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Research Article

Mapping the Nexus Between Artificial Intelligence (AI) in Sustainable Finance and Environmental Social Governance (ESG): A Bibliometric Analysis

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ABSTRACT

The primary objective of the present study is to examine the current academic research on Artificial Intelligence (AI) in Sustainable Finance and Environmental Social Governance (ESG). 252 relevant research papers were extracted from the Scopus database, covering the 2020–2024 time period. The authors employed the statistical programme R-studio & and VOSviewer software for conducting bibliometric analysis using methods such as scientific mapping (co-word analysis, bibliographic coupling) and performance analysis (most influential authors, publications, countries, and journals). The scientific mapping reveals five niche topics that prior research has focused on such as ESG and Firm value, ESG and Sustainable Finance, COVID-19 Impact on Green Investments, ESG & Innovation and Sustainable Finance & Corporate Performance. Future research should explore the influence of industry-specific variables and geographic factors on the credibility of ESG data, as well as examine the impact of COVID-19 on the correlation between ESG performance measures. Additionally, investigating the relationship between AI and renewable energy development through deep learning algorithms could enhance our understanding of ESG factors and their connection to financial performance. The

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examination of current academic research on AI in Sustainable Finance and ESG can inform policymakers on the potential of AI-driven tools to enhance the accuracy and reliability of ESG assessments, thereby guiding more effective and data-driven sustainability policies and investment strategies.

Keywords: Environmental Social and Governance (ESG), Artificial Intelligence (AI), Sustainable Finance, bibliometric analysis, Vos-Viewer, R-Studio

INTRODUCTION

Artificial intelligence (AI) is rapidly expanding into emerging fields in the fields of commerce, corporate practice, and government policy (Elouidani & Outouzzalt, 2023). The combination of artificial intelligence (AI) with the concepts of sustainable finance and Environmental, Social, and Governance (ESG) standards has attracted considerable interest in the constantly changing field of finance (D'Amato et al., 2022 ;Friede et al., 2015). Sustainable finance, which prioritizes the long-term protection of the environment, social accountability, and transparent management, is increasingly recognized as a vital element in striving for global economic stability and environmental sustainability (Sachs et al., 2019). Simultaneously, AI technologies are revolutionizing several industries by facilitating data-based decision-making, improving operational effectiveness, and strengthening predictive analytics. The convergence of artificial intelligence and sustainable finance offers a distinct and exceptional prospect. ESG involves the concept of accountability towards society and the environment, while also aiming to generate financial gain (Minkkinen et al., 2024). According to (Hughes et al., 2021) ESG maintains a minimum of USD 17.5 trillion in assets (as of 2018), representing about 25% of the total value of the global asset management business, which amounts to USD 74.3 trillion.

Investors, businesses, and government agencies have increasing difficulty in making well-rounded judgments on ESG concerns due to the exponential growth in the amount of data accessible. The information that stakeholders relied on in the 1980s was limited to official statistics and a few public reports; however, in the 2020s, they can supplement this with data from the Internet of Things, news articles, social media reviews, and aerial and satellite remote sensing (In et al., 2019). The use of AI in ESG models has become a major force in sustainable finance over the past few years. AI technologies give us new ways to look at data, calculate predictions for the future, and make decisions (Macpherson et al., 2021). This helps companies improve their ESG performance and meet the growing demands of stakeholders for openness and responsibility. Innovative financial products and services are being developed by AI, which is transforming green finance. The use of AI is rising in the context of green bond, sustainability-linked loan, and impact investment fund industries to ensure ESG compliance and track the progress of funded projects (Musleh Al-Sartawi et al., 2022). Also, prior studies have shown that the advancement of AI technology, specifically through the use of industrial robots, contributes to the reduction of inequalities between developed and developing nations (Yang & Wang, 2023). Additionally, it enhances the quality of traded goods (Lin et al., 2022), fosters environmentally friendly innovation (Lee et al., 2022), and decreases carbon emissions (Wang et al., 2023)(Yu et al., 2023). AI systems may automate the tracking of sustainability metrics to guarantee that funds are being used appropriately and making the expected impact. There have been numerous studies that encompass AI, SF and ESG (Bhutta et al., 2022) analysed the factors associated with the growth and impact of green bonds on issuers' fundamental performance measures in meeting ESG (Cardillo et al., 2023) also emphasized the effect of the ESG rating on firm performance, sustainability, and stock market performance in European countries. (Hassan et al., 2022) investigated the convergence of ESG factors with religious screening and its impact on corporate risk. however, to the best of our knowledge, no further studies have specially acknowledged the role of AI in SF and ESG that probably impacts their interaction. Therefore, the purpose of this study is to offer a comprehensive overview of the current literature and objectively investigate the emerging research themes. To accomplish this, we investigate various research questions (RQs) linked to AI, SF and ESG research. What are the most influential

authors, articles, journals, and countries in this study (RQ1)? What are the primary foundational themes that have been examined in previous studies and emerging frontiers that are likely to shape in the future (RQ2)? What are the Keywords frequently appearing together that have a thematic relationship with one another (RQ3)? The paper consists of 8 sections. Section 2 deals with research methodology. Section 3 presents results and interpretations. Section 4 consists of future direction of the study. Section 5 presents policy implication. Section 6 deals with discussion. Section 7 consists of conclusion. Section 8 presents reference.

