Sustainable Development

WILEY

Sustainable Development

RESEARCH ARTICLE OPEN ACCESS

Environmental, Social, and Governance (ESG) Reporting and Missing (M) Scores in the Industry 5.0 Era: Broadening Firms' and Investors' Decisions to Achieve Sustainable Development Goals

Sanjeev Yadav[1] | Ashutosh Samadhiya[2] | Anil Kumar[3,4] | Sunil Luthra[5] | Krishan Kumar Pandey[1]

[1]Office of Doctoral Studies, O. P. Jindal Global University, Sonipat, India | [2]Jindal Global Business School, O. P. Jindal Global University, Sonipat, India | [3]Guildhall School of Business and Law, London Metropolitan University, London, UK | [4]Department of Management Studies, Graphic Era (Deemed to be University), Dehradun, India | [5]All India Council for Technical Education (AICTE), Delhi, India

Correspondence: Anil Kumar (a.kumar@londonmet.ac.uk)

Received: 5 August 2024 | **Revised:** 22 November 2024 | **Accepted:** 25 November 2024

Keywords: environmental sustainability | ESG reporting | green issues | Industry 5.0 | missing scores | sustainable development goals

ABSTRACT

Environmental, social, and governance (ESG) factors are gradually being utilized to assess organizations' long-term success, drive capital, and inform company decision-making toward sustainable growth. Despite a few research investigations, studies on ESG are still developing by using a broader range of new technologies to improve ESG transparency; overcoming shortcomings that have arisen have yet to be examined. Industry 5.0 (I5.0) provides an effective paradigm for comprehending the significance of technology in enhancing ESG disclosure and reporting. To handle the critical shift to wider sustainable development goals (SDGs) specifically, SDG 8 (Decent Work and Economic Growth) and SDG 13 (Climate Action) within the ESG monitoring system, this research digs into current ESG reporting concerns and obstacles. The study systematically reviews I5.0 and ESG reporting literature. The study also carries out an extensive content-centric assessment of relevant sources and information mappings to accomplish the research aims. The findings reveal that the fundamental characteristics of I5.0 are consistent with ESG, while I5.0 may accommodate ESG capabilities by improving ESG disclosure reliability, expanding from retrospective to prospective and real-time reporting, customizing, broadening the range of reporting, lowering costs, and improving effectiveness. The findings suggest that ESG reporting must expand outside its company-centric emphasis, altering existing accounting methods to embrace ESG disclosure requirements more appropriately. ESG performance can be improved with clearer representation of environmental and social consequences, guiding both firms' and investors' decisions (double materiality concept) towards SDGs. New or missing (M) scores revealed by I5.0 technologies can assist both investors and company managers.

1 | Introduction

In order to achieve an ecological transition that is both prosperous and environmentally conscious, it is necessary to adhere to the 17 Sustainable Development Goals (SDGs) (Colasante et al. 2024) and provide a common framework to help nations achieve sustainable economic growth (D'Adamo, Gastaldi, and Morone 2022). In addition, SDGs illustrate the comprehensive nature of sustainability and highlight the necessary transformations required to ensure a viable future for subsequent generations (Anselmi et al. 2023). Comprehensive studies on sustainability across all three dimensions (i.e., economic, environmental, and social) are essential for pragmatic sustainability approaches (D'Adamo and Rossi 2024). This includes

conducting ex ante assessments of geographical impacts that go beyond individual ideological viewpoints. In addition, societies that want to advance beyond just economic indicators of prosperity should look to sustainable development as a guiding concept (D'Adamo et al. 2024). SDGs are the most extensive guidelines for confronting global societal issues (Wettstein et al. 2019). These issues include ecological (such as declining biodiversity, exhaustion of natural resources, and environmental degradation), social (such as worldwide malnutrition, rising inequality, racial inequality, and deficiency in human well-being and learning), and governance (such as gender disparities, corruption, and war) (Clément, Robinot, and Trespeuch 2023). Corporations are seen as key players in attaining SDGs, even though they are macro-level objectives for nations and governments (van Zanten and van Tulder 2021). By assuring that funds are generated and deployed responsibly, investors make a crucial contribution to global endeavors to attain sustainable development goals (Principles for Responsible Investment 2017). Responsible investing, sometimes referred to as socially responsible investment (SRI), is the process of incorporating sustainability factors, primarily environmental, social, and governance (ESG) evaluations, into investment analysis. In the last decade, SRI has become more widespread (Bekaert, Rothenberg, and Noguer 2023), with the valuation of the SRI portfolio increasing significantly (Global Sustainable Investment Alliance 2018). Additionally, ESG is the most critical topic for company managers to address (Lee 2023) since investors are concerned about the reliability of accessible information on firms' ESG scores, the lack of guidelines for SRI, and the ambiguous concept of categorizing SRI (Friede 2019). Even though ESG has emerged from the idea of sustainability, the emphasis now is on the potential return and risk consequences for financial investors of failing to adequately manage ESG concerns, rather than the outside impacts of corporate operations on society and the environment (MacNeil and Esser 2022). Identification of ESG-related risks and potential that might affect investors' and stockholders' returns is the primary objective of incorporating ESG standards into investment selections to balance social and environmental advantages and consequences with economic benefits (Eccles, Lee, and Stroehle 2020). In other words, ESG might be defined as the 'financialization' of sustainability. Comparably, research on the notion of socially responsible investment shows a great deal of variation (Höchstädter and Scheck 2015), despite ESG being inclined towards financial ideas, especially the monetary outcomes of SRI portfolios (Capelle-Blancard and Monjon 2012). Concerns about the accuracy and openness of current measurements are also highlighted in ESG research (Widyawati 2019). In addition, there is a lack of awareness of the significance of ESG indicators and a poor mapping of the diversity of SRI research. ESG or sustainability disclosure on Key Performance Indicators (KPIs) by organizations fulfills two important functions, that is, "performance enhancement," which is crucial for the business, and "transparency," which is crucial for investors (Maas, Schaltegger, and Crutzen 2016). For instance, there is a considerable improvement in ESG performance with the introduction of a policy on environmental credit ratings (Cao, Tao and Zhang 2024). According to published KPIs, ESG risk ratings, also known as ESG scores, assess an organization's vulnerability to major climate hazards particular to its sector, as well as its attempts to mitigate these threats (Chopra et al. 2024). In addition to the KPIs made public by each firm, unbiased organizations such as Bloomberg, Refinitiv, and Morgan Stanley Capital International also use questionnaires and survey responses to determine their ESG ratings. An organization's participation in environmentally friendly practices and overall success is indicated by its respective E, S, and G pillar scores as well as the overall ESG score (Gupta, Sharma, and Gupta 2021). Many times, ESG is presented as an umbrella for responsible investment that supports sustainability and motivates businesses and institutions to implement socially ethical procedures. Nevertheless, the scores themselves stand a risk of diminishing their significance and may even be able to misdirect sustainable investment initiatives if the fundamental KPI information that forms the basis of these ESG evaluations is dubious. In this regard, Industry 5.0 (I5.0) aims to harmonize social progress and environmental conservation with financial gain (Waheed et al. 2022). The reason for the co-emergence of I5.0 and the continuous advancement of Industry 4.0 is the mounting importance of sustainability issues. Arguments concerning businesses' obligations to lessen their environmental damage have been triggered by the effects of climate shift, habitat grief, and declining resources. The significance and usefulness of I5.0 have also been influenced by the growth of responsible consumption and social demands for firms to function ethically (Asif, Searcy, and Castka 2023). I5.0 calls for a reinterpretation of CSR that includes moral business conduct and proactive participation in tackling global issues such as depletion of resources, social injustice, and climate disruption (Zhang and Li 2023).

