Artificial Intelligence in ESG and Sustainable Finance: A Bibliometric Analysis of Research Trends

Adriana AnaMaria DAVIDESCU
Bucharest University of Economic Studies, Bucharest, Romania
adriana.alexandru@csie.ase.ro

Ioana BÎRLAN[*]
Bucharest University of Economic Studies, Bucharest, Romania
[*]*Corresponding author, ioana.birlan@csie.ase.ro*

Eduard Mihai MANTA
Bucharest University of Economic Studies, Bucharest, Romania
eduard.manta@csie.ase.ro

Cristina Maria GEAMBAȘU
Bucharest University of Economic Studies, Bucharest, Romania
geambasumaria14@stud.ase.ro

Abstract. *The integration of Artificial Intelligence (AI), including Machine Learning (ML) and Natural Language Processing (NLP), into Environmental, Social, and Governance (ESG) frameworks and sustainable finance has gained significant academic and industry attention. This study presents a bibliometric analysis of research at the intersection of AI, ESG, and sustainable finance, using Web of Science data from 2004 to 2025. Our analysis maps the evolution of research trends, identifies key authors, influential publications, and collaboration networks, and explores the intellectual structure of the field. Using co-citation analysis, keyword co-occurrence mapping, and thematic clustering, we reveal how AI-driven methodologies have shaped ESG assessments, sustainable investment strategies, and financial decision-making. Findings highlight a sharp rise in AI applications in ESG post-2015, particularly in ESG risk modelling, climate analytics, and AI-driven reporting. This study provides a comprehensive overview of the evolving academic discourse, identifying emerging research directions and challenges related to data standardization, transparency, and ethical AI applications in sustainability.*

Keywords: Bibliometric analysis, Artificial Intelligence, Machine Learning, NLP, ESG, Sustainable Finance

Introduction
The integration of Artificial Intelligence (AI), including Machine Learning (ML) and Natural Language Processing (NLP), into Environmental, Social, and Governance (ESG) frameworks and sustainable finance has emerged as a pivotal and rapidly expanding research area. The increasing complexity and significance of ESG reporting and sustainable investment strategies have driven academia and industry stakeholders towards innovative technologies capable of addressing issues related to data quality, analytical complexity, and transparency in ESG evaluations. Given the growing significance of ESG in guiding financial and investment decisions, AI methodologies provide advanced tools for enhancing accuracy, efficiency, and comprehensiveness in ESG assessments.

This study presents a comprehensive bibliometric analysis focused on the intersection of AI, ESG, and sustainable finance research, examining scholarly publications indexed in the Web of Science from 2004 to 2025. It aims to identify the evolution of research trends, prominent authors, influential works, and the structure of academic collaboration networks within this multidisciplinary domain. Utilizing techniques such as co-citation analysis, keyword co-occurrence mapping, and thematic clustering, this analysis maps the intellectual landscape of AI-driven ESG research, highlighting key developments, influential studies, and emerging thematic areas.

The primary research question guiding this investigation is: (RQ) How has the integration of AI impacted research trends and practical approaches within ESG assessment and sustainable finance between 2004 and 2025? To answer this question, two primary hypotheses were formulated: (H1) The incorporation of AI techniques into ESG assessment methodologies and sustainable finance strategies has accelerated significantly after 2015, driven by advances in technology and regulatory developments and (H2) the use of AI methodologies significantly contributes to improved ESG scoring reliability, enhanced sustainable investment strategies, and better-informed financial decision-making.

This study contributes to existing literature detailing insights into how AI influences ESG assessments and sustainable financial practices, outlining emerging challenges such as data standardization, transparency, and ethical considerations associated with AI deployment. The findings serve both academia and industry stakeholders by identifying gaps and suggesting directions for future research and practical implications for ESG and sustainable finance.

Following the introduction, the paper is structured as follows: Section 2 contains an in-depth literature review, covering important research contributions and making clear areas where a gap exists for AI ESG and sustainable finance. In Section 3, the methodology for the bibliometric analysis is described. This section explains the data collection process, what computational techniques are used and which indicators are employed. Then, in Section 4 the results and discussions are presented. This part gives an overview of current research trends, major pieces of research, key authors and theme clusters within this discipline. Finally, in the last section the main findings are synthesized.