MATERIALS AND METHODS

This study conducted an in-depth literature review on the topic of AI, sustainable finance (SF), and ESG. The primary methodology used in this study is bibliometric analysis, as described by (Donthu et al., 2021). This approach reduces the possibility of subjective interpretation bias (Pandey et al., 2023) that frequently affects evaluations utilizing qualitative methodologies (MacCoun, 1998) Furthermore, the utilization of tools and techniques, such as performance analysis, and science mapping, facilitates the management of large amounts of bibliographic data (Ramos-Rodríguez & Ruíz-Navarro, 2004). Therefore, utilizing the bibliometric strategy is appropriate for addressing our study questions.

To conduct a comprehensive examination of the relevant scientific literature, the authors conducted a search utilizing the Scopus database and utilized several keyword combinations, namely the operators 'OR' and 'AND' to combine keywords and discover pertinent material1. The chosen keywords directly compress the nexus between AI, SF and ESG. In order to address the research question (RQ1), which focuses on identifying the publishing pattern, prolific journal, most influential author(s), and articles, the study utilized performance analysis. This involves the examination of publications and their citations as indicators of production and impact, respectively (Ding et al., 2009). The authors as employed bibliography coupling for (RQ2) According to (Kessler, 1963), bibliographic coupling is a scientific mapping approach that relies on the idea that publications with shared references are likely to have similar content and words that frequently appear together have a thematic relationship with one another, for (RQ2) the authors has employed co-word analysis The primary focus of other science mapping techniques is on publications, whereas co-word analysis evaluates "words" as the unit of analysis. The technique of co-word analysis involves thoroughly examining the publication's actual content. In co-word analysis, the words are typically obtained from "author keywords." However, if these keywords are not available, notable words can be extracted from "article titles," "abstracts," and "full texts" for the analysis (Baker et al., 2020).

2.1 Software and Tools

This study employs two analytical software programs such as Vos-Viewer and RStudio. Vos-Viewer where Vos stands for (visualization of similarities) tool creates a visual depiction of the database and graphs, enabling the visualization of hotspots and interconnected networks in the study field, created in 2009 by Van Eck and Waltman from the Centre for Science and Technology Studies (CWTS) at Leiden University in the Netherlands (Eck & Waltman, 2009). RStudio is R's integrated development environment (IDE), which includes a console, a syntax highlighting editor that supports direct code execution and tools for drawing, history, debugging and words J Allaire (2012).

[1] (TITLE-ABS-KEY ("AI AND Sustainable Finance")) OR (TITLE-ABS-KEY ("Artificial Intelligence AND Sustainable Finance")) OR (TITLE-ABS-KEY ("AI and ESG")) OR ((TITLE-ABS-KEY ("Sustainable Finance and ESG"))

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2.2 Search Criteria and Article Selection

The authors have employed a synthesis of the PRISMA recommendations (Page et al., 2021) and the workflow plan suggested by (Zupic & Čater, 2015) The workflow plan has five primary stages: (1) study design, (2) compilation of bibliometric data (utilizing the PRISMA 2020 flow diagram), (3) analysis, (4) visualization, and (5) interpretation, as seen in Figure 1.