Thus, the effectiveness of ESG disclosure or reporting may be improved by I5.0, a combination of technologies that improve integration, flow of data, and reliability (Rehman and Umar 2024). Although I5.0 has characteristics that are strongly aligned with the needs of ESG, it remains a relatively new notion with limited applicability in commercial reporting (Alkaraan et al. 2022). Research conducted in analogous settings also suggests that I5.0 may be utilized to facilitate improved transparency, for example, consideration of the function of I5.0 in sustainable accounting (Olsen 2022). The most recent industrial change, known as Industry 5.0 (I5.0), resolves several shortcomings of I4.0. by aiming to increase output and organizational efficiency via improved automation, real-time knowledge, data transaction, and collaboration. I4.0 is criticized for its excessive technological and financial attention, especially its lack of dedication to the human aspect of administration, despite its facilities to improve integration and establish platforms (Xu et al. 2021). I4.0 has substantially improved the economy concerning supply chain efficiency, logistics, manufacturing, and quality, but its usefulness and worth in enhancing the human aspect of businesses and society are restricted (Asif, Searcy, and Castka 2023). There is a rising awareness that companies need to use cutting-edge technology to build human-centered, society-beneficial, and high-quality workspaces since financial prosperity may result in unacceptable social implications. I5.0 stands apart from previous versions because it seeks to restore socio-economic equilibrium via accountable governance (Aheleroff et al. 2022). The emphasis on improving sustainability and moving towards an electronic culture builds upon and contextualizes earlier versions.

Businesses utilize better ESG disclosure to learn about possibilities, risks, and managerial influence related to sustainable

practices, while investors utilize it to make informed decisions regarding the distribution of capital (Chopra et al. 2024). But in recent years, there has been criticism of ESG ratings. These involve the possibility of an upgrade to the ESG ratings from the information source within 5 years (e.g., Thomson Reuters assessments are only definite after 5 years) and a significant disparity in ESG scores from different information providers (Sahin et al. 2022). Furthermore, the availability of new ESG data, or the revelation of data that has been missing, could lead to adjustments to ESG ratings (Sahin et al. 2022). As stated by Amel-Zadeh and Serafeim (2018), "investors' employ of ESG data is poorly understood," due to a lack of deep comprehension of the obstacles associated with accessing ESG information, as well as the logic and techniques by which investors utilize it. According to Amel-Zadeh and Serafeim (2018) as well as In, Rook, and Monk (2019), the research on utilizing ESG information for investment possibilities has typically emphasized the financial effect of the firm's ESG performance metrics. On the other hand, recent research indicates that existing challenges with ESG data embrace inadequate levels of materiality and significance (Khan, Serafeim, and Yoon 2016); a lack of reliability in assessing the authentic sustainability outcomes of businesses, involving the "trustworthiness, validity, completeness, and methodological uniformity of the data being disclosed" (Cort and Esty 2020); a lack of reliability in the way businesses evaluate their own ESG performance due to the growing risk of whitewashing (Assaf et al. 2024); a lack of comparison due to misaligned criteria for ESG performance assessments (In, Rook, and Monk 2019). Most studies concur that ESG reporting is inefficient for resolving environmental issues and advancing societal objectives for sustainability (Milne and Gray 2013; Dillard and Vinnari 2019). Research focusing on reputation in nonfinancial disclosures and empirical evidence of greenwashing enhance issues regarding ineffectiveness (Waniak-Michalak, Sapkauskiene, and Leitoniene 2018; Ferrero-Ferrero, León, and Munoz-Torres 2021). Businesses are embracing ESG concepts and adopting "green" projects due to stakeholder advocacy, which improves both ESG and economic outcomes (Chopra et al. 2024). This reflects a larger social tendency in which businesses have observed an increase in customer knowledge of sustainable practices and ethics as customers proactively seek green commodities that fit with their beliefs and have a beneficial effect on firms' performance (Chen et al. 2021). It is yet uncertain how ESG monitoring will contribute to sustainable growth in the future; thus, a worldwide platform is required to avoid disintegration, enhance transparency, and streamline the intricacies of ESG declaration (De Silva Lokuwaduge and De Silva 2022). In this regard, improving ESG reporting, which is generally regarded as an indicator of an organization's willingness to carry out its social obligations, encourages the use of I5.0 (Zhang, Zhao, and Lau 2022). The effectiveness of ESG reporting can be increased by I5.0, an umbrella of technologies that improve integration, data interchange, and authentication. Even though I5.0 has many of the same characteristics as ESG, it continues to be a relatively new idea with limited known uses in business reporting (Alkaraan et al. 2022). Studies in similar contexts also indicate that I5.0 can be employed to enable enhanced disclosure, for example, the role of I5.0 in sustainability reporting (Olsen 2022). Based on the above motivation and gaps identified as shown in Table 1 of the literature review section, the following research questions are formulated:

RQ1. *How will Industry 5.0 applications facilitate better ESG reporting?*

RQ2. *How will the disclosed ESG information based on Industry 5.0 improve ESG scores or missing information?*

RQ3. *How will the disclosed ESG information and better ESG scores further facilitate investors' and firms' decisions to achieve sustainable development goals?*

To explore the above research questions, the present study is organized as follows. Section 2 details the literature review. Section 3 gives the methodology. Section 4 presents the results while Section 5 discusses these results. Section 6 provides conclusions, limitations, and future scope of the present research.

2 | Literature Review

The literature review consists of four sections; theoretical background, I5.0 technologies, ESG reporting/ scores pathways towards sustainability issues followed by previous studies on I5.0, ESG reporting and sustainable development as explained in Table 1.

2.1 | Theoretical Background

Three fundamental elements make up the core notion of Organizational Information Processing Theory (OIPT). Firstly, the complexities of the tasks and the unpredictability of the situation are the primary sources of the organization's information processing requirements (Ma et al. 2023). According to Galbraith (1974) and Bensaou and Venkatraman (1995), technological innovations, corporate procedures, and organizational frameworks all contribute to information processing skills. Galbraith (2014) suggests that the enhancement of organizational effectiveness is achieved by aligning information process capacities with requirements. An expanded network of organizations' ESG reporting may be supported by I5.0, which provides a mechanism for improving integration between companies and supply chains. To broaden the coverage of ESG reporting, OIPT supports the implementation of I5.0. Furthermore, according to Ma et al. (2023), OIPT demands the development of improved information processing capabilities that are compatible with a wider range of supply chain frameworks and can handle large amounts of information from various sources. I5.0 is specifically well-suited to provide cross-company integration, big-data transfer and cloud-based storage, protected network communications, and digital twins of actual processes, all of which have the potential to expand the parameters of ESG disclosure (Asif, Searcy, and Castka 2023).

Legitimacy theory looks at how businesses try to win over the community by functioning in a way that complies with society's standards and values or fulfilling their contractual obligations (Rezaee 2016). Del Gesso and Lodhi (2024) claim that noncompliance with this agreement may have adverse consequences for a business's economic reliability and social reputation. Consequently, disclosures of governance, social, environmental, or corporate social responsibility initiatives are employed to

TABLE 1 | Previous studies on Industry 5.0, ESG reporting, and sustainable development.

