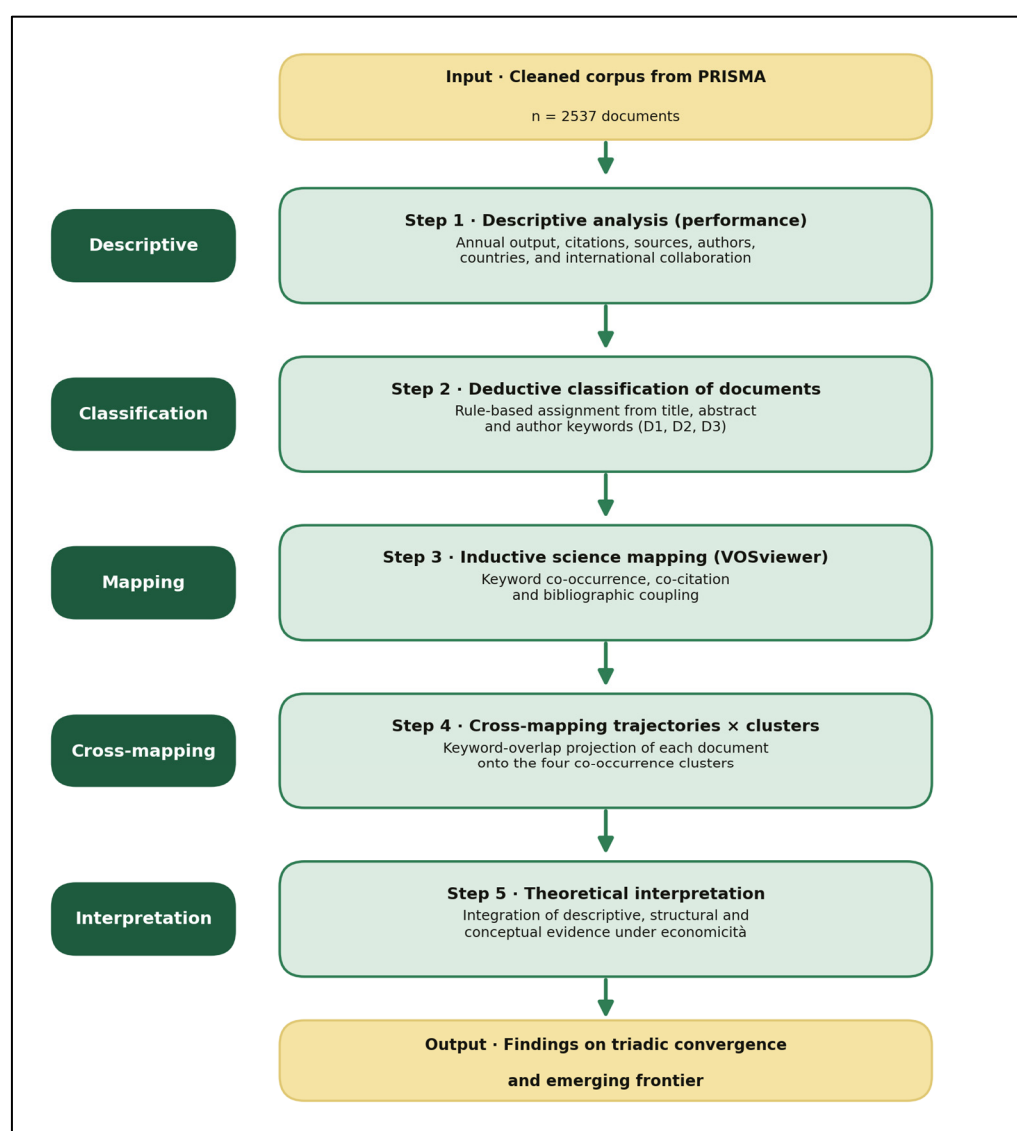


Figure 2. Analytical workflow applied to the bibliometric corpus, from descriptive analysis to theoretical interpretation.

VOSviewer was used to construct and visualize bibliometric networks due to its ability to represent networks of co-occurrence, co-citation, co-authorship, and bibliographic coupling through network maps and clustering (Van Eck & Waltman, 2010; Waltman et al.,

2010). This tool has been widely used in bibliometric studies due to its utility for the visual and structural analysis of scientific fields.

In addition, to articulate the document-level classification (Section 2.5) with the keyword-based clusters obtained from the co-occurrence network, each document was subsequently projected onto the four clusters by computing the overlap between its author and indexed keywords and the representative keywords of each cluster. Each document was assigned to the cluster with the largest keyword overlap; documents whose keywords did not overlap with any cluster were reported as having no predominant cluster. This projection is not part of the VOSviewer clustering itself, which groups keywords rather than documents, but rather a supplementary representation that allows for an empirical examination of the relationship between the three trajectories and the four clusters in Section 4.3.

2.5. Analysis of Thematic Pathways

In order to determine whether the field is primarily organized along dual pathways or whether triadic convergence constitutes a more integrated trend, the final corpus was classified into three thematic pathways. This classification was based on bibliographic metadata such as the title, abstract, and author-provided keywords, and followed the same conceptual logic used in the search strategy.

The purpose of this procedure was not to conduct a full-text systematic review of the 2537 documents, but rather to identify the thematic structure of the corpus based on the relationships among the three domains analyzed. Of these, 2471 provided sufficient evidence in their titles, abstracts, and keywords to be assigned to D1, D2, or D3, in order to avoid classifications based solely on superficial terminological matches. Table 4 presents the categories used to classify the thematic pathways of the corpus.

Table 4. Classification of thematic pathways.

Category	Thematic Overview	Operational Definition
D1	Sustainable finance and digital transformation	Documents addressing sustainable finance, green finance, ESG, climate finance, sustainability reports, or related topics such as digital transformation, fintech, artificial intelligence, blockchain, machine learning, big data, data analytics, smart contracts, or other digital technologies
D2	Sustainable finance and the circular economy	Documents addressing sustainable finance, green finance, ESG, climate finance, sustainability reports, or related topics such as the circular economy, circular business models, resource efficiency, closed-loop systems, eco-innovation, sustainable value chains, or green supply chains
D3	Triadic convergence	Documents that simultaneously address sustainable finance, digital transformation, and the circular economy within the same bibliographic record

A document was classified as D1 when the theme of sustainable finance was linked to terms related to digital transformation, without any substantial mention of the circular economy. It was classified as D2 when the theme of sustainable finance was linked to the circular economy, without any substantial mention of digital transformation. Finally, it was classified as D3 when the bibliographic record showed the simultaneous articulation of sustainable finance, digital transformation, and the circular economy.