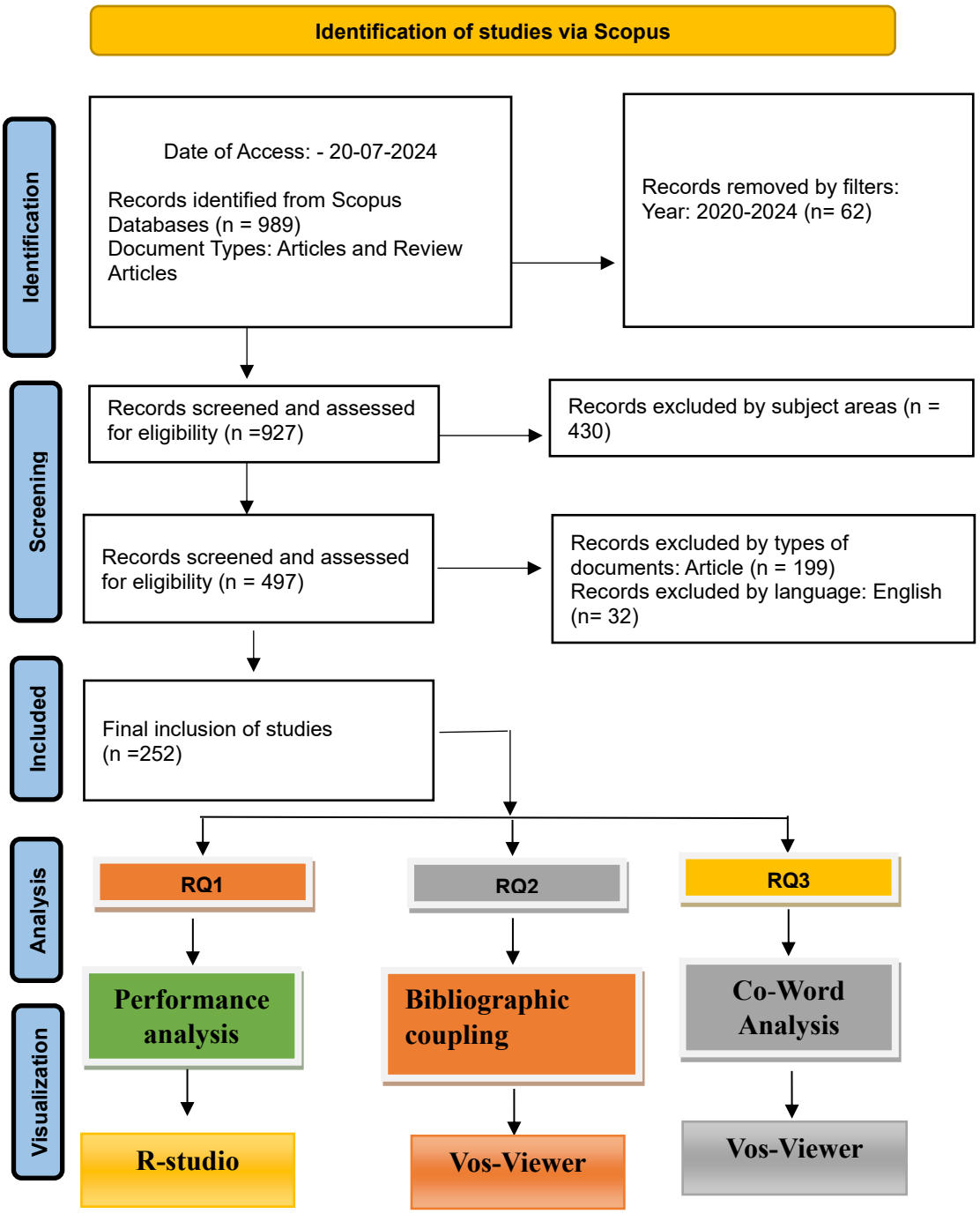

Figure 1: Prismatic Flow Chart

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RESULTS AND INTERPRETATIONS

3.1 Performance Analysis [RQ1]

Table 1: Number of articles and their citations each year in field of AI, Sustainable finance and ESG research in the time period of 2020-2024.

Year	No. of Article	Total Citation	Total Citation per year	Total Citation Article
2020	14	766	10.94	54.71
2021	15	393	6.55	26.2
2022	54	1114	6.88	20.63
2023	82	871	5.31	10.62
2024	87	152	1.75	1.75

Source: R Studio Output

Error! Reference source not found. indicates the annual publication trend in the field of AI, S ustainable finance, and ESG. During the period from 2020 to 2024, a total of 252 articles were published and received a total of 3296 citations times. This produced on an average of 13.08 citations per document. Only 14 articles were published in 2020, but they managed to receive a remarkable 766 citations and 54.71 TC citations per year. The trend of publication in AI, SF, and ESG has shown a consistent increase, with an annual growth rate of 57.89%. In 2024, a significant number of 87 articles were published, which have garnered a substantial 152 total citations. In 2022, the number of citations reached its peak at 1114.

Table 2: Top Ten Most Impactful Sources (Journal)

Sr. No	Journal	Publisher	ABDC Ranking	Total Publications	Citations
1	Journal of Cleaner Production	Elsevier	A	16	119
2	Journal of Sustainable Finance and Investment	Taylor and Francis Ltd.	-	15	245
3	Business Strategy and The Environment	John Wiley and Sons Ltd	A	13	407
4	Resources Policy	Elsevier	B	13	106
5	Energy Economics	Elsevier	A*	10	150
6	Finance Research Letters	Elsevier	A	9	120
7	Corporate Social Responsibility and Environmental Management	John Wiley and Sons Ltd	C	8	62
8	Research in International Business and Finance	Elsevier	B	7	45
9	Technological Forecasting and Social Change	Elsevier	A	7	208
10	Journal of Risk and Financial Management	MDPI	B	6	138

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Source: R Studio Output

Academic journals are regarded as the primary medium for sharing scientific output and are worthy of investigation in any scientific field (Wuni et al., 2019). An investigation has been conducted on the leading and preferred publications that have published works in the fields of AI, SF, and ESG. A total of 104 publications on the topics of AI, SF, and ESG were published in the top 10 journals from 2020 to 2024. **Error! Reference source not found.** displays the rankings of the ten most productive j ournals, including the corresponding figures, (Australian Business Deans Council) rankings and the number of publications and the number of citations. The Journal of Cleaner Production an 'A' ranked journal from Elsevier is the most prominent journal among authors, with 16 publications and 119 citations, indicating its significant influence in the field. It is followed by the Journal of Sustainable Finance and Investment, which has 15 publications and 245 citations, and Business Strategy and The Environment, another 'A' ranked journal from John Wiley and Sons Ltd, reveals a high engagement with 13 papers and 407 citations. Elsevier's Resources Policy, which is ranked B, has demonstrated strong performance with 13 published papers and 106 citations. The A* ranked Energy Economics, also published by Elsevier, has had a significant impact with 10 papers and 150 citations. Finance Research Letters, another publication from Elsevier and ranked A, has contributed 9 papers and received 120 citations. Technological Forecasting and Social Change, published by Elsevier Inc., has a total of 7 publications and a notable citation count of 208. The Journal of Risk and Financial Management, published by the Multidisciplinary Digital Publishing Institute (MDPI), has a total of 6 publications and has been cited 138 times.