Literature review

In recent decades, ESG (Environmental, Social, and Governance) scores have become a key focus area in academic and business literature. This can be proven just by looking at the growing body of bibliometric studies on ESG's evolving role and the key research gaps surrounding it.

Recent bibliometric works have highlighted the transformative role of ESG in driving strategic decisions in banking (Galletta et al., 2022; Carè et al., 2024) and further improving risk management (De Giuli et al., 2023). These studies suggest that integrating ESG criteria can be an effective way to mitigate reputational and operational risks. Similarly, Petrica et al. (2024) mapped trends in ESG research from 2009 to 2023 and identified an overlap between ESG, corporate governance and sustainability strategies.

In a similar manner, other authors conducted a bibliometric analysis covering ESG research from 2006 to 2022 (Chytis et al., 2024). Their study identified key themes such as ESG disclosure, financial performance, sustainable investing, and risk management. According to their keyword analysis, there is also a trend toward incorporating more sophisticated analytical techniques into ESG research that can lead to clearer and more standardized ESG scoring methods that can mitigate increasing concerns around greenwashing and corporate disclosure practices.

Artificial intelligence has emerged as an important theme in recent research due to its potential to improve ESG reporting and investment decision-making. For example, Doddipatla (2024) showed in his article that technologies like machine learning, predictive analytics, and big data significantly enhance decision-making in green investment contexts. Khaw et al. (2024) validated this insight through a bibliometric review, highlighting AI as a promising new approach to improving ESG reporting quality and reliability. Additionally, Brière et al. (2022) reviewed existing applications of AI for different use cases in ESG, including text-based analysis for detecting ESG incidents and the use of satellite imagery for assessing environmental degradation. Their research also identifies AI as an essential tool in the creation of alternative ESG data sources that go beyond the traditional reliance on corporate disclosures.

Recent literature also comprehensively addressed the challenges regarding the ethical and responsible deployment of AI applications in sustainable finance. Radclyffe et al. (2024), for instance, critically reviewed the "Seven Principles for Trustworthy AI" outlined by the European Union's High-Level Expert Group on AI and assessed whether they were applicable and effective in the context of sustainable finance. The authors highlighted the increasing significance of transparent, accountable, and explainable AI practices, particularly in light of concerns over data privacy, algorithmic bias, and the quality of ESG assessments. Looking towards the future, Freunek and Niggli (2024) proposed an innovative dynamic indicator based on patent data, employing text mining and machine learning to enhance ESG analysis.

Overall, the body of literature reviewed demonstrates that there is a high degree of activity and evolution occurring at the intersection of AI with environmental, social and governance, and sustainable finance themes. In addition, it reflects the vast potential of AI technologies that can enhance ESG-related analysis, reporting mechanisms, and strategic investment decisions, though highlighting the ongoing challenges regarding data standardization, transparency, and ethical considerations.

Methodology

This study uses bibliometric analysis to examine the growing body of literature on Artificial Intelligence (AI), Environmental, Social, and Governance (ESG) criteria, and sustainable finance. Based on established methodologies by Donthu et al. (2021), Broadus (1987), and Pritchard (1969), the bibliometric approach provides a comprehensive overview of the extensive academic literature, identifying emerging trends and outlining the existing research gaps in this fast-developing domain.

The first step in this analysis was to retrieve data from Clarivate Analytics Web of Science, covering articles published between 2004 and 2025. The year 2004 was chosen as the starting point because of the influential United Nations report "Who Cares Wins," which popularized ESG criteria in mainstream financial discourse (United Nations, 2004).

Based on the research questions formulated above, a structured search query was used that combines terms related to sustainability and advanced analytics. The final search query is as follows: ("ESG" OR "sustainable finance" OR "green finance" OR "sustainable investment") AND ("AI" OR "artificial intelligence" OR machine learning" AND "ML" OR "NLP") To avoid potential bias in the search results, this study only included articles available in English since the both the abstracts and titles were determined to be relevant.