The classification followed a deductive, rule-based procedure rather than an inductive or data-driven clustering technique. The three thematic pathways were defined a priori, derived directly from the same conceptual logic and Boolean structure of the search strategy

described in Section 2.2: sustainable finance as the mandatory core, articulated with the digital trajectory, the circular trajectory, or both. Consequently, the categories D1, D2, and D3 were not generated by the data but established beforehand, and each record was assigned to the category whose operational definition (Table 4) it satisfied.

Each bibliographic record was examined on the basis of its title, abstract, and author keywords. A record was assigned to D1 or D2 when its metadata showed an explicit and substantive link between sustainable finance and the digital or the circular trajectory, respectively, and to D3 only when the simultaneous articulation of all three domains was explicit within the same record. To minimize classifications based on superficial terminological matches, the mere co-occurrence of a keyword was not treated as sufficient evidence of thematic articulation; the link had to be substantively expressed in the title or abstract.

The coding was carried out independently by the two authors, and the resulting assignments were then compared. Records with divergent or uncertain classifications were jointly re-examined and resolved by consensus against the operational definitions in Table 4. Records that satisfied the sustainable-finance search criterion but did not exhibit an explicit articulation with either the digital or the circular trajectory in their metadata (66 records) were retained in the screening registry for traceability but excluded from the comparative analysis of trajectories, since their assignment could not be established with sufficient confidence. This conservative criterion was adopted precisely because the central finding of the study, the magnitude of triadic convergence (D3), depends directly on the reliability of the classification.

To ensure the traceability and reproducibility of the analysis, the search equation, the filtering log, the cleaned bibliometric matrix with the thematic dimension assigned to each record, and the network files generated in VOSviewer 1.6.20 were retained by the authors and are available from the corresponding author on reasonable request.

3. Results

Following the literature screening described in Section 2, the final corpus consisted of 2537 articles. Of these, 2471 provided sufficient evidence in their titles, abstracts, and keywords to be assigned to one of the three thematic pathways of the study: D1, D2, or D3. The remaining 79 records were retained in the screening registry but were not included in the comparative analysis of trajectories because they did not provide a sufficiently explicit thematic articulation in the available metadata.

This section presents the results of the bibliometric analysis applied to the classified corpus of 2471 articles. Section 3.1 examines the temporal evolution of scientific output and the pattern of citation impact. Section 3.2 characterizes the geographical distribution and patterns of international collaboration. Section 3.3 analyzes the main journals and sources in the field. Section 3.4 examines author productivity and the social structure of the field. Section 3.5 presents the conceptual and intellectual structure of the field based on the co-occurrence of keywords and the analysis of cited references. Section 3.6 outlines the quantitative differentiation between trajectories D1, D2, and D3, empirically identifying triadic convergence as a specific subset of the field, and closes with a synthesis of the five main findings of the bibliometric analysis.

3.1. Annual Research Output and Citation Impact

The classified corpus of 2471 articles shows markedly exponential growth during the 2015–2025 period, with a Compound Annual Growth Rate (CAGR) of 91.6%. Figure 3 illustrates this trend: while between 2015 and 2017 the field produced only 2 to 5 articles per year, starting in 2020 output accelerates steadily, reaching 577 articles in 2024 and 1333 in

2025. This trajectory coincides with the consolidation of the Paris Agreement, the European Union’s Circular Economy Action Plan, and the expansion of digital technologies applied to finance and sustainability.

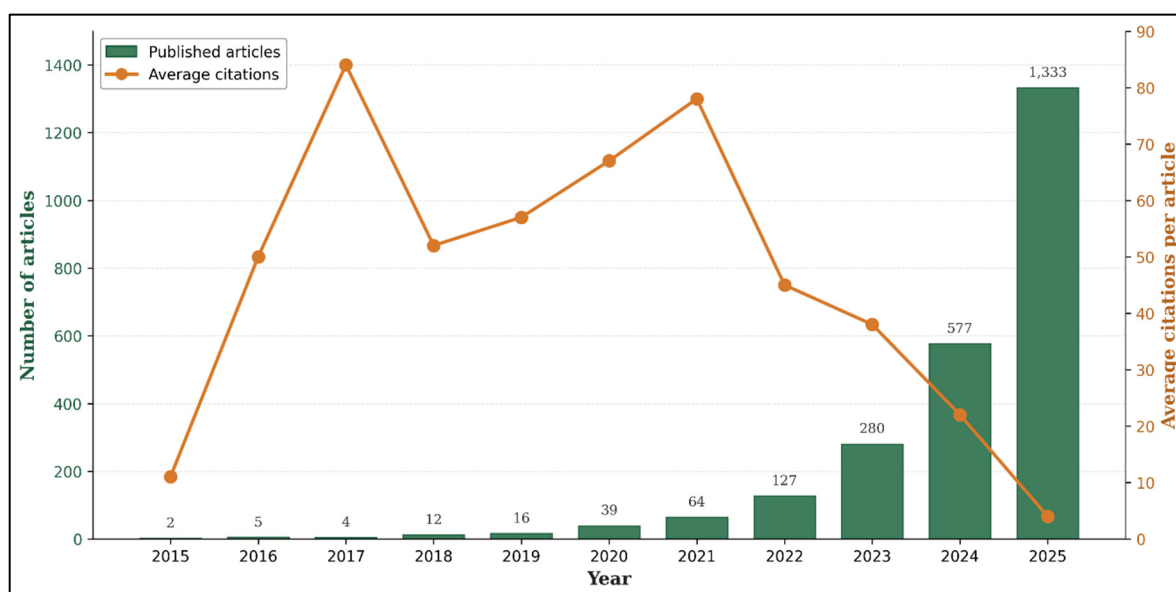


Figure 3. Annual research output and citation impact (2015–2025). Note. The bars represent the number of articles published per year; the line represents the average number of citations per article.

The trend in average citations follows the expected inverse pattern: articles published between 2017 and 2021 have high averages, 83.5 citations in 2017 and 78.1 in 2021, while more recent documents show declining averages (4.9 in 2025) due to the limited observation window. The corpus accumulates a total of 45,231 citations, with an overall average of 18.39 citations per document and a median of 6, reflecting an asymmetric distribution typical of expanding scientific fields (Donthu et al., 2021). Table 5 summarizes the main descriptive statistics of the corpus.

Table 5. Descriptive statistics of the bibliometric corpus.