Table 3: Top Ten Most Influential Articles

Author(S)	Article	Journal	Total Citation	Links
(Drempetic, et al., 2020)	The Influence of Firm Size on the ESG Score: Corporate Sustainability Ratings Under Review	Journal of Business Ethics	469	12
(Zhou, et al., 2022)	Sustainable development, ESG performance and company market value: Mediating effect of financial performance	*Business Strategy and the Environment*	179	4
(Bhutta, et al., 2022)	Green bonds for sustainable development: Review of literature on development and impact of green bonds	*Technological Forecasting and Social Change*	135	0
(Deschryver & de Mariz, 2020)	What Future for the Green Bond Market? How Can Policymakers, Companies, and Investors Unlock the Potential of the Green Bond Market?	*Journal of Risk and Financial Management*	97	0
(Cunha, et al., 2021)	Sustainable finance and investment: Review and research agenda	*Business Strategy and the Environment*	81	6
(Kuo, et al., 2021)	Do corporate social responsibility practices improve financial performance? A case study of airline companies	*Journal of Cleaner Production*	75	0
(Sciarelli, et al., 2021)	Socially responsible investment strategies for the transition towards sustainable development: the importance of integrating and communicating ESG	*TQM Journal*	70	0
(Deng, et al., 2023)	More sustainable, more productive: Evidence from ESG ratings and total	*Finance Research Letters*	63	0

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	factor productivity among listed Chinese firms			
(Schumacher, et al., 2020)	Sustainable finance in Japan	*Journal of Sustainable Finance and Investment*	62	1
(Macchiavello & Siri, 2022)	Sustainable Finance and Fintech: Can Technology Contribute to Achieving Environmental Goals? A Preliminary Assessment of 'Green Fintech' and 'Sustainable Digital Finance'	*European Company and Financial Law Review*	61	3

Source: Vos viewer Output

Table 3 displays the ten most influential articles in the field of AI, sustainable finance and ESG. The study conducted by (Drempetic et al., 2020a) found the leading article in terms of total citations (469) and links (12). Links indicate that large studies have been conducted on similar themes. The Study investigated the influence of firm size on ESG scores in the Journal of Business Ethics. Followed by (Zhou et al., 2022) with 179 citations. Their research focused on the mediation effect of financial performance on the relationship between ESG performance and firm market value. This study was published in the journal Business Strategy and the Environment. (Bhutta et al., 2022) conducted a comprehensive analysis of the progress and influence of green bonds, published in the journal Technological Forecasting and Social Change and received 135 citations. (Deschryver & de Mariz, 2020a) investigate the prospective growth of the green bond market in the Journal of Risk and Financial Management, receiving 97 citations. (Cunha et al., 2021a) provide a comprehensive analysis and outline future research directions on sustainable finance and investment. Their work has been referenced 81 times in Business Strategy and the Environment journal. (Kuo et al., 2021a) examined the impact of corporate social responsibility on the financial performance of the airline business.

Table 4: Top10 Most Productive Countries

Sr. No	Country	Total Publications	Total Citations	TC/TP
1	China	56	755	13.48
2	Italy	34	457	13.44
3	United Kingdom	33	420	12.73
4	United States	25	382	15.28
5	Germany	21	718	34.19
6	India	20	229	11.45
7	Malaysia	14	129	9.21
8	France	12	189	15.75
9	Russian Federation	12	39	3.25
10	Australia	11	93	8.45

Source: R Studio Output

Error! Reference source not found. provides a comprehensive analysis of academic output and i mpact in ten countries. It includes data on the total number of publications, total citations, and the average citations per publication (TC/TP). China is at the forefront with 56 publications and 755

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citations, which leads to a TC/TP of 13.48. Italy has 34 publications and a TC/TP of 13.44 from 457 citations. The United Kingdom has 33 publications and 420 citations, with a TC/TP ratio of 12.73. The United States has fewer publications (25), but still maintains a high impact with 382 citations and the second-highest TC/TP of 15.28. Germany's publication record may be modest with 21 publications, but it is worth noting that these publications have received a remarkable 718 citations. This impressive citation count results in Germany achieving the highest TC/TP ratio of 34.19. India has 20 publications and 229 citations, resulting in a TC/TP ratio of 11.45. Malaysia, France, the Russian Federation, and Australia have a lower number of publications and citations. It is worth noting that France has a TC/TP of 15.75, despite having only 12 publications. The Russian Federation has the lowest impact with a TC/TP of 3.25 from 12 publications. Australia has 11 publications, resulting in a TC/TP of 8.45.

Table 5: Top 10 Highly Cited Authors

Author	Institutions	NP	NC
Klein, Christian	University of Kassel	2	470
Zwergel, Bernhard	University of Kassel	2	470
Drempetic, Samuel	University of Kassel	1	469
Liu, Lian	Fudan University	1	179
Luo, Sumei	Shanghai University of Finance and Economics	1	179
Zhou, Guangyou	Fudan University	1	179
Bhutta, Umair Saeed	University of Technology and Applied Sciences	1	135
Farrukh, Muhammad	Shenzhen MSU-BIT University, Shenzhen	1	135
Iqbal, Muhammad Khalid	University of Management and Technology Sialkot	1	135
Raza, Ali	University of Management and Technology Sialkot	1	135

Source: R Studio Output

Error! Reference source not found. provides a comprehensive list of ten authors, including their affiliated institutions, number of publications (NP), and number of citations (NC). Christian Klein and Bernhard Zwergel from the University of Kassel are prominent authors, with two publications, garnering 470 citations, their research area mainly focuses theme of ESG. It was followed by Samuel Drempetic, who is also affiliated with the University of Kassel and has a publication that has received an impressive 469 citations. The authors from Fudan University, including Lian Liu and Guangyou Zhou, along with Sumei Luo from the Shanghai University of Finance and Economics, have each published a paper that has received 179 citations. Umair Saeed Bhutta, Muhammad Farrukh, Muhammad Khalid Iqbal, and Ali Raza, all from different universities, have each published one work that has received 135 citations and their study mainly emphasis the theme of green bonds and ESG.