Two primary approaches guided this analysis. First, performance analysis was conducted using metrics such as total publications (TP) and total citations (TC) to evaluate the productivity and impact of authors, institutions, and journals in the research area (Curi et al., 2024). This

provided an overview of the most influential countries, institutions, and researchers. Second, science mapping analyses were performed, including keyword co-occurrence network analysis (Newman, 2003) and co-citation network analysis among cited studies (Kessler, 1963). These techniques segmented the network of articles based on their similarities in shared references, revealing thematic clusters based on major research themes (Rasul et al., 2022; Bastian et al., 2009). Lastly, an institutional collaboration network analysis was performed and highlighted international collaboration trends particularly across Europe, North America, and Asia.

The analyses were conducted through the Bibliometrix package in R, and the metadata was retrieved solely from the Web of Science database. This analysis was limited to research article document types and only exported metadata in Bib format. The database metadata exported detailed publication information, author names and affiliations, ORCID identifiers, article titles, abstracts, keywords, citation information, and funding information, providing extensive coverage of current trends in research at the confluence of AI and ESG.

Results and discussions

A careful look into the yearly publications from 2004-2025 shows a rapidly increasing scholarly interest in applications of AI to ESG and sustainable finance, with an annual growth rate of 19.75% (Figure 1). A total of 898 documents from 496 distinct academic sources were analysed, involving contributions from 3,188 authors. The relatively young average document age of 2.26 years highlights how new and rapidly developing this field is. Additionally, there is a significant level of international co-authorship, representing 33.07% of the total, which highlights strong global cooperation in research. On average, there are 3.88 co-authors per document, reflecting strong academic cooperation, with only 75 single-authored documents identified. These articles also show significant scholarly influence—an average of 9.283 citations per article. These diverse metrics collectively reveal the rising relevance and international engagement in AI-driven ESG research and are consistent with the observations made by Chytis et al. (2024), who also observed a sharp rise in publications from 2019 onwards, fuelled by shifting regulatory climates, advances in technology, and increased corporate commitments to sustainability.

Timespan	Sources	Documents	Annual Growth Rate
2004:2025	496	898	19.75 %
Authors	**Authors of single-authored docs**	**International Co-Authorship**	**Co-Authors per Doc**
3188	75	33.07 %	3.88
Author's Keywords (DE)	**References**	**Document Average Age**	**Average citations per doc**
3094	52971	2.26	9.283

Figure 1. Summary of the bibliometric analysis

Source: Authors' own research.

In addition, this analysis indicated that a few key journals lead the conversation on AI and sustainable finance. First and foremost is Sustainability, as shown in Table 1, which published 78 articles-by far the most of any journal. This means that researchers identify Sustainability as a key forum for researching these issues. The Journal of Cleaner Production (20 articles), Energies (18 articles), and IEEE Access (17 articles) had notable contributions too, highlighting their relevance for communication of prime studies and breakthroughs. Other journals that have become significant outlets for this body of work include Journal of Environmental Management, Finance

Research Letters, and Resources Policy. Most of the journals focus on environmental sustainability, cleaner technologies and energy topics, indicating that scholarly dialogue regarding AI in ESG and sustainable finance are mostly had in environmentally concerned academic communities. This trend suggests a narrower thematic engagement, as opposed to a broad multidisciplinary practice.

Table 1. Sources and number of articles published

Sources	Articles
Sustainability	78
Journal of Cleaner Production	20
Energies	18
Ieee Access	17
Journal of Environmental Management	15
Finance Research Letters	12
Resources Policy	12
Environmental Science and Pollution Research	11
Annals of Operations Research	9
Technological Forecasting and Social Change	9

Source: Authors' own research.

Several high-impact foundational studies shaping the discourse around AI, ESG, and sustainable finance are captured through citation analysis in Figure 2. The most cited work, authored by Demolli et al. (2019) with 244 citations, explores how optimization through artificial intelligence can transform energy conversion processes and enhance sustainable energy management. Following closely, Tuptuk and Hailes (2018), with 234 citations, study cybersecurity risks in industrial systems, a topic of growing relevance due to the widespread adoption of AI-powered automation in infrastructure and manufacturing. Their focus on vulnerabilities and resilience within digital financial and industrial ecosystems has broad implications for ESG and sustainable finance, particularly in responsible AI governance.

Moosavi et al. (2022) cited 223 times, address disaster risk assessment using AI and big data, a pivotal research area in ESG as financial institutions increasingly adopt predictive models to evaluate climate-related risks. This study underscores the growing significance of AI-driven climate risk analytics, which is becoming an essential tool in sustainable finance and investment decision-making. Similarly, Kakani et al. (2020), with 203 citations, investigate AI applications in agricultural sustainability, demonstrating how machine learning models can contribute to food security and resource efficiency-both crucial components of the environmental (E) pillar of ESG.