Indicator	Value
Total number of classified items	2471
Period covered	2015–2025
Annual Compound Growth Rate (CAGR)	91.6%
Total accumulated citations	45,231
Average number of citations per article	18.39
Median number of citations per article	6
Number of unique journals	789
Number of unique authors	5618
Average number of authors per article	3.35
Authors with a single article (Lotka)	82.2%
Number of countries represented	130
International collaboration rate	34.4%

3.2. Geographic Distribution and International Collaboration

The corpus includes contributions from 130 countries, reflecting a globally diverse participation. Productivity is notably concentrated in China, which accounts for 1064 articles (43.3% of the corpus), followed at a distance by the United States (186), the United Kingdom

(186), India (158), Italy (144), and Malaysia (126). Figure 4 shows the fifteen top-contributing countries along with their average impact.

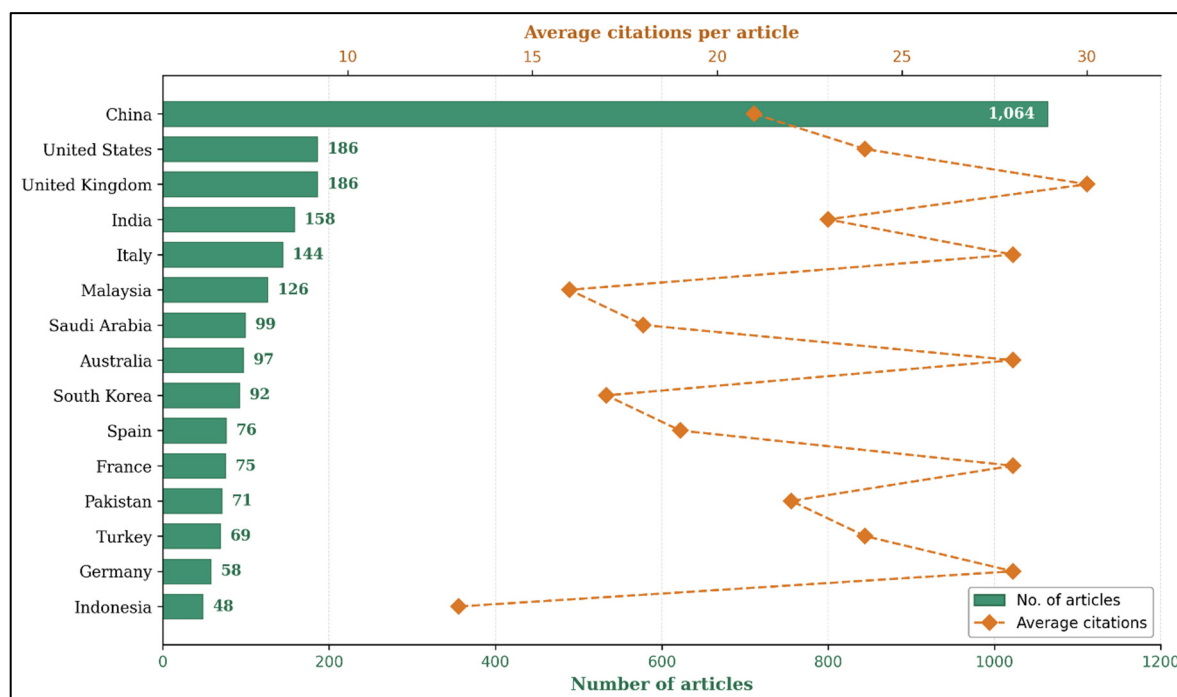


Figure 4. The fifteen countries with the highest number of contributions and their average impact. Note. Average citations per article.

The rate of international collaboration accounts for 34.4% of the corpus. The countries with the highest relative impact per paper are the United Kingdom (30.1 citations on average), France (29.9), Germany (27.8), Australia (27.3), and Italy (27.0). In terms of volume, China is the clear leader; in terms of relative impact per article, European economies hold a central position. Table 6 lists the fifteen most productive countries.

Table 6. The fifteen countries that contributed the most to the corpus.

Country	Number of Papers	Total Citations	Average Citations
China	1,064	20,809	19.56
United States	186	4,346	23.37
United Kingdom	186	5,595	30.08
India	158	3,781	23.93
Italy	144	3,884	26.97
Malaysia	126	1,973	15.66
Saudi Arabia	99	1,707	17.24
Australia	97	2,645	27.27
South Korea	92	1,550	16.85
Spain	76	1,442	18.97
France	75	2,239	29.85
Pakistan	71	1,547	21.79
Turkey	69	1,727	25.03
Germany	58	1,611	27.78
Indonesia	48	449	9.35

Note. Total number of classified items = 2471.

3.3. Journals and Primary Sources

The corpus is distributed across 789 unique journals, indicating a wide range of publishers. However, a small core of journals accounts for a significant proportion of the output, consistent with the concentration pattern described by Bradford's law (Bradford, 1934). Sustainability (Switzerland) leads by a wide margin with 238 articles (9.7% of the corpus), followed by Finance Research Letters (99), Resources Policy (70), Journal of Environmental Management (53), and Journal of Cleaner Production (48). Three of the five most productive journals are related to sustainability and environmental management, while two belong to the financial field. Figure 5 shows the fifteen most productive journals, and Table 7 presents their detailed indicators.