Studies	Type of data or information	Research context	Methodology adopted	ESG reporting/ disclosure	Industry 4.0/5.0 driven ESG reporting	Strategies for achieving sustainable development	Findings
Khamisu, Paluri, and Sonwaney (2024)	Upstream managers and sustainability head opinion	Oil and gas firms	Interpretive structural modeling (ISM)	✓		✓	The results emphasize the significance of ethical concerns and business "green-washing" in ESG. To improve the amount and quality of ESG reporting, the results indicate that practical requirements are essential
Paolone et al. (2024)	250 European banks	European context regulated by Directive 95/2014/EU	OLS regression	✓			The results show that there is a positive relationship between ESG ratings, BGD, and BCD in the European banking industry. Furthermore, the results show that diversity helps with information exchange by making regulated sectors better at ESG performance
Clément, Robinot, and Trespeuch (2023)	Systematic literature review	Not applicable	NA	✓			The discussion highlights five distinct theme concepts that have evolved regarding the utilization of ESG scores in scholarly research: sustainability, corporate social responsibility, disclosure, finance, and the analysis of ESG scores
Helfaya, Morris, and Aboud (2023)	Panel data from 784 companies	Market capitalization firms	Regression	✓			The results indicate that the disclosure of ESG practices in Europe has been positively and considerably impacted by both global reporting initiatives as well as the CSR approach and strategy of boards
Saxena et al. (2023)	Literature review	Not applicable	NA	✓	✓	✓	ESG investment has been enhanced by the utilization of Artificial Intelligence (AI) capabilities. Previously, these capabilities relied on self-disclosed, annualized corporate information that was vulnerable to inherent data problems and bias

(Continues)

TABLE 1 | (Continued)

Studies	Type of data or information	Research context	Methodology adopted	ESG reporting/ disclosure	Industry 4.0/5.0 driven ESG reporting	Strategies for achieving sustainable development	Findings
Jonsdottir et al. (2022)	Literature review	Not applicable	NA	✓		✓	The results demonstrate that there are no barriers to utilizing ESG data, such as insufficient materiality, correctness, and dependability When it comes to usefulness of the data they reveal that companies have different opinions than institutional investors
Wang et al. (2023)	Literature review	Not applicable	NA	✓		✓	The study's findings highlight the importance of risk, information, and strategy viewpoints in understanding how ESG practices may help businesses prevent damage and generate value, both directly and indirectly
Escrig-Olmedo et al. (2019)	Literature review	Not applicable	NA	✓		✓	The results demonstrate that when evaluating a company's sustainability, ESG rating firms do not completely incorporate sustainability concepts
Widyawati (2019)	Systematic literature review	Not applicable	NA	✓		✓	The findings back up the significance of ESG indicators in the SRI area, where they serve as both a measure of sustainability performance and a catalyst for the growth of the SRI market. Nevertheless, ESG measures are not as reliable as they could be due to two major problems—transparency and convergence
Lokuwaduge and Heenetigala (2016)	Reported ESG data from 30 companies	ASX's top 100 mining companies	Chi-square tests	✓		✓	To improve environmental policies and sustainable development within companies, the findings suggest that stakeholder interaction is crucial. This study concludes that reporting laws have a significant impact on ESG reporting motives

Abbreviation: NA, not applicable.

uphold or restore an organization's credibility with stakeholders (Deegan 2019). Since legitimacy theory offers a conceptual framework for examining a crucial utilization of non-financial disclosure in regulating business legitimation, it serves as the main theory that researchers have previously depended on to articulate CSR reporting procedures (Cho et al. 2015). In line with this, Lai, Melloni, and Stacchezzini (2016) explore the incorporation of ESG data as a corrective measure for low legitimacy. Therefore, the present research utilizes both OIPT and legitimacy theory as both support the application of I5.0 in extending the scope of ESG reporting. OIPT suggests that a company needs to develop information processing capabilities and frameworks that can be facilitated by I5.0 to provide real-time and prospective ESG reporting capacity (Asif, Searcy, and Castka 2023). Deegan (2019) claims that legitimacy theory is applied as the conceptual foundation for improved environmental and social reporting because of the need to legitimize the actions of organizations.

2.2 | Industry 5.0 Technologies

I5.0 leverages I4.0 technology to generate benefits for both society and the environment; financial gains can be made as it expands upon I4.0 (Mourtzis, Angelopoulos, and Panopoulos 2022). The use of I4.0 technology to provide resilience, sustainability, and human centricity essentially sets I5.0 apart. "bio-inspired innovations" support recycling, sustainability, and a circular economy; "real-time digital twins" are digital illustrations of procedures that occur in real-time; "cyber-safe information transfer" refers to the use of interoperable mechanisms; "artificial intelligence" refers to the use of artificial intelligence to identify patterns in a complicated framework and "a reliable source of autonomous and efficient energy technology." Human-centricity, sustainability, and resilience are the three guiding principles of I5.0 (Xu et al. 2021). Establishing a positive work environment, enhancing individuals' cognitive and physiological well-being, and preserving their basic rights, including confidentiality, independence, progress and advancement, economic and social safety, are all examples of human-centricity (Asif, Searcy, and Castka 2023). In this scenario, sustainability refers to the balancing of environmental, community, and financial development through the preservation of resources and the use of digital technology. According to Clément, Robinot, and Trespeuch (2023), resilience is the capability to return to the pre-disturbance condition following an interruption. It guarantees the availability of vital systems during a crisis.

2.3 | ESG Reporting/Scores Pathways Toward Sustainability Issues

Sustainability issues and policies have gradually been attracting more and more attention. ESG disclosure is said to have its roots in the broader movement towards corporate sustainability. The communication of firms' sustainability objectives, more precisely, on its 'environmental', 'social', and 'governance' objectives and its progress towards attaining them, are regarded as ESG disclosure (Khamisu, Paluri, and Sonwaney 2024). The information disclosed enables stakeholders to evaluate organizational commitment toward sustainability, which will consequently influence their decisions in rewarding firms with higher ESG initiatives (Sarti, Darnall, and Testa 2018). It has emerged in response to growing concerns relating to the effects of business practices on the environment, society, and corporate governance systems. The reliance on non-financial disclosures by stakeholders to recognize sustainable companies has led to an increasing supply of ESG reports. Investors now anticipate ESG information before making investment decisions in a business (Khamisu, Paluri, and Sonwaney 2024). Subsequently, Escrig-Olmedo et al. (2019) investigated to confirm if sustainability problems are considered by ESG rating firms. However, despite some noticeable attempts, these agencies' recognition of sustainability concerns in the development of ESG ratings was frequently inadequate (Clément, Robinot, and Trespeuch 2023). Although certain sustainability concepts are integrated into ESG scores, experts believe this is not enough to corroborate the claim that the ratings serve as an index of sustainability (Eccles, Lee, and Stroehle 2020; Clément, Robinot, and Trespeuch 2023). Conventional sustainability accounting distinguishes ESG disclosures from economic data. However, it might not explain how risks and strategies are related to one another, and other capital forms under firms' control (de Villiers, Venter, and Hsiao 2017). According to Berg, Koelbel, and Rigobon (2022), ESG ratings are seen as a means of reducing the detrimental effects of sustainability concerns on investors that arise from business decisions that degrade the environment and society. However, using ESG ratings to demonstrate a firm's sustainability or to evaluate the level of sustainable practices among various organizations is proving difficult.