1.2 Science Mapping [RQ2]

Science mapping examines the association between research elements such as (Author's, Journals, and articles). The analysis focuses on the intellectual exchanges and structural relationships among the elements of research.

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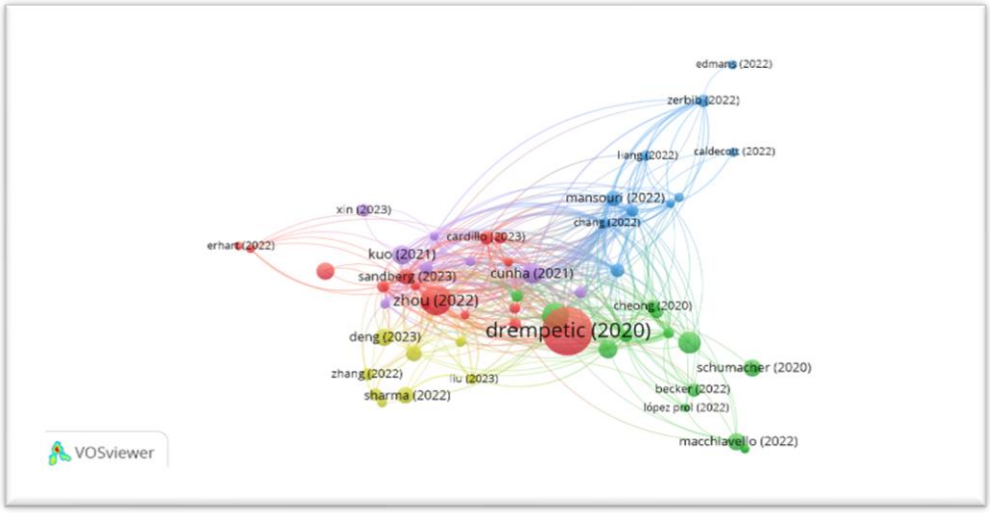

Figure 2: Major Themes Formed by Bibliographic Coupling; Source: VOS viewer output

Table 6: Top Ten Most Strongly Linked Bibliography Coupled Documents

Rank	Study	Cluster	Links	TLS	Citations	Themes
1	(Cunha, Meira, & Orsato, 2021)	5	39	169	81	Sustainable Finance and Investment
2	(Chang, Fu, Jin, & Liem, 2022)	3	34	154	24	ESG & CSR
3	(Starks, 2023)	3	32	132	28	Sustainable Finance and ESG issues
4	(D'Amato, 2022)	2	31	105	30	ESG and Stock price
5	(Cardillo, Bendinelli, & Torluccio, 2023)	1	29	82	37	ESG and Financial Performance
6	(Qian & Yu, 2024)	5	27	63	17	Green Finance & Sustainable Performance
7	(Drempetic, Klein, & Zwergel, 2020)	1	25	58	469	ESG & Firm Size
8	(Bhutta, Tariq, Farrukh, Raza, & Iqbal, 2022)	2	24	42	135	Green bond & ESG
9	(Zhang, 2023)	4	24	36	50	ESG and Green Finance
10	(Alshater, 2023)	4	19	21	21	Post-COVID financial spillovers

Source: Author compilation

Figure 2 depicts a bibliographic coupling network created using VOS viewer. The nodes refer to specific publications, and the size of each node shows the number of citations that the publication has garnered, with larger nodes denoting more extensively referenced works. The colour of the nodes represents different clusters, which are collections of articles that are more closely associated with each other due to similar references. The lines or edges connecting the nodes show the bibliographic coupling links, with lines of greater length indicating a stronger relationship based on shared citations. **Error! R eference source not found.** shows the top two articles from each cluster based on the links of the

articles. Links to the article demonstrate that the theme of the study is similar to other research work (Chopra et al., 2024).

1st Cluster (Red): ESG and Firm Value

1st Cluster consists of 15 published articles formed by bibliography coupling, mainly focusing on Firm value and Environmental, Social, and Governance (ESG). This (Drempetic et al., 2020b) becomes a prominent article by receiving 469 citations and 25 links. Links indicate that the theme of the study is similar to other research work. This study mainly focused on ESG Rating and Firm size, ESG rating data has been collected from "Thomson Reuters ASSET4". The study discovered a notable and significant association between the size of a company, the resources allocated for providing environmental, social, and governance (ESG) data, and the accessibility of ESG data, with a company's sustainability performance. The observed association can be attributed to organizational legitimacy, indicating that larger companies with greater resources may have an advantage in ESG rankings. In addition, the study of (Cardillo, Bendinelli, & Torluccio, 2023) also emphasized the effect of the ESG rating on firm performance, sustainability, and stock market performance in European countries.

