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EXPLORING THE AI–ESG NEXUS: A BIBLIOMETRIC AND TCM–ADO FRAMEWORK APPROACH

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ABSTRACT

This study examines the intersection of AI and ESG research by combining bibliometric analysis with content analysis guided by the TCM–ADO framework. A total of 157 journal articles published between 2017 and 2025 were retrieved from the Scopus database. VOSviewer was employed to map co-authorship, co-citation, and keyword co-occurrence networks, while Microsoft Excel was used for descriptive statistics. The analysis identified six thematic clusters: (1) sustainability and environmental finance, (2) corporate ESG practices, (3) AI techniques and methods, (4) green innovation with regional perspectives, (5) AI applications in sustainability, and (6) ESG performance metrics. The application of the TCM–ADO framework enabled the systematic categorization of antecedents, decisions, and outcomes, alongside theoretical, contextual, and methodological dimensions. The findings offer a comprehensive overview of the intellectual structure and evolution of AI–ESG scholarship. This study contributes by providing scholars with conceptual clarity, offering practitioners actionable insights for aligning AI with ESG strategies, and supporting policymakers in designing evidence-based policies for sustainable and responsible innovation.

Keywords: Artificial intelligence, ESG, AI-driven ESG, bibliometric analysis, TCM–ADO framework, sustainable innovation.

1. INTRODUCTION

As the global economy advances into the era of digitalization and green transformation, challenges such as carbon emissions, climate change, public health crises, and social inequality have become increasingly urgent [1], [2]. In response to the pressing goals of achieving carbon neutrality and sustainable development, the integration of artificial intelligence (AI) with environmental, social, and governance (ESG) practices is gaining significant traction [3]-[6]. AI provides powerful tools for analyzing environmental data, forecasting risks, and optimizing business operations, thereby enabling firms to reduce emissions and enhance resource efficiency [7]. At the same time, ESG offers a governance framework that aligns innovation objectives with social responsibility and long-term strategic orientation [8], [9]. The combined influence of AI and ESG not only drives green innovation and strengthens competitive advantage but also contributes to addressing global sustainability challenges [10], [6]. This underscores that leveraging the synergies between AI and ESG is not merely a strategic option but an inevitable trajectory for both corporations and economies in the new era of development.

Despite the increasing attention from both scholars and practitioners, most prior studies have examined AI and ESG separately—ESG primarily as a driver of sustainable development [2], [9] and AI as a catalyst for technological innovation and performance improvement [11], [7], [12]. Although bibliometric reviews have recently emerged to map either ESG research [13], [14] or AI applications [15], comprehensive analyses that capture their intersection remain scarce. In particular, little is known about how AI can reinforce ESG practices through technological innovation, transparency, and governance optimization, or conversely, how ESG frameworks can guide the responsible, transparent, and sustainable application of AI. This research gap signals the urgent need for a systematic bibliometric investigation that integrates the fragmented strands of knowledge and provides a holistic conceptualization of the AI–ESG nexus.

To address this gap, the present study employs a bibliometric approach complemented by content analysis to systematically review the scholarly literature on AI and ESG published between 2017 and 2025. By adopting the TCM–ADO framework, the study systematically links antecedents, decision pathways, and outcomes (ADO) with the theoretical foundations, research contexts, and methodological designs (TCM) underlying this field. This dual-lens framework enables a structured exploration of the literature, tracing its thematic evolution, clustering research domains, and uncovering critical knowledge gaps. In doing so, the study not only advances the theoretical underpinnings of sustainable development in the digital era but also provides practical implications for firms, policymakers, and other stakeholders seeking to leverage the joint potential of AI and ESG to achieve long-term green and sustainable growth. To achieve these objectives, the following research questions are proposed:

RQ1: How has research on AI and ESG evolved over time across journals, authors, and regions?

RQ2: What thematic clusters dominate the AI–ESG literature, and which emerging aspects indicate future research potential?

RQ3: What theories, contexts, methods (TCM) and antecedents, decisions, outcomes (ADO) are applied in existing studies on AI and ESG?

Given the importance of the topic, this study may prove valuable to practitioners and organizations in the field, as it identifies key trends, impacts, and managerial implications of ESG in the age of AI. Additionally, it provides useful guidance for researchers by highlighting the most influential authors, journals, themes, and perspectives shaping this research domain throughout the examined period.

2. LITERATURE REVIEW

The concept of environmental, social, and governance (ESG) can be traced back to the 1970s, when socially responsible investors began incorporating environmental and social considerations into investment decision-making to evaluate both sustainability and ethical implications [16]. Since then, ESG has evolved into a critical benchmark widely adopted by the international community to assess the long-term growth potential and sustainability prospects of economic entities [17]-[19]. It is also recognized as a key indicator of managerial competence, non-financial performance, and risk management capability [20], [21]. The growing attention from institutional and individual investors has further encouraged firms to enhance transparency and strengthen their accountability toward shareholders and broader stakeholders [22], [23].

From a strategic perspective, ESG represents integral dimensions of sustainability, focusing on how firms operate to simultaneously achieve environmental and social

responsibility while maintaining financial performance [24], [25]. The increasing convergence between sustainability and ESG reflects firms' recognition of their responsibilities in addressing environmental and social challenges while upholding sound governance practices.

A growing body of empirical evidence further supports the positive correlation between ESG disclosure and corporate financial outcomes. For instance, firm-specific characteristics have been shown to influence the extent of ESG reporting [26], while greater transparency in ESG disclosure enhances stakeholder trust and attracts investment [27]. Beyond disclosure, stronger ESG performance has also been associated with operational benefits, such as higher total factor productivity [28], and with improved market valuation, as firms fulfilling ESG responsibilities tend to create greater shareholder value [29]. Taken together, these findings position ESG not merely as a governance framework but as a strategic resource that advances competitiveness and long-term value creation.

Artificial Intelligence (AI), in general, refers to the capability to analyze and gather data from the environment and utilize that data to perform specific tasks by adapting to changes or requirements [30]. The term AI encompasses concepts such as learning, strategy formation, and problem-solving, as well as notions like comprehension, questioning, productivity, critical analysis, emotional intelligence, and reasoning [31].

Artificial intelligence (AI) has emerged as a transformative force in environmental, social, and governance (ESG) investing, offering advanced analytical capabilities to process vast and complex datasets while enhancing decision-making processes [10], [6]. Core technologies such as machine learning, natural language processing, and predictive analytics enable the systematic collection, integration, and standardization of ESG-related data from diverse sources, including corporate disclosures, regulatory filings, media reports, and social platforms [4], [32]. By processing both structured and unstructured data, AI algorithms can uncover patterns, correlations, and anomalies, thereby generating insights into firms' environmental performance, social impact, and governance practices [33]. These insights are further enhanced through visualization tools that translate ESG metrics into interactive dashboards, facilitating the monitoring of trends, benchmarking of performance, and data-driven investment decisions [34], [10].