According to Rekker, Humphrey, and O'Brien (2021), ESG ratings continue to be heavily biased in favor of social problems and overlook concerns about global warming and changing climates (Serafeim et al. 2019). As a result, it demands that I5.0 standards be adopted in ESG reporting about sustainability challenges that alter the way firms fundamentally operate (Turner and Oyekan 2023). To create intelligent and interdependent networks that optimize resource utilization, minimize waste, and encourage socio-environmentally ethical behaviors, it is necessary to integrate innovative technologies, such as artificial intelligence (AI), machine learning, and the Internet of Things (IoT), in a regulated and organized manner (Xian et al. 2024). In addition, I5.0 calls for a redefinition of corporate social responsibility that includes moral business conduct and proactive participation in tackling global issues such as resource scarcity, social inequality, and climate variability (Zhang and Li 2023).

3 | Methodology

To answer the research question and fulfill the underlying objectives regarding ESG reporting, I5.0 applications in ESG reporting issues, and the impact on sustainable development, the PRISMA protocol (PRISMA 2023) is employed, comprising steps of identification, screening, and content analysis as shown in Figure 1. The study utilizes an evidence-mapping method (Ghobakhloo et al. 2024) to illustrate the results of content analysis, explicitly emphasizing the prospective contributions of I5.0 to ESG reporting, resulting in SDGs. This

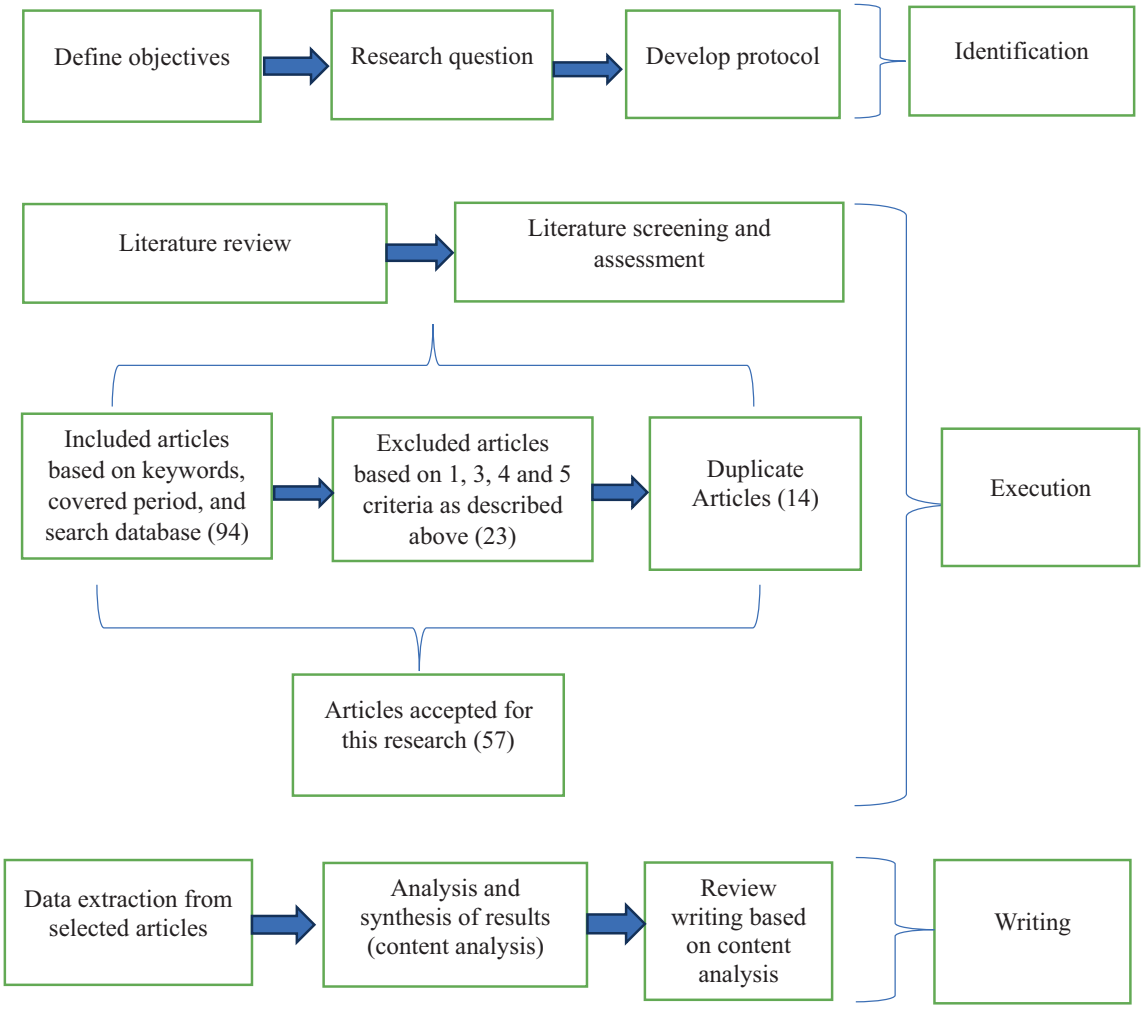

FIGURE 1 | Study selection process by PRISMA.

protocol enables researchers to formulate an appropriate strategy, comprehend probable issues, and meticulously record the process as per the strategy, hence facilitating others to compare the procedure and conduct a thorough evaluation (Ahmad, Yaqub, and Lee 2024). Additionally, it facilitates the replication and validation of review procedures, when necessary, prevents arbitrary decision-making regarding inclusion criteria and data extraction, and reduces the duplication of literature (Page et al. 2021). Consequently, we use the aforementioned practices in our evaluation due to their stated benefits. To evaluate the quality of articles, we examine the content of peer-reviewed journals obtained from various search engines including Web of Science, Google Scholar, Science Direct, Wiley Online, Scopus, and PubMed. In addition to scientific reviews, other important information published between 2015 and 2024 is retrieved from publications selected from various news journals using keywords including ESG, ESG disclosure, ESG reporting issues, I5.0 technologies application, I5.0 based ESG reporting, ESG information-driven investment, ESG performances and firm strategies, ESG information and sustainability issues, ESG disclosure and sustainable development. Articles are considered for the study if they satisfy the following inclusion and excluding criteria: (1) original English research articles; (2) published between January 2015 and April 2024; (3) discuss issues of ESG reporting; (4) contain disclosure of ESG and its use; (4) discuss industry transformation (Industry 4.0 and Industry 5.0) and ESG relations; and (5) mention the social and environmental impact of ESG reporting.

4 | Results

Results consist of three sections: applications of I5.0 technologies in effective ESG reporting, improving ESG scores by I5.0-driven ESG reporting, and the concepts of materiality and double materiality for SDGs as explained below.