2nd Cluster (Green): ESG and Sustainable Finance

The bibliography coupling cluster analysis shows authors' common citations, demonstrating a network of research influence and theme concentration in sustainable finance and ESG investments. Key contributions in the second cluster focus on ESG score prediction, evaluation, and consequences, as well as sustainable investing practices' influence on financial markets. The cluster comprises 15 articles and shows the relationship between sustainable finance and ESG. T(Friede et al., 2015). Sustainable article (D'Amato et al., 2022) that gained the highest number of links 31 and received 30 citations in this cluster. It evaluated the impact of structural data, specifically balance sheet elements, on the ESG scores provided to regularly traded stocks. Employing a Random Forest algorithm, the study examined the impact of structural data on the Thomson Reuters Refinitiv ESG scores for the companies comprising the STOXX 600 Index. (Bhutta et al., 2022) notable artists in this cluster with high citations (135) and overall link strength (42), showing their influence by conducted a comprehensive literature review to analyze the factors associated with the growth and impact of green bonds on issuers' fundamental performance measures in meeting Environmental, Social, and Governance (ESG) objectives. The study found that green bonds are being issued and popularized due to favorable regulations, improved transparency, and rising market demand. Green bonds are growing due to certification criteria, government incentives, and investor interest in sustainable financing. Green bonds improve an issuer's financial performance, reputation, and ESG integration, according to the research. Greenwashing, lack of standards, and the limited green bond market remain issues. (Deschryver & de Mariz, 2020b) and (Gigante & Manglaviti, 2022) both study the green bond market's future and the ESG influence on debt financing costs. Their study illuminates how ESG factors are changing investment and financial practices.

3rd Cluster (Blue): COVID-19 Impact on Green Investments:

This section of the bibliography explores a broad range of research that examines the incorporation of ESG (Environmental, Social, and Governance) factors in finance. It specifically delves into the effects of external events like COVID-19 and the various conceptual and practical barriers noticed in sustainable finance. This cluster is centered around (X. Chang et al., 2022), whose research on sustainable finance has received a considerable number of citations and demonstrates the strongest total link strength. Chang's research delves into the connection between ESG/CSR (Corporate Social Responsibility), firm value, and investment returns, providing a thorough framework for comprehending the financial consequences of sustainability practices. (STARKS, 2023) made a significant contribution with their presidential address on sustainable finance and ESG issues. They shed light on the ethical considerations that should be taken into account alongside financial performance when developing investment strategies. This highlights the importance of balancing value and values in the investment

world. In a similar vein, (Gyönyörová et al., 2023) offer a critical analysis of ESG ratings, raising doubts about their reliability. The study presents compelling evidence from the S&P Global 1200, which holds significant value for investors in search of dependable ESG information. Researchers such as (Agoraki et al., 2023) and (Caldecott, 2022) delve into the impact of COVID-19 on green investments and the significance of transition finance in the recovery after the pandemic. The studies highlight the importance of sustainable finance in addressing global crises and the necessity of strong financial mechanisms to aid in recovery and promote growth. The articles (Mansouri & Momtaz, 2022) and (Zerbib, 2022) explore in-depth financial models and measurement techniques, including the Sustainable Capital Asset Pricing Model (S-CAPM) and ESG valuation for sustainable entrepreneurship. These works offer effective methodologies for evaluating and incorporating ESG factors into financial decision-making.

4th Cluster (Yellow): ESG and Innovation

The articles in this cluster demonstrates a clear connection through their citation patterns, highlighting a concentrated discussion on ESG (Environmental, Social, and Governance) and innovation factors and their impact on finance and productivity. It is worth mentioning (Deng et al., 2023) and (Zhang, 2023) have the highest total citation counts (TC) of 63 and 50, respectively. Additionally, they demonstrate considerable total link strength, emphasizing their essential position within the network. (Deng et al., 2023) delves into the correlation between ESG ratings and productivity among Chinese firms, providing ample evidence to support the favorable effects of sustainable practices. (Zhang, 2023) explores the topic of greenwashing and investigates the effectiveness of green finance in addressing ESG-related risks. These works are highly interconnected, which indicates their significance in the discourse on ESG and green finance. (Liu et al., 2023) and (Zhang, 2022) provide valuable insights into the stability and innovation dynamics associated with ESG investments. (Liu et al., 2023) discusses the potential stabilizing effects of ESG investments on financial markets, while (Zhang, 2022) examines the differential impacts of subsidies on environmental innovation. Their citation counts and link strengths indicate their significance and impact in the field. (Alshater et al., 2023) and (Sharma et al., 2022) are significant contributions to the field. Alshater's work delves into broader bibliometric analyses, while Sharma's research focuses on post-COVID financial spillovers. These works offer contextual and methodological frameworks that bolster the comprehensive empirical studies of ESG impacts.