Adding to this narrative, Wang M. (2021) provides insights into structural economic adjustments driven by green finance, with 145 citations, further emphasizing the role of financial mechanisms in sustainable industrial transitions.

These studies are prominent due to their critical role in shaping discussions around AI, sustainability, and financial systems. Collectively, they showcase the growing dependence on AI-driven analytics, risk modelling, and green financial instruments to help dictate sustainable investment strategies and policy designs. Interdisciplinary research intertwines AI, environmental science, and financial analytics to solve sustainability problems. These works will continue to play an important role in policy discussions regarding ESG integration, and the use of financial

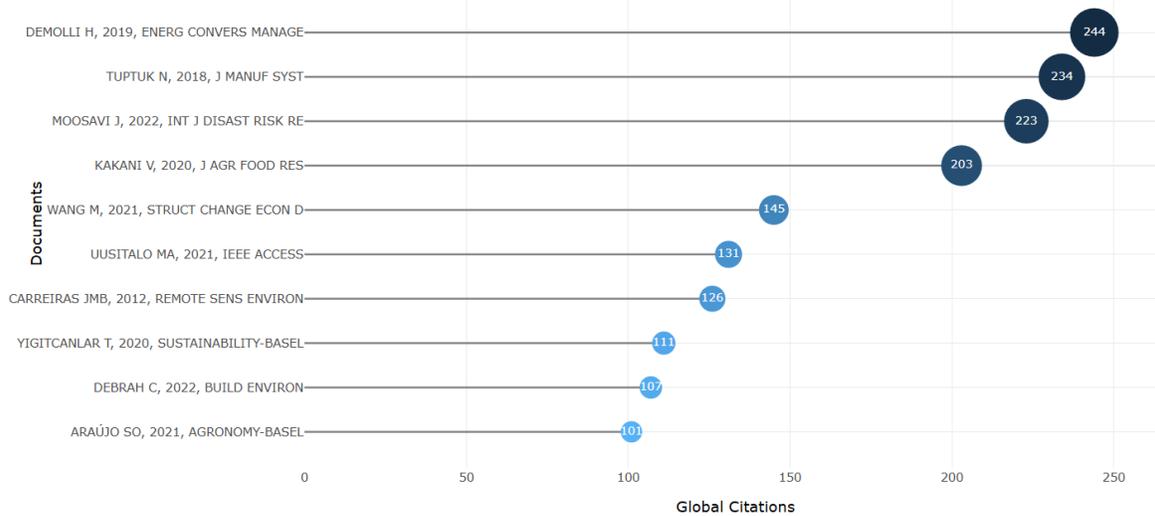innovation to help build resilience and sustainability in economies worldwide.

Figure 2. Most Cited works

The keyword network in Figure 3 offers a structured summary of the growing dialogue surrounding AI, ESG and sustainability. At the core of this network, impact and performance emerge as dominant themes, reflecting a research interest in measuring and improving the concrete benefits of ESG activities. These concepts are closely aligned with corporate social responsibility (CSR), innovation, and governance functions, indicating an increasing trend towards harnessing AI capabilities not only for monitoring ESG results but also potentially for driving improvements in sustainability outcomes.

One significant branch of the network is centred on models, with key terms such as prediction, optimization, regression, and neural networks. This cluster underscores the increasing use of AI algorithms in ESG-based decisions. These terms highlight the role of machine learning and big data in improving the accuracy of risk assessments, climate impacts, and financial investments to drive environmental, social, and governance (ESG) performance.

Another distinct cluster is centred around management, incorporating terms such as artificial intelligence, big data, frameworks, and systems. This categorization of AI's potential impact reflects its role in operationalizing ESG traits that improve an organization's ability to build and manage more efficient supply chains, environmental emissions tracking and integration of sustainability factors into both strategic and operational planning.

There is also a smaller but significant cluster correlating renewable energy and economic growth in which words like energy consumption, productivity and responsibility indicate an academic interest in managing the balance between economic advancement and environmental sustainability. This emphasizes the function of artificial intelligence in allowing more effective usage of resources and guiding use policies that benefit both economic development and environmental targets.