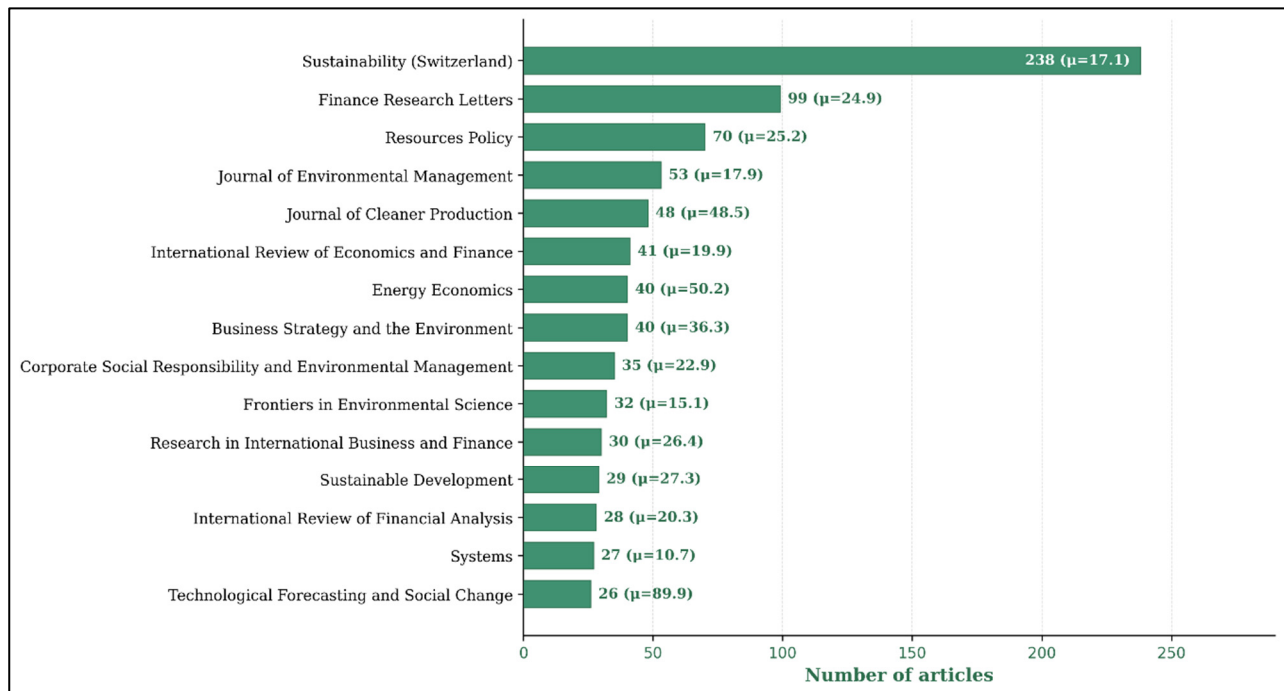


Figure 5. The fifteen most productive journals in the corpus. Note: μ = average citations per article.

Table 7. The fifteen most productive journals in the corpus.

Journal	Number of Papers	Total Citations	Average Citations
Sustainability (Switzerland)	238	4.061	17.06
Finance Research Letters	99	2.463	24.88
Resources Policy	70	1.766	25.23
Journal of Environmental Management	53	946	17.85
Journal of Cleaner Production	48	2.328	48.50
International Review of Economics and Finance	41	817	19.93
Energy Economics	40	2.007	50.18
Business Strategy and the Environment	40	1.453	36.33
Corporate Social Responsibility and Environmental Management	35	800	22.86
Frontiers in Environmental Science	32	484	15.12
Research in International Business and Finance	30	792	26.40
Sustainable Development	29	792	27.31
International Review of Financial Analysis	28	568	20.29
Systems	27	288	10.67
Technological Forecasting and Social Change	26	2.337	89.88

It is worth noting that the journals with the highest average impact within the top 15 are not necessarily the most productive: Technological Forecasting and Social Change publishes just 26 articles but averages 89.9 citations, while Energy Economics publishes 40 articles with an average of 50.2 citations. This asymmetry between productivity and impact suggests that journals with a more technology-economics focus capture the seminal works in the field, while sustainability journals publish a higher volume but with a more evenly distributed impact.

3.4. Author Productivity and Social Structure

The corpus includes 5618 unique authors with 8239 instances of authorship, resulting in an average of 3.35 authors per document. The distribution of productivity closely follows Lotka's law (Lotka, 1926): 82.2% of the authors have contributed a single article to the corpus, while only a small number have published three or more. The most productive authors are Zhang (44 articles), Wang (42), Li (39), Liu (36), and Li (36). Notable for their average impact are Wang S. (39.3 citations per paper), Sun (29.9), Zhang (30.5), Zhang (27.0), and Li (26.1). The social structure of the field reveals a pronounced concentration within the Chinese academic community.

3.5. Conceptual and Intellectual Structure of the Field

The co-occurrence analysis of author keywords identified 5942 unique terms in the corpus. The most frequent keywords are ESG (405 occurrences), green finance (278), digital transformation (268), machine learning (218), sustainability (203), fintech (202), ESG performance (199), artificial intelligence (174), circular economy (131), and sustainable development (130). This distribution shows that the field is simultaneously structured around financial (ESG, green finance, fintech), technological (digital transformation, machine learning, artificial intelligence), and sustainability (sustainability, circular economy, sustainable development) axes.

The keyword co-occurrence network identified four distinct thematic clusters, presented visually in Figure 6 and summarized in Table 8. Cluster 1 (red) highlights the convergence between corporate ESG and digital transformation, integrating ESG performance, green innovation, corporate governance, financing constraints, corporate sustainability, internal control, and green technology innovation. Cluster 2 (blue) groups together green finance, fintech, sustainable finance, blockchain, China, green bonds, environmental sustainability, renewable energy, sustainable development goals, and innovation; it is the largest cluster in terms of the number of keywords (23) and represents the financial-technological core of the field. Cluster 3 (green) is the smallest, grouping the terms "environmental" and "social" and explicitly articulating the environmental and social components of the ESG framework. Despite its relatively small size, this cluster plays a significant structural role in the network by acting as a conceptual bridge between the corporate, financial, and methodological fronts represented by the other clusters. Cluster 4 (orange) groups machine learning, sustainability, artificial intelligence, circular economy, digitalization, climate change, sustainability reporting, and climate risk, forming the methodological-applied front where computational techniques are applied to climate risk analysis and circular models.

An examination of the intellectual structure of the field, based on an analysis of the references cited in the corpus documents, reveals a broad bibliographic network: the references cited in the 2471 articles in the corpus include more than 60,000 cited authors and more than 7000 unique cited sources. It is important to distinguish this figure from the 5618 authors in the corpus reported in Section 3.4: those are the authors who wrote the analyzed articles, while these are the external authors to whom those articles refer. The most cited authors within the corpus belong primarily to the Chinese academic community, with

surnames such as Wang, Li, Zhang, Liu, and Chen among the most common. This result should be interpreted with caution due to the usual limitations of name disambiguation in bibliometric studies.