5th Cluster (Purple): Sustainable Finance and Corporate Performance

Cluster 5th consists of 8 influential articles and emphasizes the theme of sustainable finance and corporate performance. This cluster has received 298 total citations and 155 links. (Cunha et al., 2021b) the study received the highest number of total citations (81) and links (39). It conducted systematic literature review on sustainable finance and investment (SFI) with selecting 166 most relevant articles. The study on sustainable finance and investment (SFI) emphasizes the difficulties in promoting positive social and environmental outcomes. It points out the absence of a clear definition, a tendency to prioritize immediate financial benefits, and a lack of evidence regarding the long-term effects of SFI on society and the environment. Furthermore, the disorganized state of the current literature makes it challenging to differentiate SFI from traditional financial and investment approaches. (Kuo et al., 2021b) investigated the impact of corporate social responsibility (CSR) activities on financial performance, specifically focusing on the aviation sector as a case study. In his study, (Kabir Hassan et al., 2021) investigated the convergence of ESG (Environmental, Social, and Governance) factors with religious screening and its impact on corporate risk. This research sheds light on a specialized yet expanding field of inquiry. (Bengo et al., 2022) and (Martini, 2021) present conceptual frameworks that elucidate the European Union's strategy towards sustainable development by means of financial laws and socially responsible investing, respectively. (Kumar et al., 2022) examined the impact of corporate sustainability practices on financial performance in the global energy sector. (Qian & Yu, 2024) and (Xin et al., 2023) further explore the relationship between green finance and the sustainable

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performance of small and medium-sized enterprises (SMEs) in the digital era, highlighting the broadening focus of research in sustainable finance.

1.3 Co- word analysis [RQ3]

Co-word analysis can enhance comprehension of thematic clusters derived from bibliographic coupling. This is because the themes formed through shared characteristics in publications are often broad in nature (Y.-W. Chang et al., 2015). Scholars may rapidly learn about the academic field's research hotspots and future research paths by looking at the co-occurrence of words. In this study, Co-word network graph was created by Vos-viewer, as shown Figure 2. We set minimum of 5 occurrence of a keyword to analysis among all 812 keywords, only 31 keywords meet threshold.

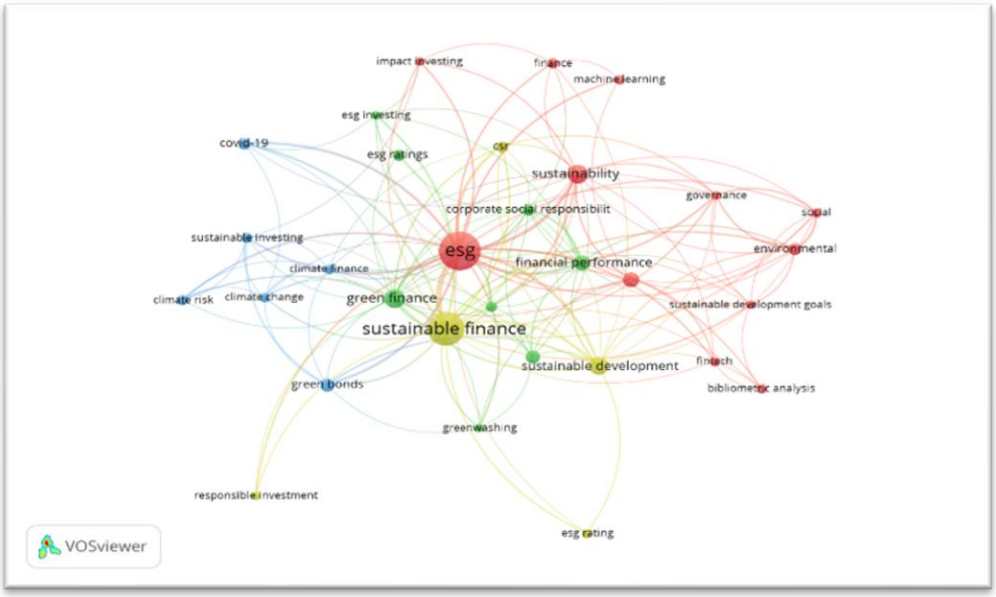

Figure 3: Co-Word Analysis Map; *Source: Vos-Viewer output*

Figure 3 shows a co-word analysis using a VOS viewer. Through this analysis, we were able to identify the current areas of focus in the fields of AI, SF, and ESG. The size of the nodes represents the total frequency of the keywords, while the thickness of the lines between nodes shows the number of times the keywords appear together (Moral-Muñoz et al., 2020).Thus, the intensity of the lines connecting two nodes reflects the level of interest shown by scholars or academics from different study directions, as well as the extent of interconnection between important aspects**.** The co-word analysis displays the interconnections between several words associated with ESG (Environmental, Social, and Governance), and sustainable finance. The central nodes, such as "ESG" and "sustainable finance," act as the main focal points, linking other interconnected concepts.

Cluster 1st (Red) consists of 12 keywords that emphasize the strong correlation between ESG and phrases such as "financial performance," "ESG performance," and "fintech". Out of all the keywords in cluster 1 (red), ESG is the most prominent keyword appearing 92 times, followed by sustainability 23 and AI 11 times occurrence. The Continued advancement of technology AI technology helps in measure the ESG score of the companies.

Cluster 2 (Green) consists of 8 keywords, that highlight the highest interconnection between "ESG" and "financial performance", "Green finance" and "CSR". It is indicated by the thickness of the lines between the nodes. In this cluster "green finance" is the most occurrence keyword (22 times), followed by financial performance and ESG performance, 15 and 11 times respectively.

Cluster 3rd (Blue) consists of the 6 most frequently appearing keywords. This cluster green bond is the most prominent keyword, appearing 11 times with a total link strength of 21. It emphasizes the connections between "green finance," "green bonds," and "climate finance," to demonstrate the link between sustainable finance and environmental initiatives as well as new subjects like "COVID-19," "impact investing," and "climate change."