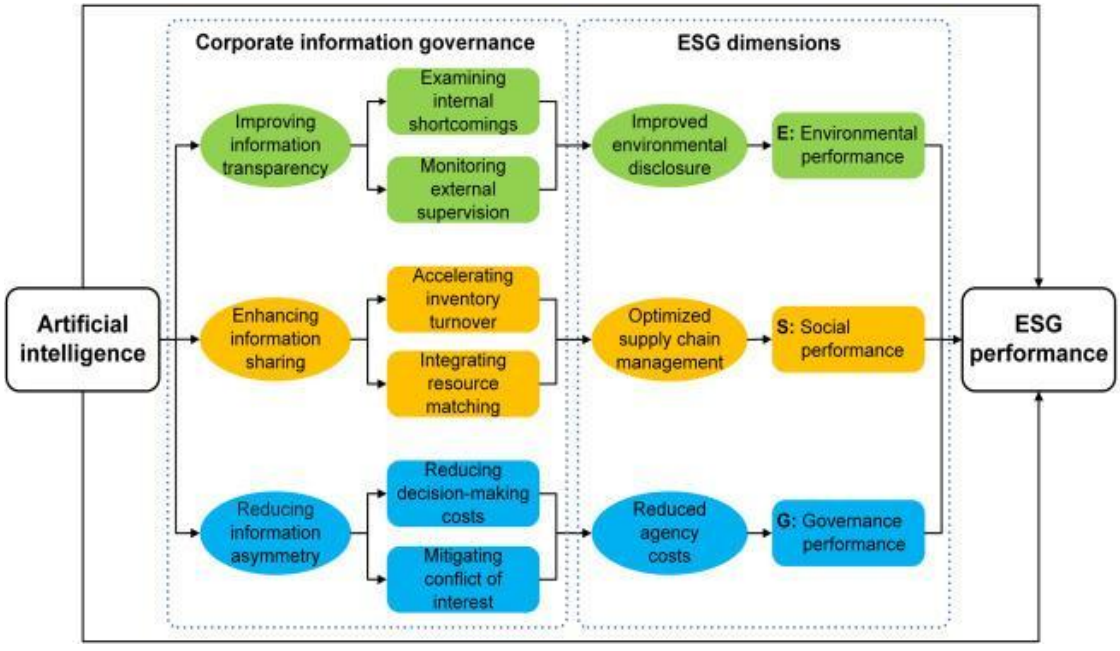

Figure 1. The impact of artificial intelligence on ESG performance [35].

Figure 1 illustrates how AI improves ESG performance through three primary governance mechanisms: enhancing information transparency, improving information sharing, and reducing information asymmetry. These mechanisms enable more efficient monitoring, decision-making, and resource allocation, which in turn lead to improved environmental, social, and governance outcomes. The figure supports the argument that AI not only facilitates ESG data processing but also acts as a strategic enabler linking organizational processes to measurable ESG performance.

Beyond descriptive analysis, AI supports investors in identifying opportunities, assessing risks, and optimizing portfolio allocation through machine learning and predictive modeling [36]. In particular, AI-based ESG analytics strengthen risk management by detecting vulnerabilities associated with climate change, supply chain disruptions, or regulatory shifts, thus helping investors mitigate adverse exposures and safeguard long-term portfolio resilience [37]. Moreover, by aligning investment strategies with sustainability objectives, AI enables the construction of balanced portfolios that not only generate financial returns [38] but also promote positive environmental and social outcomes [10], [6]. AI is reshaping ESG by not only enabling data-driven investment and risk management but also empowering firms to embed sustainability into core strategies, enhance accountability, and strengthen stakeholder trust. By bridging financial performance with responsible corporate practices, AI-driven ESG analytics drive lasting value creation for businesses and society alike.

3. METHODOLOGY

This study employs a combination of bibliometric analysis and content analysis guided by the TCM–ADO framework to examine the intersection of artificial intelligence (AI) and environmental, social, and governance (ESG) research. Bibliometric analysis provides a quantitative perspective by mapping publication trends, citation networks, and collaboration structures [39], while the TCM–ADO framework ensures a structured interpretation of antecedents, decisions, and outcomes, as well as theories, contexts, and methodologies [40]. The integration of these approaches enhances rigor and comprehensiveness, enabling a systematic assessment of the field and identification of future research directions. To ensure transparency and replicability, the review process was documented and visualized through a PRISMA flow diagram (Figure 2).

A total of 157 English-language journal articles published between 2017 and 2025 were retrieved from the Scopus database using a structured keyword search. Bibliometric analysis was conducted with VOSviewer to map co-authorship, co-citation, and keyword co-occurrence networks, while Microsoft Excel was used for descriptive statistics such as publication trends, citation counts, and journal distribution. This dual approach provided both quantitative evaluation and network visualization, offering comprehensive insights into the structure and evolution of AI–ESG research.

Subsequently, content analysis guided by the TCM–ADO framework was applied. Using axial coding, information was extracted and categorized into six dimensions: antecedents, decisions, outcomes, theories, contexts, and methods. This systematic classification enhanced the transparency and organization of the analysis, revealed the relationships among ADO elements, and integrated contextual and methodological perspectives, thereby identifying thematic patterns and future research directions.

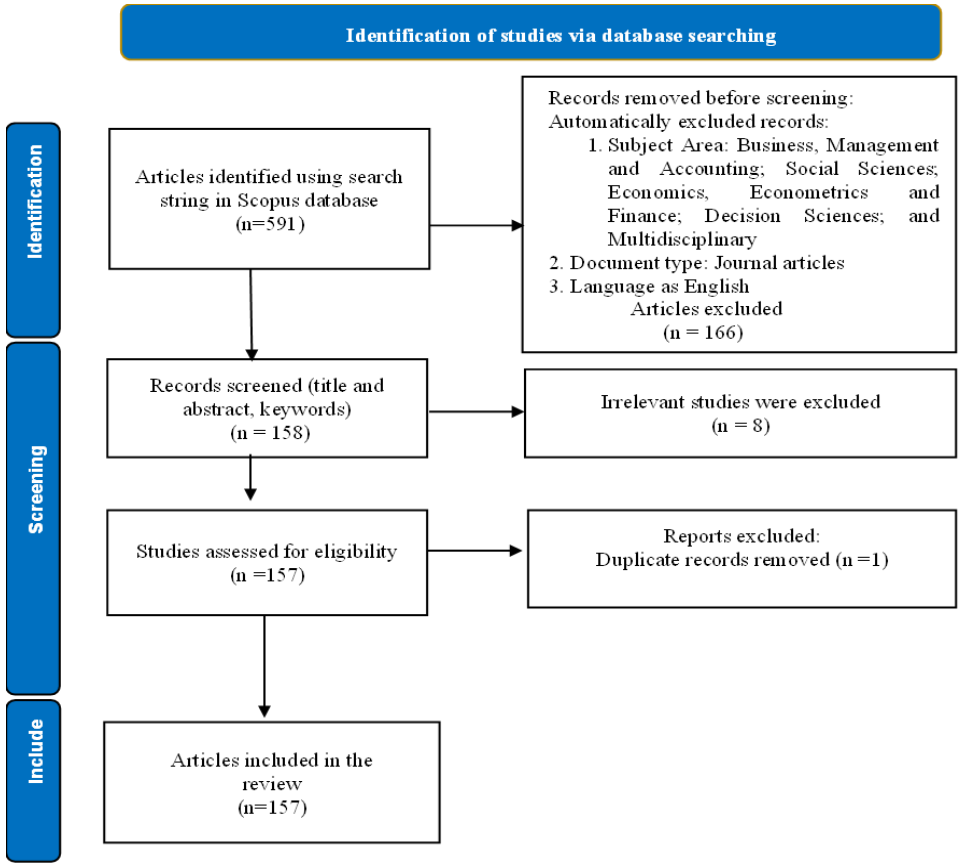

Figure 2. Adapted PRISMA flowchart for the literature selection process.

(Source: authors' elaboration)

4. RESULTS

4.1. Publishing Trends Over the Years

AI in ESG has witnessed a dynamic transformation and significant growth in academic and research activities. An examination of publication patterns from 2017 to 2025 reveals a steady and remarkable increase in scholarly output (Figure 3), suggesting not only quantitative expansion but also a gradual maturation of the research field.