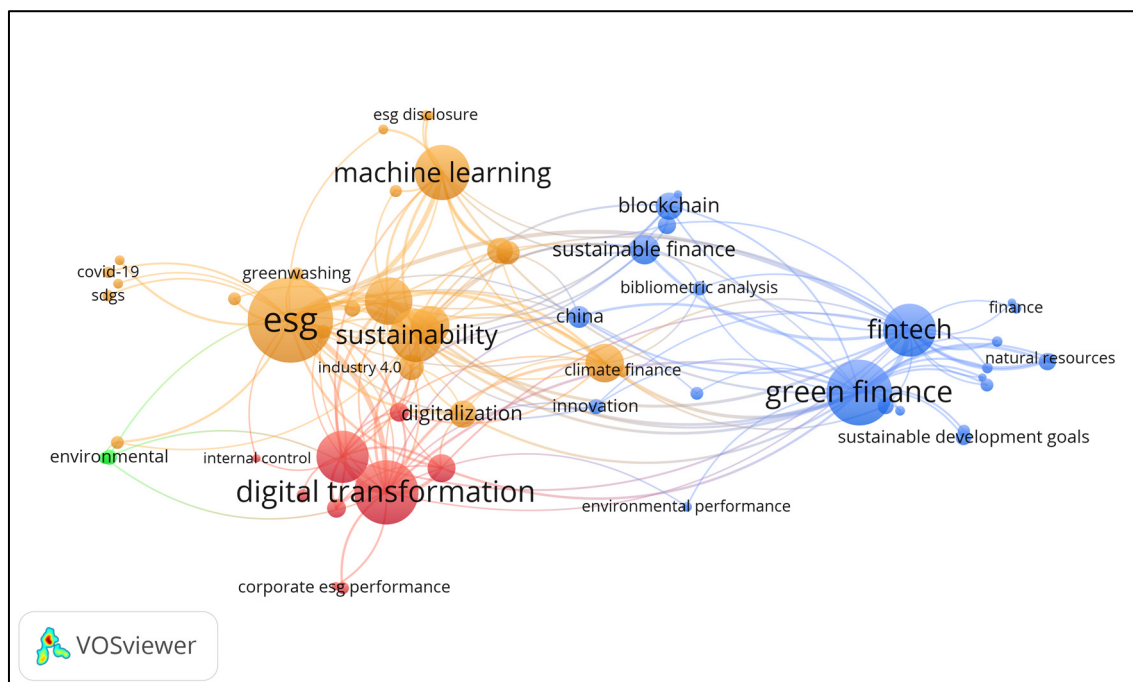


Figure 6. Co-occurrence network of keywords and thematic clusters identified in the corpus. Note. $n = 59$ nodes, 166 edges, 4 clusters.

Table 8. Thematic clusters identified in the co-occurrence network.

Cluster	Thematic Focus	Representative Keywords	Interpretation
1 (red)	Corporate ESG and Digitalization	ESG performance, green innovation, corporate governance, financing constraints, corporate sustainability, internal control, green technology innovation	Corporate Empirical Front
2 (blue)	Green finance, fintech and blockchain	green finance, fintech, sustainable finance, blockchain, China, green bonds, environmental sustainability, renewable energy, sustainable development goals, innovation	Financial and Technology Hub
3 (green)	Environmental and social components of the ESG framework	environmental, social	A conceptual bridge between the other clusters
4 (orange)	AI, climate risk, and circularity	machine learning, sustainability, artificial intelligence, circular economy, digitalization, climate change, sustainability reporting, climate risk	Methodological-applied approach

Among the most frequently cited sources are the SSRN Electronic Journal and high-impact journals in finance and sustainability. The recurring presence of seminal works on ESG integration among the most cited references (Bassen et al., 2006; Serafeim, 2015) confirms the theoretical consolidation of the construct prior to the study period, while the

abundance of references to recent works (2021–2023) indicates that the field is in an active phase of conceptual development.

3.6. Thematic Pathways and Triadic Convergence

Classifying the corpus by thematic trajectory yielded the distribution summarized in Table 9. The dominant trajectory is D1 (SF + Digital), with 2044 documents (82.7% of the classified corpus), indicating that the vast majority of recent literature on sustainable finance incorporates at least one component linked to digital technologies, whether fintech, blockchain, artificial intelligence, or big data analytics. Trajectory D2 (SF + Circular) comprises 361 documents (14.6%), constituting a more limited but thematically compact trend. The triadic convergence D3, in which the study's three thematic domains appear simultaneously, forms a subcorpus of 66 documents (2.7%).

Table 9. Distribution of the corpus by thematic trajectory.

Category	Thematic Overview	n	%
D1	Sustainable finance + digital transformation	2044	82.7%
D2	Sustainable finance + circular economy	361	14.6%
D3	Triadic convergence (sustainable finance + digital + circular)	66	2.7%
	Total	2471	100%

Note. n = Total number of classified items.

Although D3 is numerically small, its temporal profile distinguishes it from the two dyadic trajectories and supports its interpretation as an emerging rather than an artefactual category. The first document exhibiting full triadic articulation appears only in 2021, whereas the digital (D1) and circular (D2) trajectories were already established several years earlier; 65 of the 66 D3 documents (98.5%) were published from 2022 onward. This delayed emergence indicates that triadic convergence is a recent phenomenon that postdates the consolidation of the underlying dyads, consistent with a field in which the simultaneous integration of the three domains is only beginning to take shape. At the same time, the share of D3 within annual output remains stable at around 2–3%, suggesting that, while genuinely emergent, triadic convergence has not yet entered a phase of accelerated expansion.

Synthesizing the descriptive, structural and conceptual evidence presented above, the bibliometric analysis yields five main findings. First, sustainable finance integrated with digital transformation and the circular economy is a rapidly expanding field, growing at a compound annual rate of approximately 91.6% between 2015 and 2025. Second, the field is geographically concentrated, with documents authored from Chinese institutions accounting for 43.3% of the classified corpus, although European countries display significant relative impact. Third, the editorial output is concentrated in a small group of journals, with around 30% of the documents published in the top outlets identified in Section 3.4. Fourth, the keyword co-occurrence network reveals four thematic clusters: corporate ESG and digitalization; green finance and fintech; the social and environmental dimension; and computational methods applied to sustainability and the circular economy. Fifth, the triadic convergence of sustainable finance, digital transformation and the circular economy currently constitutes only 2.7% of the classified corpus, indicating an emerging frontier rather than a consolidated stream. A detailed interpretation and discussion of these findings, along with a comparison to previous research, is provided in the following section.

A detailed interpretation and discussion of these findings, along with a comparison to previous research, is provided in the following section.

4. Discussion

This section interprets the bibliometric findings presented in Section 3 by placing them in dialogue with the existing literature. Five subsections structure the analysis: Section 4.1 interprets the accelerated growth of the field and its sustainable transition regime; Section 4.2 critically examines the observed geographic concentration; Section 4.3 analyzes the four identified thematic clusters; Section 4.4 problematizes the study's central finding—triadic convergence as an emerging frontier—and anchors within the theoretical framework of *economicità* (Onida, 1971); finally, Section 4.5 discusses the resulting academic, practical, and regulatory implications, with a specific focus on emerging markets.

4.1. Accelerated Growth of the Field and Sustainable Transition Regime

The annual compound growth rate of 91.6% documented for the 2015–2025 period is one of the study's most striking findings. This rate of expansion places the field among the fastest-growing areas of financial research of the decade and exceeds the growth pattern reported in previous bibliometric reviews on sustainable finance and related fields (S. Kumar et al., 2025), suggesting that the incorporation of digital and circular trajectories has substantially expanded the field's thematic scope. The magnitude of this growth suggests a regime shift in research, linked to three converging forces: regulatory consolidation around the Paris Agreement and climate disclosure frameworks: (i) Task Force on Climate-related Financial Disclosures (TCFD), (ii) International Sustainability Standards Board (ISSB), and (iii) Corporate Sustainability Reporting Directive (CSRD), the rapid institutional adoption of digital technologies in the financial system, and growing social and market pressure for circular business models.