In summary, the network demonstrates the growing importance of AI in ESG conversations. No longer simply an add-on tool in support of sustainability efforts, AI is playing a central role in how companies, investors and policymakers are implementing ESG. From advanced analytics, automation or improved reporting mechanisms, AI is driving the more data-

driven and outcome-focused approach to sustainable finance and corporate responsibility.

Figure 3. Key words analysis

Source: Authors' own research.

The co-citation mapping in Figure 4 provides a view of the intellectual foundations of AI and ESG research, highlighting influential studies that have shaped discourse in these fields. The largest cluster, centred around Friede et al. (2015), represents foundational work on socially responsible investment (SRI), corporate social responsibility (CSR), and ESG integration in financial decision-making. This research and its interconnected works explore the growing role of sustainability disclosure, corporate governance, and ethical investing (Alhasnawi et al., 2024; Roy & Vasa, 2025).

A second important cluster, led by Berg et al. (2022), of the use of AI in ESG analysis, focusing on the role of alternative data and state-of-the-art sustainability evaluation. This cluster showcases the growing role of analytics (using big data), sentiment analysis, and machine learning models in ESG scoring. The developments are also indicative of the growing importance of corporate transparency, with AI improving the quality of ESG disclosure and helping reduce information asymmetry in company investments.

A third, smaller group, which includes Friedman (2001) and Breiman (2001), focuses on statistical and machine learning approaches critical to AI-based ESG data analytics. They also introduced ensemble learning methods like random forests and bagging, which can be used for ESG risk prediction, corporate reputation analysis and impact investing strategies.

The red cluster, which includes Acemoglu and Restrepo (2020) and Graetz and Michaels (2018), looks at AI's wider economic and social impact, with a particular focus on the labour market. As opposed to the ESG-focused clusters, this cluster looks at the implications of automation, robotics, and AI-based technologies on employment, income, and labour displacement. Evidence from Acemoglu and Restrepo (2020) indicates that industrial robots decrease employment and wages in the local labour market, while Graetz and Michaels (2018) show that robot adoption raises productivity but does not lower aggregate employment, though it affects labour demand towards lower skill workers. This cluster indicates the complex, systemic

nature of AI's engagement with ESG and macroeconomic factors - a signal of both its potential and risk.
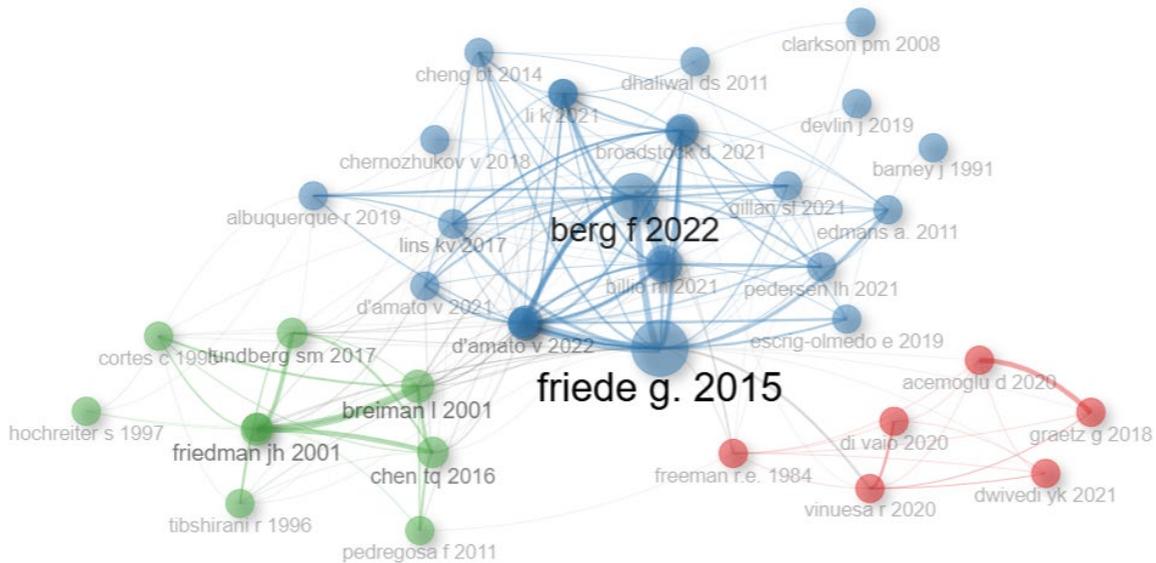
Figure 4. Papers co citation

Source: Authors' own research.