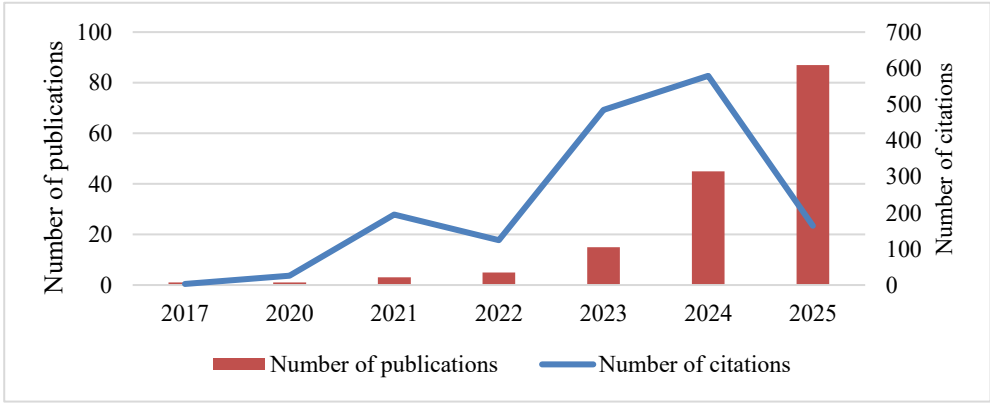

Figure 3. Annual distribution of published research articles (2017–2025)

(Source: authors' elaboration)

Early studies examining the intersection of AI and ESG emerged as early as 2017, initially receiving limited citation attention. Notably, in 2020, a single publication attracted 26 citations, indicating that although early contributions were few, they played a foundational role in shaping subsequent research directions. Between 2021 and 2022, both publication output and citation counts grew, with 3 publications and 195 citations in 2021, followed by 5 publications and 124 citations in 2022, reflecting increased scholarly engagement and the consolidation of AI–ESG as a distinct research stream. The year 2023 marked a significant acceleration, with 15 publications garnering 485 citations, demonstrating heightened academic interest and impact. This momentum continued into 2024, reaching 45 publications and 579 citations, highlighting intensified research activity in AI applications for ESG. Preliminary data from 2025 indicate 87 publications with 164 citations, suggesting sustained expansion in this field. Overall, these trends indicate a transition from early-stage exploratory research toward more application-oriented and impact-driven studies, which aligns with the evolution described in the TCM–ADO framework, where theoretical grounding increasingly informs decision-making processes and measurable ESG outcomes. Figure 3 illustrates these developments clearly.

Table 1 summarizes the research institutions affiliated with authors publishing on AI and ESG from 2017 to 2025, ranked by publication count and total citations to reflect productivity and impact. Sda Bocconi School Of Management, Østfold University College leads in both metrics, highlighting its key role in advancing AI-driven ESG research. While other institutions contribute less extensively, the variety of affiliations underscores the global and interdisciplinary nature of the field. Most institutions remain in early stages of involvement, with eight publishing two papers each and 391 producing a single publication. This pattern indicates that AI and ESG research is still fragmented, with no dominant institutional hub established.

Table 1. Institutional contributions to the topic (2017–2025)

No.	Organization	Number of citations	Number of Publications	Citations per document
1	Sda Bocconi School Of Management, Via Sarfatti 10, Milan, 20136, Italy	160	1	160
2	Faculty Of Business, Languages, The Social Sciences, Østfold University College, Halden, N-1757, Norway	113	1	113
3	Department Of Electrical Engineering, Jis College Of Engineering, West Bengal, Kolkata, 741235, India	85	1	85
4	Department Of Engineering, Universidad Internacional Iberoamericana, Arecibo, 00613, Puerto Rico	85	1	85
5	Department Of Project Management, Universidad Internacional Iberoamericana, Cp, Campeche, 24560, Mexico	85	1	85
6	Department Of Project Management, Universidade Internacional Do Cuanza, Estrada Nacional 250, Bairro Kaluapanda, En250, Bié, Cuito, Angola	85	1	85
7	Digital Transformation Portfolio, Tshwane University Of Technology, Staatsartillerie Rd., Pretoria West, Pretoria, 0183, South Africa	85	1	85
8	Higher Polytechnic School, Universidad Europea Del Atlantico, C/Isabel Torres 21, Santander, 39011, Spain	85	1	85
9	Law College Dehradun, Uttaranchal University, Uttarakhand, Dehradun, 248007, India	85	1	85

10	Uttaranchal Institute Of Management, Uttaranchal University, Uttarakhand, Dehradun, 248007, India	85	1	85
11	Uttaranchal Institute Of Technology, Uttaranchal University, Uttarakhand, Dehradun, 248007, India	85	1	85
12	Adam Smith Business School, University Of Glasgow, Glasgow, G12 8Qq, United Kingdom	81	1	81
13	School Of Business, Central South University, Changsha, China	81	1	81
14	School Of Geography And The Environment, Oxford University Centre For The Environment, University Of Oxford, Oxford, Ox1 3Qy, United Kingdom	70	1	70
15	School Of Economics, Capital University & Economics And Business, China	55	1	55
16	Department Of Information Systems, Hanyang University, Seoul, 04764, South Korea	53	1	53
17	School Of Business Management, Nanyang Polytechnic, Singapore, Singapore	52	1	52

(Source: authors' elaboration)

4.2. High-Impact Journals

This section identifies the most influential journals contributing to the advancement of Artificial Intelligence (AI) and Environmental, Social, and Governance (ESG) research between 2017 and 2025. The analysis considers both publication volume and citation impact, thereby highlighting the academic outlets that have shaped scholarly discourse in this domain. As shown in Figure 4, Sustainability (Switzerland) leads the field with 19 publications, followed by Finance Research Letters with 9 and Energy Economics with 7 contributions. Scientific Reports accounts for 6 publications, while both Research in International Business and Finance and the Journal of Cleaner Production contributed 5 papers each. In addition, the International Review of Financial Analysis and Systems published 4 articles each. Other noteworthy outlets include Sustainable Development, Business Strategy and Development, and Discover Sustainability, each with 3 publications. This distribution suggests that AI–ESG research is inherently interdisciplinary, spanning sustainability, finance, economics, management, and systems science. Moreover, the variation in publication volume across journals reflects differences between dissemination-oriented outlets and those contributing more selectively to theoretical and empirical advancement.

Figure 4. Top Journals by Publication Volume. (*Source: authors' elaboration)*

Beyond these, the remaining contributions were scattered across a diverse set of journals, reflecting the multidisciplinary nature of AI–ESG research and its diffusion across fields such as sustainability, finance, economics, management, and systems science.

Table 2 presents the most influential journals in the field of AI and ESG, including *Sustainability (Switzerland)*, *Energy Economics*, *Sustainable Development*, and *Research In International Business And Finance*, among others. These journals play a critical role in shaping and advancing scholarly understanding of how AI impacts ESG practices. Collectively, they serve as foundational platforms for disseminating high-impact research that explores both theoretical and practical dimensions of AI-driven ESG strategies.

Table 2. Top Journals in the Area of AI and ESG

Publishing Journals	Total citations	Number of publication	Total link strength
Sustainability (Switzerland)	528	19	1
Energy Economics	156	7	0
Sustainable Development	90	3	0
Research In International Business And Finance	61	5	1
Artificial Intelligence Review	52	1	2
Quality And Quantity	50	1	0
Human Resource Development Review	49	1	2
Finance Research Letters	40	9	0
Journal Of Cleaner Production	39	5	0
Journal Of Chinese Economic And Business Studies	36	1	1
Sustainability Accounting, Management And Policy Journal	34	2	1
Journal Of Sustainable Finance And Investment	32	2	1
Intelligent Systems In Accounting, Finance And Management	30	1	1
International Review Of Financial Analysis	28	4	0
Humanities And Social Sciences Communications	27	1	0

(Source: authors' elaboration)

The most influential article, *"Sustainability of the Metaverse: A Transition to Industry 5.0"* (2023), has already garnered 160 citations, highlighting its strong academic impact and the relevance of metaverse-driven sustainability. Likewise, *"A framework for evaluating and disclosing the ESG-related impacts of AI with the SDGs"* (2021) has accumulated 113 citations, reflecting its foundational role in linking AI with global sustainability goals. Other highly cited works, such as *"Technologies Empowered ESG: An Industry 4.0 Landscape"* (2023, 85 citations) and *"AI adoption rate and corporate green innovation efficiency"* (2024, 81 citations), further underscore the significance of AI in advancing sustainable innovation and corporate practices. Collectively, the citation patterns presented in Table 3 demonstrate that AI–ESG research has achieved substantial visibility and influence in a relatively short period, underscoring its growing importance across both academic and practical domains.