This pattern is consistent with recent regulatory and academic trends that view sustainable finance, digitalization, and circularity as structurally interconnected domains (Macchiavello & Siri, 2022). However, the results also suggest a risk associated with the speed of growth: in fields undergoing rapid expansion, the abundance of publications may precede conceptual consolidation, resulting in methodological heterogeneity, fragmentation of constructs, and editorial dispersion. The asymmetric distribution of citations observed in the corpus, with an average of 18.39 citations per article versus a median of 6, precisely reflects this asymmetry: a small core of seminal works concentrates the impact, while most recent contributions accumulate limited visibility. This dynamic, characteristic of scientific fields in the conceptual construction phase, constitutes both an opportunity and a challenge for the theoretical consolidation of the field in the coming decade.

4.2. Geographic Concentration and Europe's Central Position

The finding that 43.3% of the corpus is concentrated in China is robust but requires a nuanced interpretation. The works of Muganyi et al. (2021), Yang et al. (2021), and X. Zhou et al. (2020) have documented the central role of Chinese research in developing the nexus between green finance, fintech, and quality economic growth. The most productive author profiles mostly correspond to authors associated with the Chinese academic community, including Zhang (44 articles), Wang (42), Li (39), Liu (36), and Li (36), although these results should be interpreted with caution due to the usual limitations of name disambiguation in bibliometric studies, especially for authors with common surnames represented by initials. However, this quantitative dominance coexists with a pattern of relative impact that favors European economies: the United Kingdom averages 30.1 citations per article, France 29.9, Germany 27.8, Italy 27.0, and Australia 27.3, compared to China's average of 19.6 citations.

This duality—high productivity in Asia and relatively high impact in Europe—qualifies the simplistic view of Chinese dominance and suggests a functional division within the field: European research consolidates conceptual and regulatory frameworks on ESG

integration in contexts of mature financial regulation (Bătae et al., 2021; De Lucia et al., 2020), while Chinese research provides the bulk of the empirical evidence on digitalization applied to ESG performance in emerging markets. However, this duality raises a relevant interpretive question: Does Chinese leadership represent a theoretical consolidation of the field or, rather, an empirical expansion driven by the availability of administrative data, the orientation of public policies toward green finance, and the volume of national academic output? The answer has direct implications for the transferability of the findings: if Chinese dominance reflects theoretical consolidation, its results are generalizable to other emerging markets with ESG regulation still under development; if it reflects contextually determined empirical expansion, its transferability requires careful consideration. This geographical complementarity represents, in any case, an opportunity for the development of international comparative agendas on synergies between digitalization and circularity in sustainable finance, capable of articulating Asian empirical contributions with European regulatory frameworks.

4.3. *The Four Thematic Clusters as a Structural Map of the Field*

Before discussing these clusters, it is important to distinguish them from the three thematic trajectories (D1, D2, and D3) introduced earlier, as the two structures answer different questions and are derived from different procedures. The trajectories result from a deductive, document-level classification that assigns each article to a mutually exclusive category according to which domains it articulates (Section 2.5); they describe how the corpus is partitioned by type of convergence. The clusters, by contrast, emerge inductively from the keyword co-occurrence network and group terms, not documents, according to how frequently they appear together; they describe how concepts are organized within the field. The two views are therefore complementary rather than competing: a single trajectory may span several clusters, and a single cluster may contain keywords drawn from documents belonging to different trajectories. Read jointly, the trajectories quantify the relative weight of each form of convergence, while the clusters reveal the conceptual structure through which that convergence is articulated.

The four thematic clusters identified in the keyword co-occurrence network form a coherent structural map of the field. Cluster 1 (Corporate ESG and Digitalization) reflects the dominant empirical focus of recent research—particularly from China—on the influence of digital transformation on corporate ESG performance. The works of Lu et al. (2024), Wang and Esperança (2023), and Ren et al. (2023) illustrate this front: they empirically document how digitalization improves transparency, traceability, and the quality of ESG disclosure in Chinese listed companies. This cluster likely represents the area with the greatest short-term output potential, but it also faces the highest risk of thematic saturation.

Cluster 2 (green finance, fintech, and blockchain) constitutes the financial-technological core of the field and brings together studies on sustainable financial instruments facilitated by digital technologies. Hammoudeh et al. (2020) examine the relationship between green bonds and financial and environmental variables using variable-order causality; Le et al. (2021) analyze the connectivity between fintech, green bonds, and cryptocurrencies; and Taghizadeh-Hesary and Yoshino (2019) discuss how to encourage private sector participation in green finance. The breadth of this cluster—23 keywords, the largest—reflects the centrality of digitized sustainable financial instruments as an integrative space within the field.

Cluster 3 (environmental and social components of the ESG framework), although relatively small in size, plays a significant structural role by linking the environmental and social dimensions of the ESG framework. Its function as a conceptual bridge between the other clusters suggests that generic sustainability terms serve as cross-cutting vocabulary

within the field, connecting corporate, financial, and methodological fronts. Cluster 4 (AI, climate risk, and circularity) constitutes the applied-methodological front where computational techniques are applied to climate risk analysis and circular models. The work of Huang et al. (2023) on financial information extraction using large language models, Huynh et al. (2020) on diversification in the era of the Fourth Industrial Revolution, and N. Kumar et al. (2021) on risk assessment and critical infrastructure in the face of climate change illustrate the methodological heterogeneity of this cluster, which is projected to be the front with the greatest potential for methodological innovation in the coming years.

To make the relationship between the three thematic trajectories and the four co-occurrence clusters explicit, we projected each document onto the cluster with which it has the greatest keyword overlap. The mapping (Table 10) reveals a coherent and complementary structure rather than redundancy between the two views. D1 (sustainable finance and digital transformation) is concentrated in C1, the Corporate ESG and Digitalization cluster, where 37% of its documents are anchored, consistent with the empirical centrality of digital monitoring and ESG performance within this trajectory. D2 (sustainable finance and the circular economy) is concentrated in C3, the Environmental and Social ESG cluster, where 46% of its documents anchor, which matches the environmental-side rationale of the circular trajectory. D3 (triadic convergence), by contrast, is the only trajectory whose documents distribute almost evenly across three clusters simultaneously (C1: 33%, C2: 26%, C3: 30%), drawing on the corporate-digital, financial-technological, and environmental-social vocabularies at the same time. This pattern provides direct empirical support for the interpretation of D3 as triadic: while the dyadic trajectories anchor predominantly in a single cluster, triadic documents traverse three. Cluster C4 (AI, climate risk and methods) is largely transversal and methodological, contributing weakly to any single trajectory.