Cluster 4th (Yellow) demonstrates the incorporation of more extensive concepts such as "sustainable development," "CST," and "sustainable finance," This group of keywords highlights the interdisciplinary nature of ESG and sustainable finance, demonstrating how these ideas are interconnected across many fields and areas of study.

2. Future Direction

1. Exploring the influence of industry-specific variables and nation residence on the credibility and accuracy of ESG data might be the next step for ESG ratings research (Drempetic et al., 2020b).
2. Further studies might examine the impact of COVID-19 on the correlation between ESG performance measures (Al Amosh & Khatib, 2023)
3. Subsequent research can further our understanding of the fixed connection between AI and renewable energy development (RED) by investigating the hysteresis and spatial autocorrelation characteristics (Zhao et al., 2024).
4. Deep learning algorithms can reveal concealed connections between ESG factors and financial performance, enhancing the precision of forecasting investment risks and opportunities in ESG portfolios (Jain et al., 2023)

DISCUSSION

In recent years, there has been significant academic and corporate interest in the incorporation of Artificial Intelligence (AI) into sustainable finance and Environmental, Social, and Governance (ESG) standards. This bibliometric study seeks to identify the research landscape, identify pivotal patterns, and highlight prominent studies that have impacted the discussion around the role of AI in promoting sustainability and encouraging ethical investment practices. Our study found five emerging themes “ESG and Firm Value”, “ESG and Sustainable Finance”, “COVID-19 Impact on Green Investments”, “ESG and Innovation”, and “Sustainable Finance and Corporate Performance” through bibliography coupling. The study topics suggest that prior research has focused primarily on ESG and other related areas, with limited exploration of the possibilities of artificial intelligence in the ESG field. On the other hand, (Cardillo et al., 2023) investigated the impact of ESG ratings on firm performance, sustainability, and stock market performance, with a specific focus on European countries. Their research further supports the notion that ESG ratings are a critical determinant of firm success in today's market landscape. By emphasizing the effect of ESG performance on stock market outcomes this literature contributes to the growing body of evidence that ESG considerations are not merely ethical or regulatory concerns but are fundamentally linked to financial performance and market valuation. Co-word analysis found the most connected keywords in the study, in the red cluster primarily emphasized ESG and firm performance. In addition, cluster (green) focuses on sustainable finance and green finance which are mostly used by the author(s) in their research work.

3. Policy Implications

Integrating AI into sustainable finance and Environmental, Social, and Governance (ESG) practices requires modernized regulatory frameworks. Policymakers need to align AI technologies with existing ESG standards, emphasizing transparency and accountability. Regulations must address the ethical use of AI in data analysis, decision-making, and financial reporting to prevent biases and ensure that AI-driven strategies support sustainability goals. Bibliometric analysis offers a valuable tool for policymakers, helping them identify trends and gaps in the literature on AI, sustainable finance, and

ESG. This approach allows for the development of targeted policies informed by the latest research and emerging challenges. Additionally, bibliometric tools enable the tracking of AI's evolving role in sustainable finance, ensuring regulations keep pace with technological advancements. Policies should promote collaborative research across these fields, supported by funding and institutional frameworks that encourage cross-sector partnerships. Bibliometric analysis can pinpoint key research clusters, facilitating collaboration among academics, industry stakeholders, and policymakers. Given the reliance on large datasets for AI in ESG-related financial analysis, policies must ensure the integrity and transparency of these datasets. Regulatory bodies should establish standards for data collection, processing, and reporting to prevent the use of biased or incomplete information, ensuring that AI-driven insights are reliable and contribute meaningfully to sustainability efforts.

CONCLUSION

This study represents an attempt to critically analyse the literature on AI in sustainable finance (SF) and ESG. We conducted a thorough bibliometric analysis of the literature, which allowed us to determine the research performance, research hotspots, influential authors, leading countries, top ten publications, bibliographic coupling, Co-word analysis, network visualization, and clustering. The study found that the research on AI, SF and ESG has gained significant traction since 2022. China and Italy have made significant contributions to the research, as expected. The research findings not only identify the top ten impactful sources and authors but also investigate into the core areas of the author(s). A bibliography coupling analysis of research on AI, SF and ESG reveals that major five emerging themes in the research field include *ESG and Firm value, ESG and Sustainable Finance, COVID-19 Impact on Green Investments, ESG & Innovation* and *Sustainable Finance & Corporate Performance*. We also found the most occurrences of the keywords 'ESG", "Sustainability", "Sustainable Finance", "Green Bond" and "Sustainable development". These keywords support the bibliography coupling themes.

The study mention mainly three limitations. First and foremost, it is crucial to acknowledge that only depending on the Scopus database may result in a biased selection of data. In order to augment our literary resources, it would be prudent to incorporate supplementary databases like web of science, alongside book chapters and conference papers. Furthermore, it is possible to do subsequent searches by incorporating other keywords. The first collection of keywords may have restricted the search, and the study is highly dependent on the specific search terms employed to collect data. Despite our best efforts, it is possible that we may have overlooked significant papers that employed distinctive or specialized terminology not accounted for in our literature search methodology. Furthermore, the absence of any chosen publications between 2020 and 2024 may result in a postponement of the selection process for articles from that period forward. Our study may be limited in examining specific specialized subjects or new areas due to a scarcity of relevant publications within our chosen timeframe. To surpass these constraints and offer fresh perspectives, further bibliometric analyses might approach this subject matter from an alternative perspective.

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