Table 3. Most influential publication

Title	Year	Total citations	Citations per year
Sustainability of the Metaverse: A Transition to Industry 5.0	2023	160	53
A framework for evaluating and disclosing the esg related impacts of ai with the sdgs	2021	113	23
Technologies Empowered Environmental, Social, and Governance (ESG): An Industry 4.0 Landscape	2023	85	28
AI adoption rate and corporate green innovation efficiency: Evidence from Chinese energy companies	2024	81	41
Alternative esg ratings: How technological innovation is reshaping sustainable investment	2021	70	14
The pathway to curb greenwashing in sustainable growth: The role of artificial intelligence	2024	55	28
Proposing an Integrated Approach to Analyzing ESG Data via Machine Learning and Deep Learning Algorithms	2022	53	13
Environmental, social, and governance (ESG) and artificial intelligence in finance: State-of-the-art and research takeaways	2024	52	26
The AI ESG protocol: Evaluating and disclosing the environment, social, and governance implications of artificial intelligence capabilities, assets, and activities	2023	50	17
Examining the research taxonomy of artificial intelligence, deep learning & machine learning in the financial sphere—a bibliometric analysis	2024	50	25
Socially Responsible Artificial Intelligence Empowered People Analytics: A Novel Framework Towards Sustainability	2024	49	25
Exploring the linkages between FinTech and ESG: A bibliometric perspective	2024	37	19
Bridging the gap–the impact of ChatGPT on financial research	2023	36	12
Promoting sustainable development goals through generative artificial intelligence in the digital supply chain: Insights from Chinese tourism SMEs	2025	35	35
Corporate governance performance ratings with machine learning	2022	30	8

(Source: authors' elaboration)

4.3. Most Productive Authors in AI and ESG

Table 4 presents the most active authors contributing to AI–ESG research. Among them, Sætra is the most influential, with 163 citations across two publications, far surpassing other authors. A second group of contributors, including Ardeshiri, Danielson, Neidermeyer, Rana, Samsten, Svanberg, and Öhman, each recorded 36 citations, indicating consistent but comparatively moderate influence. Meanwhile, Hall, Kim, and Sohn achieved 29 citations, and Xie had 12 citations. Overall, while publication output remains uniform across authors, citation impact varies significantly, with Sætra emerging as the most prominent scholar in the field.

Table 4. Most Prolific Authors in AI and ESG

Authors	Number of publications	Total citations	Total link strength	H_index
Sætra	2	163	0	20
Ardeshiri	2	36	14	10
Danielson	2	36	14	20
Neidermeyer	2	36	14	9
Rana	2	36	14	14
Samsten	2	36	14	8
Svanberg	2	36	14	9
Öhman	2	36	14	30
Hall	2	29	7	94
Kim	2	29	7	35
Sohn	2	29	7	9
Xie	2	12	3	5

(Source: authors' elaboration)

4.4. Geographical Distribution of Publications/ Scientific Production of the Countries

This section analyzes the geographical distribution of publications related to AI and ESG during the 2017–2025 period. The data highlight the countries and regions that have shown the highest research activity, offering insights into global research trends and international collaboration.

In terms of country-level contributions, the global distribution of research on AI and ESG reflects a broad but uneven landscape. As shown in Figure 5, scholars from 55 countries have published in this field, demonstrating its international relevance. China emerges as the leading contributor with 50 publications, over 21% of the total—and 424 citations. The United States follows with 27 publications (11%) and 221 citations, underscoring its strong influence. Other countries with notable contributions include India, the United Kingdom, Malaysia, South Korea, Australia, and Canada, highlighting the increasingly global engagement with AI–ESG research.

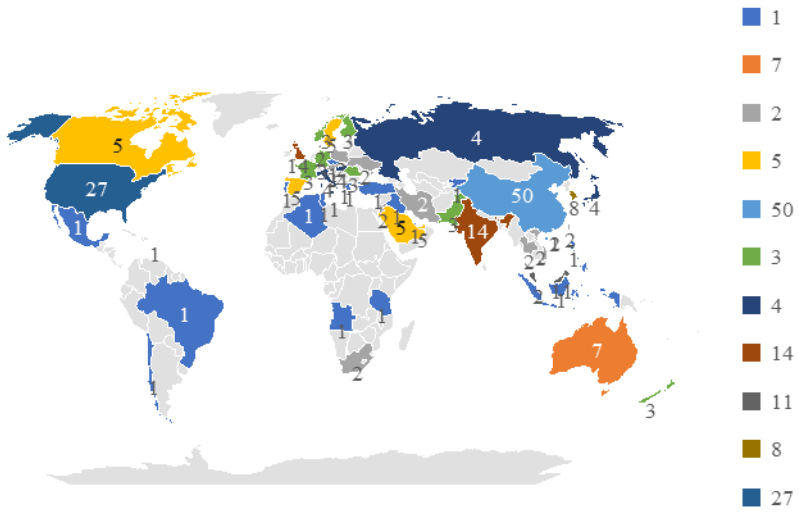

Figure 5. Countries with Scientific Publications. *(Source: authors' elaboration)*

The international collaboration network, constructed using VOSviewer, encompasses 55 countries with strong interconnections. Overall, the collaborative structure in this domain has reached a relatively mature stage, reflecting the growing global integration of AI and ESG research. In the visualization, larger circles and font sizes denote greater centrality and prominence. Notably, China, the United States, India, Malaysia, the United Kingdom, South Korea, Sweden, France, and Australia emerge as the most influential countries, both in terms of research output and international collaboration, underscoring their leading roles in shaping the global AI–ESG research landscape. Such international collaboration not only facilitates the diffusion of knowledge but also plays a crucial role in harmonizing methodological approaches, advancing comparative insights, and fostering globally aligned standards in the integration of AI with ESG practices.

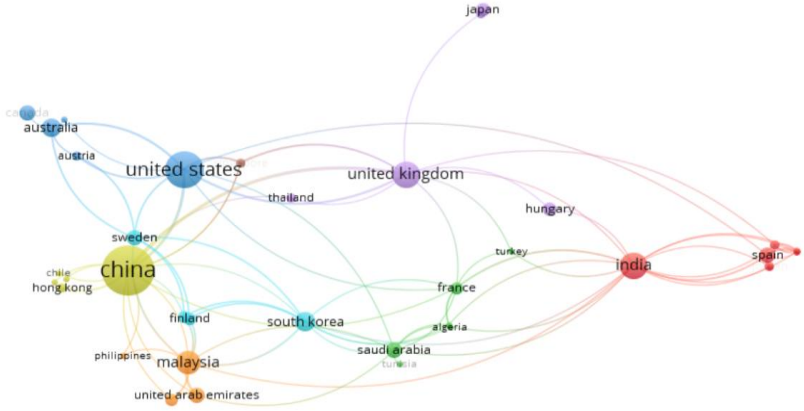

Figure 6. International Collaboration Network. (*Source: authors' elaboration*)

Figure 6 illustrates a highly interconnected global collaboration structure, with several central hubs, particularly China, the United States, and the United Kingdom, acting as key knowledge brokers. The density of connections suggests that AI–ESG research has moved beyond isolated national efforts toward coordinated international collaboration. This pattern reinforces the importance of cross-country knowledge exchange in shaping both methodological convergence and the global diffusion of AI-driven ESG practices.

4.5. Keyword Visualization

Figure 7 illustrates a visual trend and identifies the most frequently occurring words in the studies, helping to reveal key themes and trends.