Table 10. Distribution of each thematic trajectory across the four co-occurrence clusters.

Trajectory	C1 (Corporate ESG & Digitalization)	C2 (Green Finance, Fintech & Blockchain)	C3 (Environmental & Social ESG)	C4 (AI, Climate Risk & Methods)	No Predominant Cluster	Total
D1 (Sustainable finance + digital transformation)	756 (37.0%)	500 (24.5%)	390 (19.1%)	213 (10.4%)	185 (9.1%)	2044
D2 (Sustainable finance + circular economy)	62 (17.2%)	95 (26.3%)	167 (46.3%)	3 (0.8%)	34 (9.4%)	361
D3 (Triadic convergence)	22 (33.3%)	17 (25.8%)	20 (30.3%)	0 (0.0%)	7 (10.6%)	66

Note. Each document was projected onto the four clusters by computing the overlap between its author and indexed keywords and the representative keywords of each cluster (Table 8). Documents whose keywords did not overlap with any cluster are reported as “no predominant cluster”. Percentages are row-based: each row reports the share of documents within the corresponding trajectory (D1, D2 or D3), and the five columns of each row sum to 100%.

The share of documents reported as having no predominant cluster is similar across the three trajectories (9.1% in D1, 9.4% in D2, 10.6% in D3) and is therefore best read as a structural property of the keyword-overlap projection rather than a feature of any particular trajectory. Two mechanisms account for it. First, a subset of records carries only one or two author keywords, which is often insufficient to generate any overlap with the representative vocabulary of the four clusters. Second, certain documents employ specialized terminology, particularly methodological or technical terms, that lies outside the representative keywords of the four clusters, even when their substantive contribution falls clearly within sustainable finance and one of the convergence pathways. Both mechanisms operate at the metadata level and do not invalidate the trajectory assignment, which is based on a substantive reading of titles, abstracts and keywords (Section 2.5). The proportion of unassigned documents is consistent with what is commonly observed in keyword-based projections in bibliometric studies and does not alter the dominant patterns described above.

4.4. Triadic Convergence as an Emerging Frontier

The most significant finding of the study is the empirical evidence that the triadic convergence of sustainable finance, digital transformation, and the circular economy is present in only 66 documents (2.7% of the classified corpus). This figure contrasts with the 82.7% of the corpus that focuses on the sustainable finance–digital dyad and the 14.6% that integrates sustainable finance–circular. This finding should be interpreted with caution: it does not mean that the triadic convergence is irrelevant, but rather that it constitutes an emerging frontier that has not yet been academically consolidated.

The data thus qualify the more optimistic claims made by [Macchiavello and Siri \(2022\)](#) regarding the existence of an integrated paradigm of sustainable digital finance and green fintech as established fields. The results of the present study suggest, in contrast, that what those authors describe as an integrated paradigm is still a dyadic convergence (sustainable finance + digital) rather than a full triadic articulation. [Alkaraan et al. \(2023\)](#), in their analysis of UK firms, move toward triadic convergence by examining the synergy between Industry 4.0 and the circular economy under robust governance mechanisms; their work belongs to subcorpus D3 identified in this study and, notably, is one of the most cited in the corpus. This combination, an empirically under-explored but conceptually influential frontier, is consistent with the idea that triadic convergence offers high academic and practical returns for those who systematically investigate it in the coming years.

A closer reading of the D3 subcorpus reveals the thematic contours of this emerging frontier. The most recurrent concepts articulate green finance and the circular economy with digitalization, Industry 4.0, and, increasingly, Industry 5.0, while artificial intelligence and big data appear as enabling technologies and dynamic capabilities as a frequent theoretical lens. Beyond [Alkaraan et al. \(2023\)](#), representative contributions address the role of business and management in driving sustainable development through digital and circular practices, and green-innovation strategies that mobilize circular-economy principles under digital monitoring. At the same time, the subcorpus is thematically heterogeneous and includes technically oriented studies whose connection to financial decision-making is indirect, which reinforces the interpretation of triadic convergence as a still-coalescing rather than a consolidated research stream. Three observations follow. First, the triadic literature remains predominantly conceptual or case-based, with comparatively little large-sample financial evidence on how the simultaneous integration of the three domains affects the cost of capital, valuation, or risk. Second, theoretical framing is fragmented across innovation, operations, and sustainability traditions, with no shared analytical core. Third, this fragmentation is itself the principal opportunity the present study identifies: a frontier where the logic of *economicità* could integrate what the literature has so far treated separately.

The theoretical interpretation of this finding draws particularly on the framework of *economicità* ([Onida, 1971](#)), which conceives of sustainability not as an external constraint on profitability, but as a condition for the firm's long-term economic equilibrium. From this perspective, the three domains analyzed are neither interchangeable nor equivalent: sustainable finance provides the logic of capital allocation oriented toward intertemporal equilibrium; digital transformation expands the measurement, verification, and information processing capabilities necessary to sustain that equilibrium; and the circular economy extends the horizon of value creation toward less linear and more material-efficiency-oriented production models. The observed scarcity of triadic convergence (2.7%) suggests that the field has not yet fully articulated this functional complementarity, and that firms and academics tend to prioritize the SF–digital dyad, where results materialize more quickly over integration with circularity, whose benefits operate over longer time horizons.

This theoretical framework allows us to reinterpret the emerging frontier not as an absence, but as a structural opportunity: triadic convergence represents the space where

the logic of economicità can be fully operationalized, bringing together the three functional domains of sustainable economic equilibrium. Recent work on digital technologies, Industry 5.0, and ESG outreach (Asif et al., 2023; De Giovanni, 2023) partially anticipates this direction, although it has not yet fully developed a triadic integration that explicitly articulates sustainable finance, digitalization, and circularity. Triadic convergence, therefore, should not be interpreted as a marginal trend, but rather as the frontier where the field can consolidate its most original theoretical contribution over the next decade.

4.5. Academic, Practical, and Regulatory Implications

For the academic community, the most significant finding of the study is the quantitative identification of triadic convergence as an emerging frontier: the availability of an empirical map of the field allows researchers to prioritize lines of research with high potential for original contributions. The future research agenda should focus on studies that explicitly link the three thematic domains—sustainable finance, digital transformation, and the circular economy. This agenda could be developed through quasi-experimental designs, multi-country case studies, longitudinal analyses, and sector-specific research. These approaches would allow for an examination of how convergence operates in specific industries and institutional contexts, as well as the temporal maturation of integration among the three domains. Foundational work on ESG integration (Bassen et al., 2006; Serafeim, 2015) and classic theoretical frameworks such as economicità (Onida, 1971) provide solid conceptual anchors for this agenda, while the bibliometric methodology developed by Donthu et al. (2021) and the VOSviewer 1.6.20 tool (Van Eck & Waltman, 2010) facilitate its replication in specific sectoral or geographical contexts.