4.1 | Applications of Industry 5.0 Technologies in Effective ESG Reporting

ESG has emerged as a crucial factor in assessing an organization's ESG scores. Organizations evaluate score measures based on the ESG data they acquire along their process flow. Implementing I5.0 technologies is crucial for optimizing ESG reports. Figure 2 depicts a system that combines all the enabling technologies of I5.0 to gather ESG data. It also showcases an intelligent platform for evaluating ESG reports and metrics. Figure 1 displays the I5.0 functionalities that are highly useful

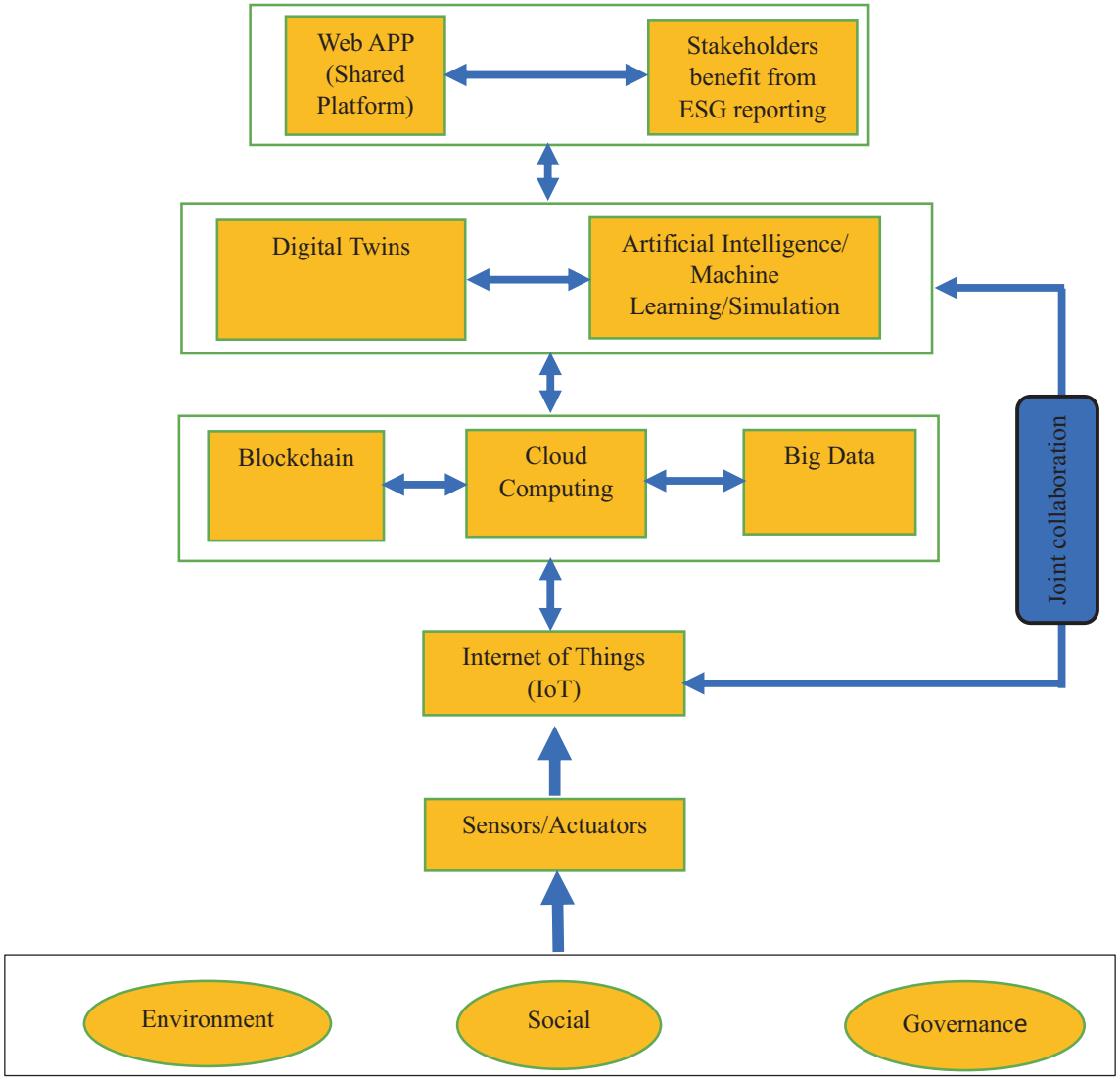

FIGURE 2 | Industry 5.0-driven ESG reporting.

in ESG disclosure. Table 2 provides support for Figure 2 by demonstrating how I5.0 technologies can effectively tackle ESG challenges.

4.1.1 | Blockchain

Blockchain (BC) is a fundamental component of I5.0 and plays a crucial role in facilitating decentralized transactions (Asif, Searcy, and Castka 2023). It consists of a network of computers connected via peer-to-peer technology. The utilization of network members' confirmation ensures the security and authenticity of information and transactions. This feature enhances security and prevents unauthorized manipulation (Rehman and Umar 2024). Additionally, it enables the monitoring of transactions and the verification of their legitimacy (Ali et al. 2021). BC technology is increasingly being used in environmental activities, such as ESG reporting. BC technology can be utilized to enhance governance and facilitate transparent decision-making, a fundamental aspect of ESG practices. BC-based voting relies on governance tokens, which grant voting rights based on the amount of tokens held by individuals (Coindesk 2020).

4.1.2 | Digital Twins

In the context of physical processes, "digital twins" are representations in the digital realm (Aheleroff et al. 2021). These systems, based on the integration of cyber-physical ones, can simplify supply chains, optimize supply networks, react rapidly to interruptions, increase worker safety, decrease emissions, and serve as a digital representation of the supply chain (Saxena et al. 2023). Digital Twins as a Service (DTaaS) is an evolution of these technologies that is emerging in various economic sectors, including mining, manufacturing, agriculture, construction, and others (Verdouw et al. 2021). Nowadays, much of the data generated by the Internet of Things is kept in a cloud server (Jiang, Guo, and Wang 2021; Lee et al. 2022). The yearly carbon footprint is increased by data storage, which has an impact on the environment. The development of digital twins, however, has opened the door to the possibility of using IoT data to reduce

TABLE 2 | Industry 5.0 application in the release of new ESG missing (M) information.

ESG reporting issues	Description	Industry 5.0 application in the release of new ESG missing (M) information	References
Authenticity	• Authenticity issues, also known as decoupling, pertain to a discrepancy between a company's assertions and its actual implementation • The decoupling phenomena are widely documented in academic literature; other labels, such as greenwashing, CSR-washing, pinkwashing, and corporate hypocrisy, all describe the same fundamental discrepancy between public assertions and real-world actions	• Sensors/RFID technology facilitates the automatic gathering of data, hence minimizing errors and decreasing the necessity for human involvement, leading to improved precision and effectiveness (**M1**) • BC guarantees the ability to trace transactions. If there is a discrepancy between a supplier's sales record and a buyer's purchase record, the transaction will not be verified (**M2**) • AI can sift through massive amounts of data in search of mistakes, fraud, or anomalies (**M3**)	Liu et al. (2021); Asif, Searcy, and Castka (2023); Rehman and Umar (2024)
Retrospective reporting	• Given the rapid pace of change in the business world and the importance of meeting deadlines set by both regulators and customers, a profile that only looks at the company's previous performance is now insufficient. • Companies' current ESG performance cannot be adequately captured by retrospective reporting. • One major flaw that puts ESG credibility at risk is the present reporting frameworks' incapacity to include real-time data.	• Sensors acquire environmental and social data immediately and consistently from many locations in the supply chain, facilitating instantaneous reporting (**M4**) • RFID technology facilitates communication with digital applications and transmits data in real-time (**M5**) • The use of digital twins allows for immediate ESG disclosure by providing a digital replica of real processes; this represents the most up-to-date version of processes (**M6**) • The IoT enables real-time ESG reporting by collecting data from various sources and sending it to various dashboards via the network (**M7**) • Services are provided over the internet by cloud computing applications; these also enable the infrastructure for real-time reporting and synthesizing data into ESG reports (**M8**)	Asif, Searcy, and Castka (2022); Castka, Searcy, and Mohr (2020); Asif, Searcy, and Castka (2023); Rehman and Umar (2024)
Customizability	• The fact that ESG is primarily targeted at investment managers who utilize these measures for risk analysis and decision-making is a frequent point of criticism • Enhancing the customizability of ESG reports means providing customers and other stakeholders with a wider range of options to choose from when picking characteristics of interest, level of detail, and comparing ESG profiles of firms within the same and other industry sectors	Machine learning, AI, cloud computing applications, and digital dashboards work in tandem to: • Provide users with highly relevant ESG metrics to enable them to make informed and contextually appropriate decisions (**M9**) • Present reports to dashboards of end-users (**M10**)	Reber, Gold, and Gold (2022); Asif, Searcy, and Castka (2022); Asif, Searcy, and Castka (2023)