International research collaborations formed a complex web across Europe, North America, and Asia which is reflected in the institutional network visualization (Figure 5). The Chinese Academy of Sciences emerges as an important institution for cross-border academic collaborations with institutions such as Sun Yat-sen University, Korea University, and Sichuan University.

A distinct network emerges around Azerbaijani and Chinese institutions, particularly the Ministry of Education of Azerbaijan Republic and Shanghai University of Finance and Economics. This cluster is a reflection of the increasing regional focus on economic and educational research and the cooperation between the regions in the respective areas. Similarly, the University of London and University College London appear as key nodes in the European research landscape, with ties extending to the University of California System and Beijing Institute of Technology, showcasing transatlantic collaboration.

As shown in the network, the color-coded clusters present different, but interrelated research communities, where European and North American institutions seem more centralized in the network and Asian institutions have a more dispersed structure. This pattern suggests a recent shift away from Eurocentric research partnerships towards a diversified and integrated global model. The growing presence of institutions from China and Azerbaijan highlights their rising role in driving global research priorities.

Figure 5. Founding Institutions

Global research collaboration is shown in Figure 6, indicating strong academic collaboration between China and the United States and other parts of Asia and Europe. The deep blue areas show that the main nodes of scientific activity occur with China and the U.S. These two countries dominate knowledge transfer internationally. The connecting lines illustrate bilateral partnerships, with a significant concentration of collaborations between North America and Asia, particularly China and India. The lighter blue regions indicate moderate research engagement, whereas grey areas suggest limited or no academic exchanges. The overall trend highlights the prominence of China and the U.S. in producing international collaboration networks, reinforcing their influence in international scientific cooperation.

Figure 6. Countries publishing

Our findings align with previous research highlighting the increasing role of AI in ESG assessments and sustainable finance. The sharp rise in AI applications for ESG post-2015, as identified in our study, is consistent with the observations of Chytis et al. (2024), who also noted a growing emphasis on AI-driven methodologies in ESG research, particularly in areas such as ESG disclosure, risk management, and sustainable investment strategies. Additionally, the ethical concerns regarding AI deployment in ESG frameworks, which we identified as a key emerging challenge, were also highlighted by Radclyffe et al. (2024), who emphasized the need for greater

transparency and accountability in AI applications for sustainable finance. Collectively, these studies confirm the increasing reliance on AI for ESG assessments while also emphasizing the need for standardized methodologies and ethical guidelines to ensure responsible AI implementation in sustainability practices.

Conclusion

This paper systematically analyses the academic literature at the confluence of Artificial Intelligence, ESG, and sustainable finance from 2004 to 2025. The findings provide powerful evidence that after 2015, AI and ESG research papers increased. The findings prove Hypothesis 1 and it is closely related to advances of the AI technology itself, increased regulatory pressure for ESG disclosure as well.

Our results also substantiate Hypothesis 2, indicating that AI methodologies significantly improve the reliability and precision of ESG assessments and sustainable finance strategies. AI applications, including predictive analytics, NLP, and machine learning models, are increasingly influential in refining ESG scoring, enhancing sustainability risk assessments, and guiding sustainable investment decisions. However, our analysis also highlights significant ongoing challenges related to data standardization, ethical considerations, and transparency of AI-driven ESG applications.

This study presents several limitations, primarily stemming from the exclusive reliance on the Web of Science database, which may omit relevant literature available in other databases or languages. Furthermore, the analysis predominantly included journal articles, potentially overlooking valuable insights from conference proceedings, industry reports, and grey literature.

Future research should extend the analysis to other databases, such as Scopus or Google Scholar, to capture a more comprehensive view of the literature. Additionally, further exploration of AI applications in specific ESG domains such as social and governance aspects could provide more detailed insights. Moreover, addressing ethical and regulatory implications of AI deployment in ESG and sustainable finance represents a crucial avenue for future investigations.

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