The keyword visualization highlights "artificial intelligence" as the central theme, closely connected to "machine learning," "big data," and "ESG performance." Emerging terms such as "ChatGPT" and "blockchain risks" indicate the diversification of research directions and the growing interdisciplinary applications in AI–ESG studies. Rather than representing isolated themes, these keywords collectively suggest a structured interaction between technological capabilities, organizational practices, and performance outcomes. These patterns suggest that future research will increasingly integrate advanced AI techniques with sustainability-oriented frameworks, thereby shaping novel pathways for both academic inquiry and practical implementation.

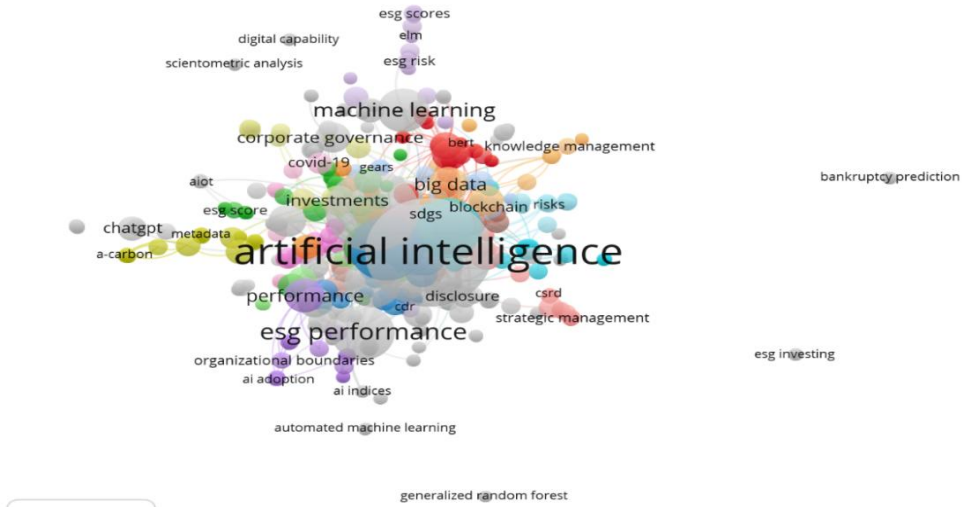

Figure 7. Keyword Visualization. (*Source: authors' elaboration*)

4.6. Co-citation Analysis

Figure 8 presents the co-citation analysis of authors in the research domain of AI and ESG. This analysis was conducted to uncover the intellectual foundation and thematic structure of the field by identifying patterns of co-citation among scholars. In total, 50 authors met the citation threshold and were included in the network visualization. The map reveals five distinct clusters, each representing a group of authors who are frequently cited together, suggesting shared theoretical perspectives or research interests. The size of each node indicates the number of citations received, while the proximity and thickness of the connecting lines reflect the strength of co-citation relationships. These clusters highlight key scholarly communities that have shaped the academic discourse on the integration of AI in ESG.

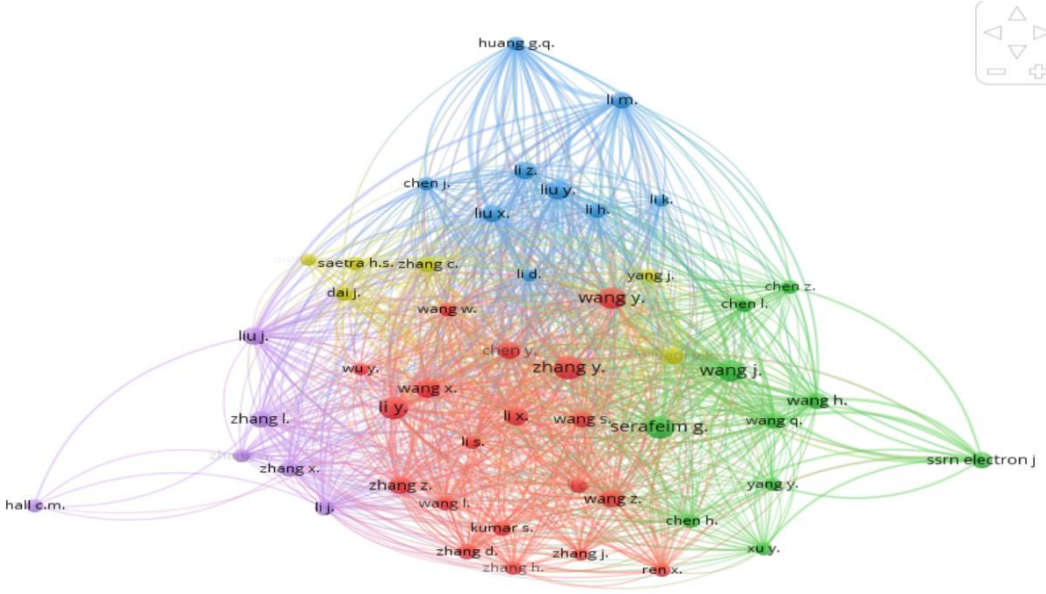

Figure 8. Co-citation Analysis of Authors. (*Source: authors' elaboration*)

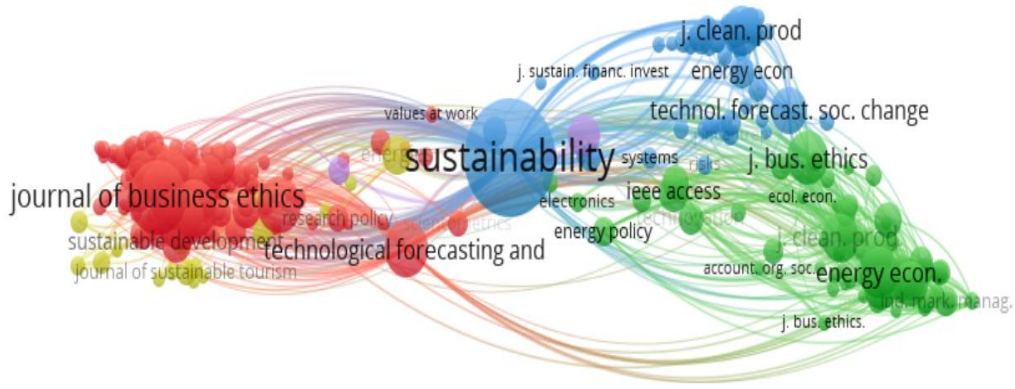

Figure 9. Co-Citation Analysis of Journals. (*Source: authors' elaboration*)

The co-citation frequency and link strength analysis identifies the journals that constitute the intellectual foundation of AI–ESG research and illustrates how different disciplinary traditions converge in this emerging field. Core outlets with the highest link strength—such as Sustainability, Journal of Business Ethics, Technological Forecasting and Social Change, Journal of Cleaner Production, Journal of Business Research, Business Strategy and the Environment, Energy Economics, and Corporate Social Responsibility and Environmental Management—demonstrate broad interdisciplinary influence, bridging sustainability studies, management, economics, and technological innovation (Figure 9).