(Continues)

TABLE 2 | (Continued)

ESG reporting issues	Description	Industry 5.0 application in the release of new ESG missing (M) information	References
Scope of ESG reporting	• ESG disclosure often focuses exclusively on the companies responsible for reporting • The limited extent of ESG disclosure contradicts the principle of full ESG disclosure; since supply chains are made from interconnected companies that share information and materials, their social and environmental effects cannot be evaluated separately • An accurate representation of a firm's ESG performance should encompass data regarding the firm's interactions with supply chain members and the effects of these supply chains	IoT, blockchain, cloud computing, digital twins, and AI enable: • Extended reporting scope, covering upstream and downstream supply chains (**M11**) • Comprehensive ESG impact assessment: broader scope prevents shifting impact across entities (**M12**) • Transparent supply chains, that is, I5.0, provide x-ray-like clarity for ESG disclosure (**M13**)	By Asif, Searcy, and Castka (2023); Rehman and Umar (2024)
Cost	• ESG reporting incurs significant expenses and necessitates the allocation of financial, informational, human, and technology resources • The use of technology for ESG performance analysis and reporting, as well as the development of formal reporting and communication frameworks, are not cheap; they become more expensive as businesses grow	• Reducing setup costs and improving cost-effectiveness can be achieved by utilizing common ESG platforms offered by I5.0 (**M14**) • The most significant cost savings would occur in companies that establish their ESG disclosure on I5.0-based shared platforms which offer services to both individual and corporate users (**M15**)	Drempetic, Klein, and Zwergel (2020); Asif, Searcy, and Castka (2022); Asif, Searcy, and Castka (2023); Rehman and Umar (2024)
Efficacy	• Efficacy is characterized by the capacity to produce ESG reports that are informative, insightful, and relevant to the context • Recent ESG scandals show that companies can engage in malpractice yet score highly in ESG reports • Efficacy concerns can arise owing to several factors, including malicious intentions (such as prioritizing economic gain over proper investigation) or succumbing to institutional constraints and choosing to only partially comply with ESG standards (known as decoupling) • One possible operational reason for ESG's lack of effectiveness is the fact that it is technically difficult to maintain complicated ESG data faced with many risks	• Sensors, RFID, and IoT provide immediate data gathering; blockchain ensures transaction security; machine learning and AI enhance ESG reporting by making it more sophisticated and informative. Collectively, they improve the effectiveness of ESG reporting (**M16**). • I5.0 can combine a vast amount of data (referred to as large volume) that is acquired directly from the source and in real-time (known as high veracity). This enables fast processing (referred to as high velocity) and allows for the acquisition of diverse data from many points in the supply chain (known as high variety), which ultimately improves the effectiveness of ESG (**M17**)	Ghobakhloo (2020); Bai et al. (2020), Asif, Searcy, and Castka (2022)

carbon emissions while bolstering an organization's management systems (Lee et al. 2022). Not only that, according to Saad, Faddel, and Mohammed (2020), digital twins help organizations determine what data needs to be collected, kept, and used to create ESG data.

4.1.3 | Big Data

Data collection, data storage and analytics, as well as data visualization are the three main components of a basic big data application that can be used for ESG reporting. Data

for ESG reports typically comes from operational systems, social visualization, end-user IoT devices, and remote sensing (Asif, Searcy, and Castka 2023). According to Schulz and Feist (2021), the data used for ESG reports typically comes from places such as social media, operational systems, end devices of the IoT, and remote sensing. These sources produce massive amounts of data. Big data allows us to discover previously unseen patterns, correlations, trends, and consumer preferences (Saxena et al. 2023).

4.1.4 | Machine Learning and AI

Machine learning involves the use of algorithms that continuously learn from user data and consistently improve the suggestions and outputs they provide. This can be observed in applications such as those used by Amazon and Netflix. A machine learning-powered ESG dashboard will filter out irrelevant data and provide users with concise information on the most significant ESG parameters (Selim 2020). An essential aspect of creating customizable ESG reports is the continuous analysis of user behavior and the subsequent improvement of the report outputs (Macpherson, Gasperini, and Bosco 2021). Artificial intelligence can analyze various data sources such as supply chains, procurement, and accounts to detect irregularities, fraud, and patterns in processes. It can also provide alerts for possible system breakdowns, allowing for proactive reporting. Artificial intelligence can provide consumers with the most pertinent ESG measures for a specific industry sector. For example, the health and welfare of employees are relevant and important matters.

4.1.5 | IoT (Sensors and RFID)

Sensors can monitor various aspects of the environment, such as carbon emissions, biodiversity, deforestation, greenhouse gas emissions, the acidity of wastewater, concentration of dissolved solids in discharged water, and the existence of harmful chemicals in wastewater that is released into natural reservoirs (Lynch et al. 2013). By leveraging other I5.0 technologies, this data may be merged to generate a comprehensive and precise representation of a company's environmental and social profile (Asif, Searcy, and Castka 2023). RFID technology enables the tracking of goods, providing data on their location and time, as well as enhancing other information to gain a comprehensive understanding of supply chains (Payer, Quelhas, and Bergiante 2024). This includes analyzing their socio-environmental effects, vulnerability, resilience, and other relevant factors (Olsen and Tomlin 2020).

4.1.6 | Miscellaneous Technologies

Data standardization, automated data collecting, the creation of ESG measures, and the facilitation of increased ESG transparency are all within the purview of cloud computing applications. According to Saxena et al. (2023), satellite imagery provides improved monitoring capabilities, thus enhancing ESG transparency. It details how the land is being used, how much water is stored, how clean the air is, and how the vegetation changes (Lynch et al. 2013). Drones can keep an eye out for human trafficking, examine components at great heights, and keep tabs on distant fields and confined locations (Appelbaum and Nehmer 2017). The technologies listed above are merely examples of what I5.0 can encompass; the specification could contain many more technologies or omit some of those mentioned entirely. According to Asif, Searcy, and Castka (2023), all of the technologies that make up I5.0 operate together in an integrative approach, even if they have to cover a wide spectrum.

4.2 | Improving ESG Scores by I5.0 Driven ESG Reporting/Information

Table 3 examines the significance and quantity of ESG information that is absent, using I5.0-driven ESG reporting as a possible means of generating new ESG information that could affect ESG ratings in the future. The current study includes a novel component known as the Missing (M) pillar and establishes new scores: Environmental, Social, Governance, and Missing (ESGM) scores, by combining the M pillar with the three ESG pillars simultaneously (Sahin et al. 2022). The ESGM scores can be readily understood as a combination of the E, S, G, and newly introduced M pillar scores, following a convex pattern. Thomson Reuters ESG Scores are widely recognized as a reliable indicator of ESG performance across industries, based on the evaluations offered by different rating agencies (Pagano, Sinclair, and Yang 2018). The ESG ratings are accessible for more than 7000 corporations worldwide, provided time series data. These ratings include information on the ESG performances of the firms across 10 significant themes, with data available since 2002 (Thomson Reuters 2019). Refinitiv gathers publicly accessible ESG data from firms and consolidates it to assign the companies with 10 ESG category ratings; these are compared against Thomson Reuters Business Classifications Industry Group or the corresponding Country Group (Refinitiv 2021a, 2021b). According to Sahin et al. (2022), the 10 ESG categories are Innovation (EI), Resource Use (RU), Emissions (EM), Workforce (WF), Human Rights (HR), Community (CO), Product Responsibility (PR), Management (MG), Shareholders (SH), and Corporate Social Responsibility (CS). Table 3 displays the enhanced scores obtained by considering the missing scores.