For professionals and practitioners in the financial sector, the findings suggest that the true strategic advantage does not lie in adopting digital technologies to optimize ESG disclosure, a path already widely taken by leading firms, but rather in linking that digitalization to explicit circular economy practices. In other words, the competitive challenge is not digital ESG, but the deliberate integration of digitalization and circularity within a sustainable financial framework. The work by Alkaraan et al. (2023) on the synergy between Industry 4.0 and the circular economy under robust governance mechanisms illustrates the type of combination that firms can adopt to differentiate themselves, while Lu et al. (2024), Wang and Esperança (2023), and Ren et al. (2023) empirically document how digitalization improves corporate ESG performance. According to the findings of this study, the integration of both vectors with circular objectives constitutes a still underutilized area for value creation.

For financial and environmental regulators, particularly those operating in emerging markets, the findings suggest three complementary implications. First, the scarcity of studies on triadic convergence indicates that regulatory frameworks treating financial digitalization, ESG, and circularity as separate domains may be underestimating their synergies; Macchiavello and Siri (2022) anticipate this implication by proposing integrated regulatory frameworks for green fintech. Second, the presence of China (1064 articles), India (158), Malaysia (126), Saudi Arabia (99), Pakistan (71), Turkey (69), and Indonesia (48) among the fifteen most productive countries in the corpus reveals that emerging markets are not passive consumers of knowledge generated in the Global North, but active producers within the field. The works of Udeagha and Muchapondwa (2023) and Udeagha and Ngepah (2023) on green and digital transition in Africa, Wang and Esperança (2023) on Chinese SMEs, Madaleno et al. (2022) on the nexus between environmental responsibility, green technology, and green finance, as well as Mansouri and Momtaz (2022) on sustainable finance, ESG measurement, and corporate performance, illustrate the empirical richness of these contributions. Third, the emerging regulatory agenda must comparatively articulate

these experiences to build frameworks for harmonization, traceability, and comparability capable of incorporating the institutional, regulatory, and technological diversity of the contexts in which the field is developing, avoiding the uncritical transfer of models designed for mature economies.

5. Conclusions

This study provides empirical evidence that the convergence of sustainable finance, digital transformation, and the circular economy currently constitutes, in bibliometric terms, an emerging frontier rather than a consolidated stream. Of the 2471 classified articles, only 2.7% simultaneously address all three thematic domains, compared to 82.7% concentrated on the sustainable finance–digital transformation dyad and 14.6% relating sustainable finance to the circular economy. Two complementary pieces of evidence reinforce this characterization. First, the temporal profile of the triadic subcorpus differs from that of the two dyadic trajectories: the first triadic document appears only in 2021 and 98.5% of D3 documents were published from 2022 onward, indicating a phenomenon that postdates the consolidation of the underlying dyads. Second, the keyword-overlap projection of documents onto the four co-occurrence clusters shows that, while the dyadic trajectories anchor predominantly in a single cluster (D1 in the corporate ESG and digitalization cluster; D2 in the environmental and social ESG cluster), triadic documents distribute almost evenly across three clusters at once. Interpreted under the lens of *economicità* (Onida, 1971), these results suggest that the field has not yet fully articulated the functional complementarity among the three domains of sustainable economic equilibrium: capital allocation, information measurement, and long-term value creation.

The structural findings of the analysis confirm that the field is undergoing a phase of rapid expansion, with a compound annual growth rate of 91.6% between 2015 and 2025, making it one of the fastest-growing areas of financial research of the decade. Publication output is geographically concentrated in China (43.3% of the corpus), while the relative impact per article favors European economies, creating a functional division between Asian productivity and European conceptual consolidation. The field is editorially structured around a small core of journals, fourteen of which account for nearly 30% of the output, and conceptually around four thematic clusters: corporate ESG and digitalization; green finance and fintech; the social and environmental components of the ESG framework; and artificial intelligence applied to climate risk and circularity. This organization reflects the interdisciplinary nature of the field and, simultaneously, the asymmetry that continues to characterize the integration among its three constituent domains.

The results should be interpreted in light of five limitations. First, the corpus was constructed exclusively using Scopus, which prioritizes disciplinary coverage and traceability over cross-database comprehensiveness; future studies could cross-reference with Web of Science or Dimensions to assess the robustness of the findings. Second, the classification by thematic trajectory was based on bibliographic metadata—title, abstract, and author keywords—rather than full-text articles, which may underestimate articles whose triadic articulation is developed in the body of the work without being explicitly stated in the metadata.

Third, the disambiguation of author names in bibliometrics that rely on initials is a recognized limitation that affects the accuracy of individual productivity rankings. Fourth, the 2015–2025 time window captures the field’s consolidation period, but the most recent documents have accumulated insufficient citations to assess their actual impact. Fifth, the search was restricted to publications in English, which excludes relevant contributions produced in other languages, particularly Chinese, Spanish and France.

The future research agenda stemming from these findings is oriented toward four complementary directions. The first involves empirical studies explicitly focused on the D3 subcorpus, which use longitudinal and comparative designs to examine how the triadic relationship matures in specific sectors and institutional contexts. The second calls for the development of analytical frameworks that integrate Asian empirical contributions with European regulatory frameworks, avoiding the uncritical transfer of findings between systems with different regulations, data, and priorities. The third points toward sector-specific studies examining how triadic convergence operates in specific industries (i) energy, (ii) manufacturing, (iii) agribusiness, and (iv) financial services, where the articulation between sustainable finance, digitalization, and circularity faces distinct material and regulatory conditions. The fourth opens the possibility of revising regulatory frameworks that treat the three domains as separate spheres, moving toward integrated schemes capable of capturing their synergies. In summary, triadic convergence should not be interpreted as a marginal trend within the field, but rather as the space where the next decade of research can consolidate its most original theoretical contribution to the articulation between financial sustainability, technological innovation, and long-term value creation.

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Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial Intelligence
CAGR	Compound Annual Growth Rate
CE	Circular Economy
CSRD	Corporate Sustainability Reporting Directive
D1	Sustainable finance—digital transformation pathway
D2	Sustainable finance—circular economy pathway
D3	Triadic convergence pathway
DOI	Digital Object Identifier
ESG	Environmental, Social, and Governance
FinTech	Financial Technology
IoT	Internet of Things
IRB	Institutional Review Board
ISSB	International Sustainability Standards Board
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SDGs	Sustainable Development Goals
SF	Sustainable Finance
TCFD	Task Force on Climate-related Financial Disclosures

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