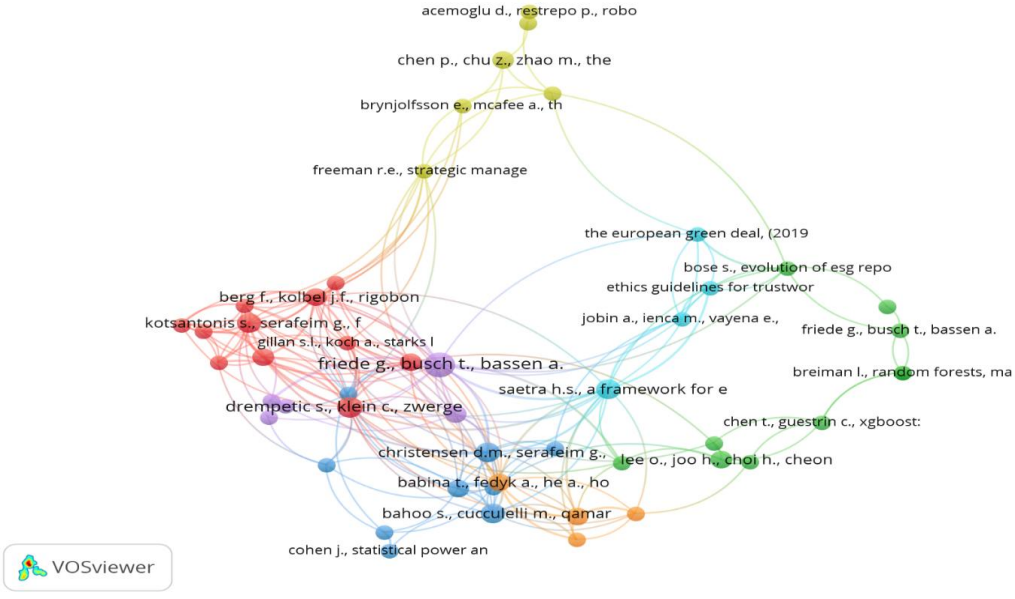

Figure 10. Co-citation analysis of cited references. (*Source: authors' elaboration*)

To uncover the theoretical foundations of research at the intersection of AI and ESG, a co-citation analysis of cited references was conducted. A total of 52 references met the inclusion criteria and were visualized through a network mapping approach. The results identified seven distinct clusters, each reflecting specific thematic orientations and conceptual underpinnings of the field. These clusters represent frequently co-cited works, signaling shared theoretical frameworks, methodological approaches, or topical relevance. The distribution

underscores the multidisciplinary nature and growing complexity of AI applications in ESG research. Importantly, as AI technologies increasingly shape corporate governance, sustainability reporting, and stakeholder engagement, future studies will benefit from integrating behavioral, technological, and ethical perspectives. This multidimensional structure demonstrates not only the consolidation of established frameworks but also the emergence of new research frontiers, highlighting the dynamic evolution of AI-driven ESG scholarship (Figure 10).

4.7. Co-occurrence cluster analysis

The cluster analysis was conducted based on a dataset of 157 publications. The author keywords, as specified in the search strategy, were used as the primary unit of analysis. The keyword co-occurrence analysis reveals how AI and ESG interact across various contexts and disciplines. The significance of this analysis lies in its ability to identify key thematic areas and the relationships among them, offering deeper insight in to how the fields are structured and interconnected.

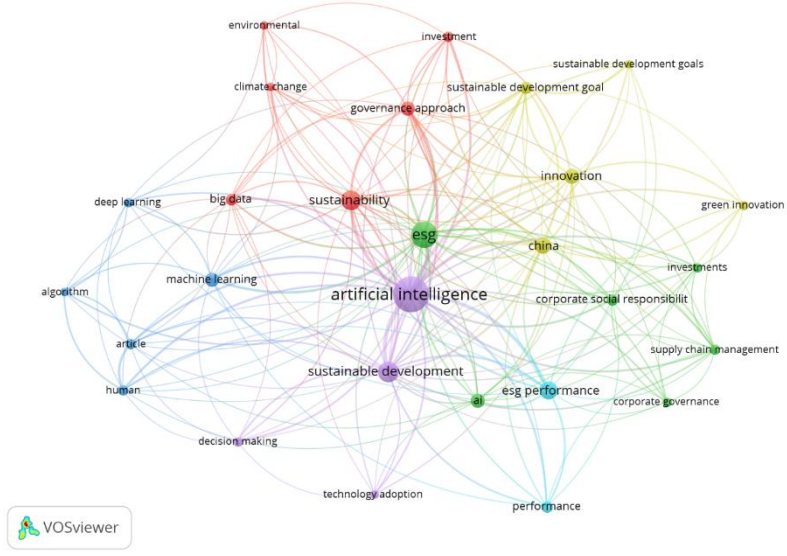

Figure 11. Keyword co-occurrence analysis. (*Source: authors' elaboration*)

The bibliometric analysis reveals six core thematic clusters that collectively map the research landscape of AI and ESG integration. Each cluster reflects unique but interconnected research foci, which are discussed in detail below (see Figure 11).

- Cluster 1 (red) focuses on sustainability and environmental finance, with keywords such as "climate change" (120 occurrences), "big data" (95 occurrences) and "investment" (88 occurrences) as the most frequent terms. These themes highlight the integration of environmental issues with financial governance and sustainable investment practices.

- Cluster 2 (green) emphasizes corporate ESG practices, featuring keywords like "corporate governance" (130 occurrences), "corporate social responsibility" (112 occurrences) and "supply chain management" (90 occurrences), reflecting research on organizational implementation of ESG principles and CSR strategies.

- Cluster 3 (blue) explores AI techniques and methods, with prominent keywords such as "deep learning" (105 occurrences), "machine learning" (98 occurrences) and "algorithm" (85 occurrences), underscoring the technical foundations and methodological advances of AI applied within ESG research.

● Cluster 4 (yellow) centers on green innovation and regional focus, with keywords including "China" (140 occurrences), "green innovation" (115 occurrences) and "sustainable development" (110 occurrences), showcasing the growing interest in region-specific policies and technological advancements in sustainability, especially in emerging economies.

● Cluster 5 (purple) highlights AI applications in sustainability, evidenced by keywords like "artificial intelligence" (95 occurrences), "decision making" (88 occurrences) and "technology adoption" (80 occurrences), illustrating the practical integration of AI tools in sustainability decision processes.

● Lastly, Cluster 6 (cyan) concentrates on ESG performance metrics, with dominant keywords such as "ESG performance" (100 occurrences) and "performance" (90 occurrences), reflecting the importance of measurement, benchmarking and evaluation of ESG initiatives.

Taken together, these clusters offer a comprehensive view of the evolving interdisciplinary field of AI and ESG research, highlighting foundational technical methods, corporate practices, regional innovation dynamics, and the critical role of performance measurement. Importantly, these clusters should not be interpreted in isolation but rather as interconnected dimensions, where technological methods (Cluster 3) enable corporate applications (Cluster 2 and 5), ultimately influencing ESG performance and innovation outcomes (Cluster 4 and 6).

4.8. Emerging Research Trends in AI and ESG

The overlay visualization highlights several emerging research trajectories at the intersection of AI and ESG, as reflected by the yellow-colored keywords that indicate recent scholarly attention. These trends demonstrate a shift from foundational themes, such as sustainability and corporate governance, toward more application-oriented and context-specific areas. Notably, "AI," "decision-making," and "technology adoption" are gaining momentum, emphasizing the role of advanced algorithms in enhancing corporate ESG strategies and stakeholder engagement (see Figure 12).