4.3 | The Concepts of Materiality and Double Materiality for SDGs

The term "materiality," an essential notion in finance, pertains to the information that corporations are obligated to provide to investors (Nielsen 2023). According to the International Accounting Standards Board (IASB) in 2010, information is considered material if its omission or misstatement could affect the decisions made by users based on financial information about a particular reporting entity. When companies offer ESG data (ESG reporting driven by I5.0) to investors using this materiality definition, they primarily concentrate on factors that could have a financial impact on the company. These factors include the risks and opportunities that ESG factors may create for the company (Delgado-Ceballos et al. 2023). This conception of materiality aligns with the concept of financial materiality and primarily focuses on investors. Nonetheless, the external ramifications of corporations on society and the natural environment

TABLE 3 | Interplay of Missing (M) ESG scores given by Industry 5.0 with "Thomson Reuters" ESG scores.

ESG scores given by Thomson Reuters	Description	Missing ESG scores given by I5.0 for improving Thomson Reuters ESG scores	References
Resource Use Score (ESG1)	The Resource Use Score is a measure of how well a company manages its supply chain to reduce the amount of resources used, whether it be water, energy, or materials	M6, M7	Rajesh and Rajendran (2019); Asif, Searcy, and Castka (2022); Sahin et al. (2022); Asif, Searcy, and Castka (2023); Helfaya, Morris, and Aboud (2023); Saxena et al. (2023); Clément, Robinot, and Trespeuch (2023) and Rehman and Umar (2024)
Emissions Score (ESG2)	The Emission Reduction Score is a measure of how serious and successful a business is in cutting down on emissions, especially during production and operations	M10, M11	
Innovation Score (ESG3)	The Innovation Score measures a company's ability to decrease the environmental expenses and burdens for its clients, hence generating new market prospects through inventive environmental technology and processes or eco-designed products	M14, M15	
Workforce Score (ESG4)	The Workforce Score is a measure of how well a business takes into account the needs of its employees in terms of job satisfaction, workplace health and safety, diversity and equal opportunity, and professional development	M1, M2	
Human Rights Score (ESG5)	The Human Rights Score assesses a company's ability to adhere to the fundamental conventions of human rights	M16, M17	
Community Score (ESG6)	The Community Score reflects the company's dedication to upholding public health and adhering to ethical business practices, demonstrating its commitment to acting as a responsible corporate citizen	M9, M15	
Product Responsibility Score (ESG7)	The Product Responsibility Score evaluates a company's ability to manufacture high-quality products and services by incorporating practices related to consumer health and safety, integrity, and data protection	M3, M4, M6	
Management Score (ESG8)	The Management Score reflects a company's dedication and efficiency in adhering to established corporate governance rules	M12, M13	
Shareholders Score (ESG9)	The Shareholders Score is a measure of how well and fairly a firm treats its shareholders; it takes anti-takeover measures into account	M2, M11, M13	
CSR Strategy Score (ESG10)	The CSR Strategy Score measures a company's efforts to effectively explain, include, and merge the financial, social, and environmental aspects of sustainability into its daily decision-making processes	M16, M13	

also occupy the attention of stakeholders (including but not limited to governments, employees, consumers, NGOs, and communities) (Delgado-Ceballos et al. 2023). Organizations satisfy the requirement for stakeholder materiality when they furnish information to external stakeholders regarding the external effects of their operations and strategies via ESG data (enhanced ESG scores). Many investors have begun to factor this information into their investment decisions, even though stakeholder materiality primarily targets stakeholders. Financial materiality and stakeholder materiality are thus collectively referred to as "double materiality." The double materiality perspective, according to our hypothesis, offers a comprehensive understanding of the connection between ESG information and the strategies that corporations employ to assess the external consequences of their operations on the environment and society. Figure 3 shows how SDGs, sustainability, ESG, and the twofold materiality perspective are all interconnected. The right-hand arrows show how SDGs and their aims at the societal level have grown in importance to investors, who factor them into their investment choices and make them financially material to the business. Enhanced ESG reporting at the firm level typically leads to better ESG ratings; these are utilized more and more in the due diligence procedures of investors (MacNeil and Esser 2022). According to Hahn and Tampe (2021), the left arrows indicate how companies are making an effort or have already decided to enhance their sustainability performance at the company level concerning

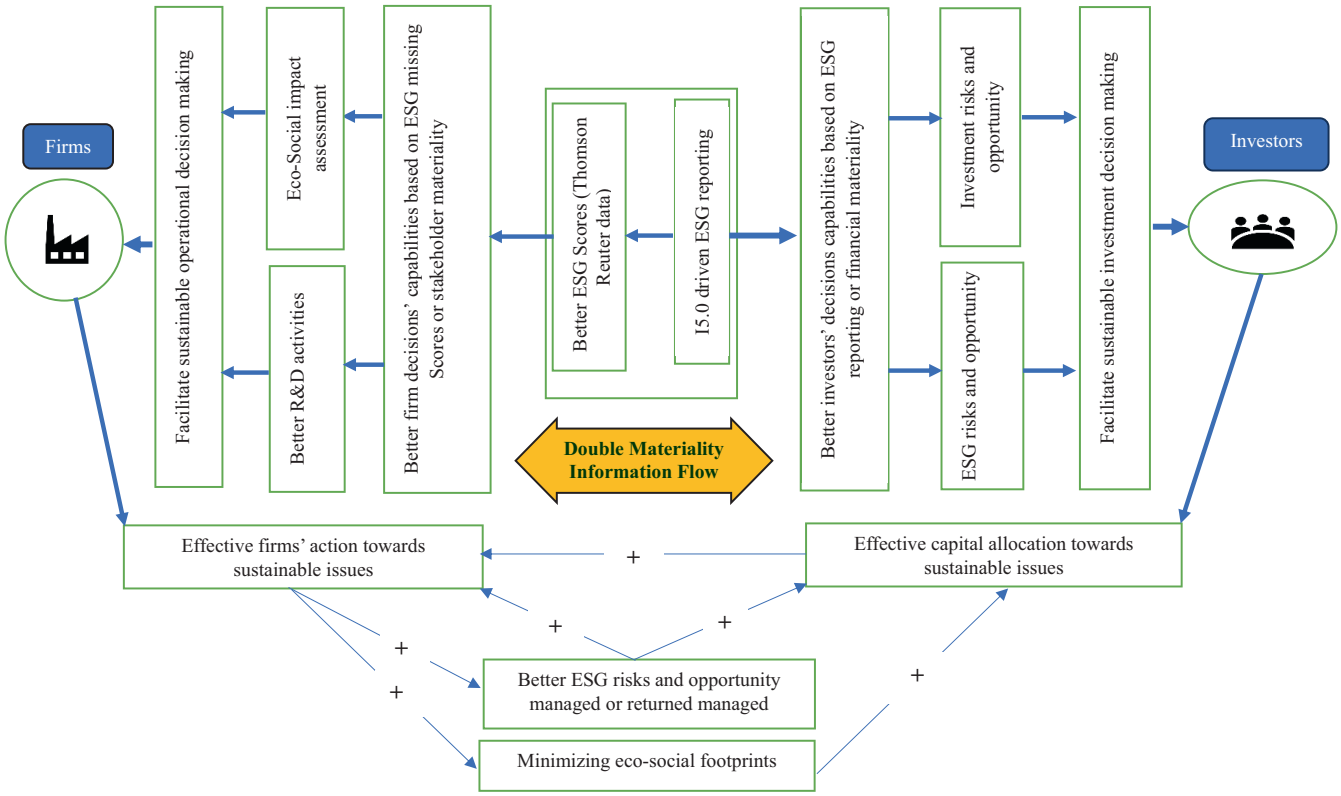

FIGURE 3 | Concept of double materiality to achieve SDGs via investors and firms' decisions.