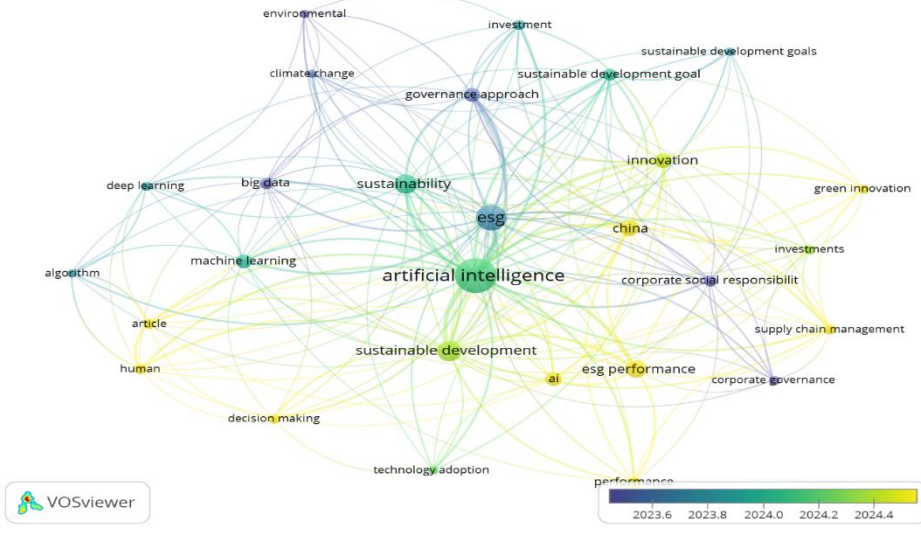

Figure 12. Research trends over the years. (*Source: authors' elaboration*)

Similarly, "ESG performance," "supply chain management," and "corporate social responsibility" represent growing interests in leveraging AI to improve transparency, efficiency, and accountability across organizational processes. Compared with the earlier

keyword and cluster analyses, these trends further confirm a shift toward outcome-oriented and decision-centric research. Geographic-specific inquiries, exemplified by the keyword "China," highlight the increasing contextualization of AI-driven ESG research in emerging economies and their regulatory environments. Moreover, the rising prominence of "green innovation" underscores the dual imperative of aligning technological advancement with sustainable development goals. Collectively, these emerging themes suggest that future research will concentrate on integrating AI-enabled decision-making, responsible innovation, and localized ESG practices to address both global sustainability challenges and firm-level competitiveness.

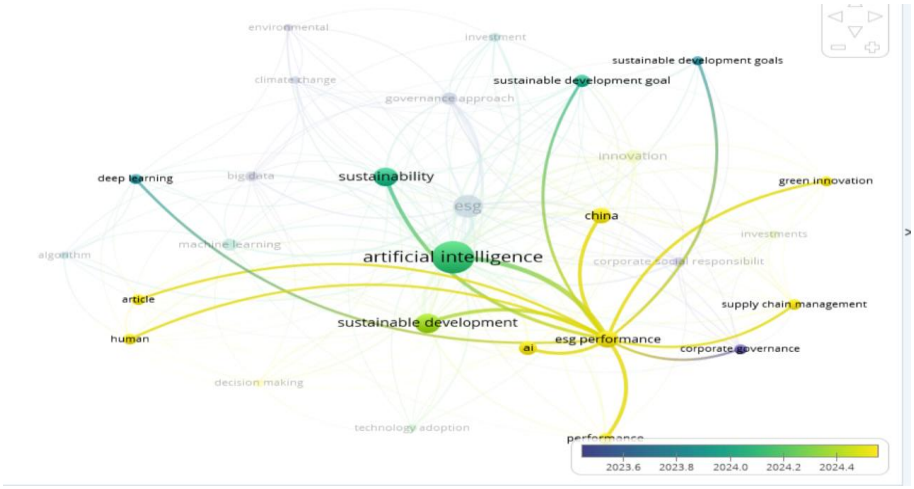

Figure 13. Emerging Research Trends. (*Source: authors' elaboration*)

Figure 13 presents the latest research trends in AI and ESG, capturing the field's evolving priorities toward sustainability, ethics, and human–machine interaction. In summary, emerging trends emphasize the dual role of AI in advancing sustainable development and transforming communication practices. Research at this intersection highlights not only organizational adaptation to technological disruption but also the reconfiguration of customer experiences, stakeholder engagement, and the dynamics of both human–human and human–machine relationships. These directions open new pathways for scholarship to bridge sustainability imperatives with technological innovation, ensuring that AI-enabled ESG practices remain both ethically grounded and socially responsive.

4.9. TCM–ADO framework

Based on the TCM–ADO framework, several important insights can be drawn regarding the research landscape and practical applications of AI in the ESG domain.

First, the TCM framework highlights that the theoretical foundations of AI–ESG research are built upon a wide range of perspectives, spanning from classical theories such as the Resource-Based View (RBV), Stakeholder Theory, and the Theory of Planned Behavior (TPB) to more contemporary lenses such as Digital Transformation, Fuzzy Set Theory, the Technology Acceptance Model (TAM), and Innovation Resistance Theory. This diversity underscores the interdisciplinary and multidimensional nature of the field. Regarding the research context, both developed economies (e.g., the United States, the United Kingdom, Germany, Japan, South Korea, Singapore) and emerging economies (e.g., China, India, Brazil, Indonesia, Thailand) are represented, reflecting the global significance of the topic while also pointing to heterogeneity in the adoption and integration of AI into ESG practices. Methodologically, the field demonstrates substantial variation, employing qualitative approaches (thematic analysis, case studies, focus groups), quantitative

approaches (DID, GMM, PLS-SEM, ML, MCDM), and mixed methods (e.g., fuzzy TOPSIS), which enhances both generalizability and robustness of findings. The scope of stakeholders studied including customers, managers, employees, policymakers, and investors, further confirms the broad reach of AI–ESG, spanning from intra-organizational processes to broader socio-economic ecosystems.

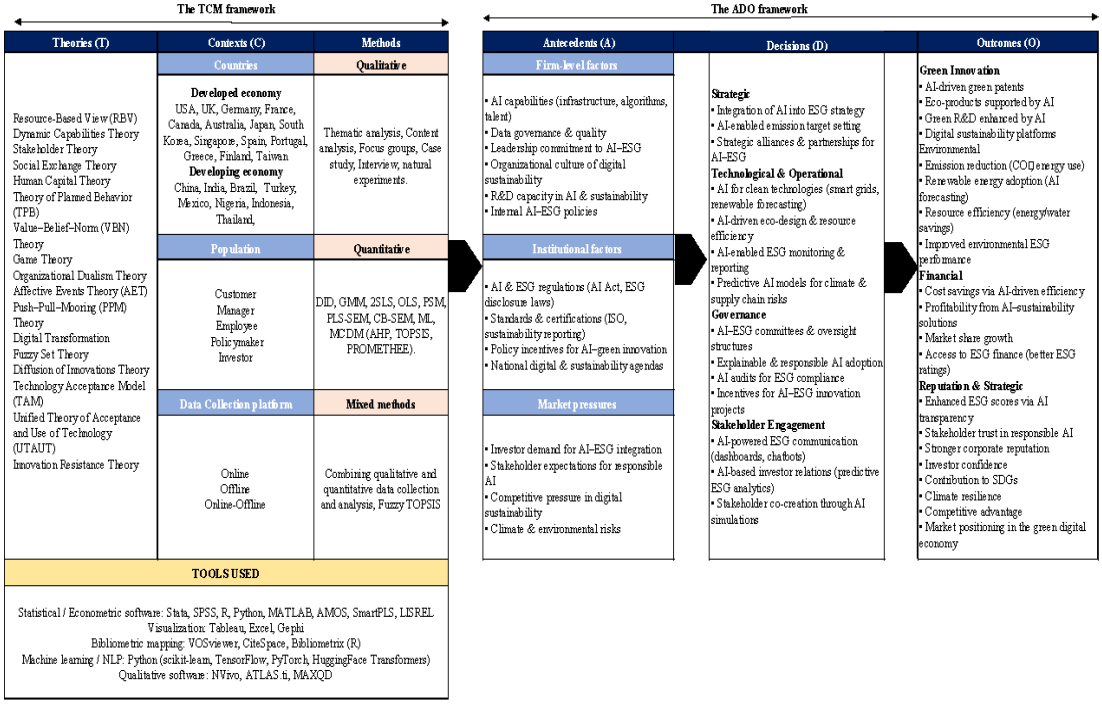

Figure 14. TCM–ADO framework in the context of AI and ESG.

(Source: authors' elaboration)

Meanwhile, the ADO framework emphasizes the dynamic relationships between Antecedents, Decisions, and Outcomes. In the Antecedents stage, AI–ESG developments are driven by three sets of factors: (i) internal organizational resources such as AI capabilities, digital culture, R&D capacity, and internal ESG policies; (ii) institutional factors such as legal frameworks, standards, and governmental incentives for green innovation; and (iii) market pressures from investors, customers, and environmental risks. These antecedents shape Decisions across four key dimensions: strategic, technological operational, governance, and stakeholder engagement. Notable examples include AI-based renewable energy forecasting, ESG monitoring dashboards, AI-driven risk assessment in supply chains, and ESG-oriented customer engagement via intelligent platforms. Finally, Outcomes demonstrate multidimensional impacts: green innovation (eco-products, AI-driven green patents), environmental performance (reduction of emissions, resource efficiency), financial performance (cost savings, profit gains, and enhanced access to ESG-oriented capital), and reputational–strategic outcomes (investor trust, contribution to the UN SDGs, and competitive advantage in the digital green economy).

Taken together, the integration of TCM and ADO reveals a comprehensive and complementary perspective. While the TCM framework emphasizes the diversity of theoretical foundations, contexts, and methodologies, the ADO framework highlights the dynamic chain linking conditions, strategic decisions, and multidimensional outcomes. This synthesis suggests that AI–ESG research is transitioning from a descriptive, theory-building stage toward an application-oriented and impact measurement stage.

Compared with recent bibliometric studies, such as Alessandro [13], which explore the linkages between FinTech and ESG through trend mapping, and [41], which examine circular economy adoption in European SMEs, the present study advances the literature by embedding bibliometric findings within the TCM–ADO framework. Unlike prior studies that primarily focus on identifying thematic structures and research evolution, this approach provides additional analytical depth by explaining how AI-related capabilities are translated into ESG-related decisions and outcomes across different institutional and organizational contexts.

At the same time, adopting a more balanced perspective is essential. Despite its transformative potential, the application of AI in ESG is associated with several challenges, including the high energy consumption of large-scale AI models, potential algorithmic bias in ESG evaluation processes, and concerns regarding transparency and accountability. These challenges may affect the reliability and sustainability of AI-driven ESG practices, thereby underscoring the need for responsible AI governance and robust ethical oversight frameworks.

Future research should strengthen interdisciplinary approaches, big data applications, and AI-driven predictive models, while also deepening connections with public policy, market forces, and societal needs. Such directions will not only enrich theoretical contributions but also provide actionable managerial insights, enabling firms and policymakers to leverage AI as a transformative enabler of sustainable development.

5. CONCLUSION

This study reveals that research on the intersection of Artificial Intelligence (AI) and Environmental, Social, and Governance (ESG) has resulted in a remarkable transformation in both volume and influence. Early publications (2017–2020) were limited in scope and received modest attention, reflecting the nascent stage of scholarly engagement with the topic. However, from 2021 onwards, a sharp increase in both the number of publications and citations demonstrates a significant shift toward mainstream recognition. The surge in 2023–2025, with exponential growth in outputs, underscores the rapid institutionalization of AI–ESG research as a critical domain in sustainability science, corporate governance, and technological innovation. Additionally, co-citation and clustering analyses identify seven thematic orientations, ranging from sustainable development, corporate governance, and green innovation to technology adoption, decision-making, and machine learning, demonstrating the field's intellectual diversity and theoretical depth. Rather than representing isolated streams, these themes collectively indicate an emerging integrated research structure in which technological capabilities, organizational practices, and sustainability outcomes are increasingly interconnected. The co-citation network further shows that leading journals such as Sustainability, Journal of Business Ethics, and Technological Forecasting and Social Change provide the foundational foundations for AI–ESG discourse, while the country-level collaboration analysis underscores the central role of China, the United States, India, and the United Kingdom in shaping global knowledge production. Taken together, these patterns suggest that AI–ESG scholarship is transitioning from a fragmented and exploratory phase toward a more consolidated and application-oriented stage, while still expanding into new thematic directions. The keyword co-occurrence analysis further illustrates the intellectual structure of the field. Instead of reiterating isolated clusters, the results highlight a set of interconnected domains, including: (1) sustainability and environmental finance; (2) corporate ESG practices; (3) AI techniques and methods; (4) regional and green innovation focus; (5) AI applications for sustainability decision-making; and (6) ESG performance measurement. Collectively, these domains reflect a multidimensional research agenda in which methodological advancements in AI increasingly inform governance practices and performance evaluation.

From the perspective of the TCM–ADO framework, several insights emerge. Theoretically, AI–ESG research is grounded in diverse paradigms, including the Resource-Based View, Stakeholder Theory, Dynamic Capabilities, and the Theory of Planned Behavior, Diffusion of Innovations Theory, and Innovation Resistance Theory... which collectively frame how AI capabilities enhance sustainability outcomes. This diversity, as captured in the TCM framework, reflects not only theoretical richness but also the absence of a unified explanatory model, highlighting the need for integrative approaches.

Methodologically, the field employs both qualitative and quantitative approaches, ranging from case studies and thematic analysis to advanced techniques, reflecting an increasing level of analytical sophistication. Contextually, studies span both developed and developing economies, with a notable concentration in China and other emerging markets, suggesting that AI–ESG adoption is highly shaped by national digital agendas and institutional environments. At the same time, the ADO framework underscores the dynamic interplay between antecedents, decisions, and outcomes in AI–ESG research. Antecedents arise from internal organizational capabilities (AI expertise, R&D, digital culture, ESG policies), institutional environments (regulations, standards, incentives), and market pressures (investors, customers, environmental risks). These factors shape strategic, economic, governance, and stakeholder-related decisions, such as deploying AI for renewable energy forecasting, ESG monitoring dashboards, supply-chain risk analytics, or intelligent platforms for stakeholder engagement. Importantly, this ADO structure provides a causal explanation of how AI-related resources and contextual conditions are translated into concrete ESG practices and measurable outcomes. The resulting outcomes extend beyond operational efficiency to include green innovation, improved environmental and financial performance, and enhanced reputational legitimacy, ultimately positioning AI, ESG integration as both a sustainability driver and a source of long-term competitive advantage.

The implications of these findings are threefold. First, for theory, this study highlights the growing need for integrative frameworks that bridge technological innovation with sustainability governance. In contrast to prior bibliometric studies (e.g. [13], [41]), which primarily emphasize trend identification and thematic mapping, the integration of ADO and TCM offers a theory-driven lens that explains the underlying mechanisms linking AI capabilities to ESG outcomes. While existing theories provide strong foundations, the complexity of AI–ESG interactions calls for cross-theoretical models that capture technological, organizational, and institutional dimensions simultaneously. In this regard, the integration of ADO and TCM contributes by offering a structured lens that links fragmented bibliometric evidence to underlying causal mechanisms. Second, for practice, organizations can leverage AI to enhance ESG integration by adopting AI-driven monitoring systems, predictive climate analytics, and green innovation strategies. Firms that align AI capabilities with sustainability objectives not only improve ESG performance but also strengthen competitive advantage and stakeholder trust. Third, for policy, the findings stress the importance of regulatory frameworks and institutional support in shaping responsible AI–ESG adoption. Governments and regulators can foster sustainable AI ecosystems through policies that encourage innovation while ensuring transparency, accountability, and ethical compliance.

However, the study is not without limitations. First, the bibliometric approach does not replace in-depth critical literature analysis, as it lacks the capacity to capture divergent perspectives or provide qualitative insights into content and context. Second, the dataset was limited to publications indexed in the Scopus database, potentially excluding relevant studies from other repositories such as Web of Science or Google Scholar. Third, only English language publications were included, which may have led to the omission of valuable research in other languages.

Despite the limitations and the relatively early stage of research at the intersection of AI and ESG, this review establishes a solid foundation for future empirical inquiry. By mapping the intellectual structure of the field and identifying critical gaps and emerging trends, it highlights the importance of advancing scholarly engagement with AI-driven sustainability practices, governance mechanisms, and ethical challenges, thereby underscoring the transformative potential of AI in shaping ESG strategies in the digital era.

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