the materiality of stakeholders. When these initiatives are put into action, they help achieve SDGs while also benefiting the people who matter most to businesses—their employees, customers, communities, and investors. Stakeholder materiality is symbolized by this left arrow. Therefore, the double materialism approach to sustainable development consists of both financial materiality and stakeholder materiality. Double materiality refers to the simultaneous consideration of both financial materiality and stakeholder materiality. It serves as a framework to align investors' concerns with sustainability and guide companies' sustainable initiatives by taking into account the external impact of their business on the natural environment and society. A (+) sign means a change in the influencing variable will produce a change of the same direction in the target variable.

5 | Discussion of Results

This study provides a theoretical investigation of how I5.0 might be used to improve the effectiveness of ESG transparency to respond to the first research question. The European Commission (2020) popularized the developing idea of I5.0, although research on the subject is still in its infancy (Xu et al. 2021). Its goals and values make it clear that it may be beneficial to ESG, although its uses in ESG are still not clear. As a result, the present research is theoretically based as it explores solutions to improve ESG reporting using I5.0 applications (Asif, Searcy, and Castka 2023). The current study is dedicated to examining the function and availability of missing ESG data as a possible avenue for the introduction of new ESG data that might affect ESG ratings in subsequent years; this supports the second research question. Therefore, by concurrently combining the M pillar with the three ESG pillars, the present research proposes a new pillar that we term the Missing (M) pillar, thus establishing an additional score—Environmental, Social, Governance, and Missing (ESGM) scores (Rajesh and Rajendran 2019). A symmetrical combination of the E, S, G, and the recently added M pillar scores may be used to simply comprehend the ESGM scores (Sahin et al. 2022). Finally, to guide the third research question, this study aims to outline a framework of double materiality (investment/investors' decisions and stakeholders/firms' decisions) for sustainable development driven by ESG scores (Chopra et al. 2024).

Companies and their management practices can only be considered to be truly responsible for ESG issues if they disclose accurate information regarding their ESG obligations and implement ESG initiatives to boost non-financial, substantive corporate performance (Cort and Esty 2020). Therefore, ESG performance and ESG disclosure concerns are both concrete actions and public language that must be included in business ESG practices (Clark and Dixon 2024). There is still a significant problem with the veracity of ESG disclosure; this can damage the credibility of ESG (The Economist 2022). Nirino et al. (2021) identify numerous instances of fraud and systemic non-compliance in existing literature. According to legitimacy and OIPT theory, instances of this kind will persist so long as certain motivations persist, such as economic greed, insufficient reporting frameworks, and unreliable reporting methods. Implementing I5.0, which allows for source-level data collection, less reliance on human involvement, and transaction traceability, is the primary means by which these issues can be resolved (Liu et al. 2021; Yu et al., 2022). Resource Use Score (ESG 1), Workforce Score (ESG 4), Human Rights Score (ESG 5), and Community Score (ESG 6)

can all be improved with the help of this information. ESG relies on historical data, contrasting with real-time and prospective data. The accuracy of disclosure reports is contingent upon the firm's data collection capabilities at the current time (Dai and Vasarhelyi 2016). A retrospective profile provides an assessment of the firm's previous performance, which is insufficient given the dynamic and constantly evolving organizational environment (Castka, Searcy, and Mohr 2020), as well as the need for timely information from regulators and consumers (Reid and Castka 2023). Thus, due to the continuous emergence of new paradigms (such as the digital revolution), advanced technologies (like I5.0), and evolving criteria for assessing data quality (including data velocity, volume, variety, and veracity), the need for current and up-to-date data becomes more prominent (Asif, Searcy, and Castka 2022).

As companies' activities are being closely examined by investors, customers, and other interested parties, having access to up-to-date information is crucial for establishing a genuine ESG profile. The use of I5.0 technologies will offer an optimal solution for ESG reporting, delivering real-time ESG performance, future-oriented insights, and past audits (Asif, Searcy, and Castka 2023). Real-time reporting provides users with up-to-date information about current events. Prospective reports forecast the future trajectory of processes and provide warnings before any non-compliance arises, for example, if there is a likelihood of ESG 2, ESG 6, ESG 8, and ESG 9 scores increasing, decreasing, or being unchanged in future. These studies also assess the vulnerability of a supply chain to an impending danger. The preceding discourse is substantiated by the fact that BC technology may be utilized to enhance governance and facilitate transparent decision-making, an essential component of ESG practices. Blockchain-based voting utilizes governance tokens to grant voting rights based on the stakes held by token holders (Coindesk 2020). BC technology is being utilized to exchange emission certificates and manage digital contracts. A practical case already in use involves the use of blockchain technology to ensure the safety of a Spanish energy company's supply chain (Respol 2023; Wan Ismail, Madah Marzuki, and Lode 2024). Digital twins are especially useful for improving ESG reporting since they can generate instantaneous reports that are transparent, customizable, and accessible to many stakeholders. Furthermore, AI can provide consumers with the most pertinent ESG information for a specific industry. As an example, many developing nations' garment manufacturers have a history of serious mishaps involving worker health and safety, including fires and building collapses (Asif 2019). Avoiding human trafficking and slavery is a must for major corporations doing business in California. Selim (2020) argues that AI has the potential to make ESG disclosure more informative, relevant, and transparent by considering unique contextual elements like sector type and local laws and extracting the most relevant data. Scores in ESG 4 (Workforce), ESG 5 (Human Rights), and ESG 6 (Community) can all be improved with the help of this information.

It is possible to model and improve ESG disclosure using simulations because they mimic real systems (Kang and Arikrishnan 2024). A variety of technologies, including simulations, AI, machine learning, IoT, and cloud computing applications, come together to create data management capabilities that are secure and suitable for disclosure of ESG. According to Asif, Searcy, and Castka (2023), the operational models of certain logistics organizations incorporate sensors, AI, and simulations. To create loading models, sensors that are mounted to the motors of cranes measure the weight of containers as they are loaded onto ships. This information is utilized by the ship's 3D model to direct the positioning of containers, resulting in increased space and improved fuel economy through weight distribution. According to ISO Focus (2018), businesses can save up to $1000 per day on fuel expenses by optimizing their weight. Gaining a better ESG 2 score (Greenhouse gas emissions from production and operational processes) and an ESG 3 score (Innovation) can be achieved with the help of this information. Last but not least, accounting makes use of RFID and the Internet of Things for dynamic accounting; this allows for the collection of procurement data and the generation of accounting vouchers (Yu et al., 2022). Companies also use RFID to monitor staff movement, which might reveal how much they are taking advantage of their human resources department. According to Saxena et al. (2023), IoT paves the way for ESG disclosure by facilitating data exchange among devices and granting the ability to integrate horizontally and vertically. In addition to collecting data from inside the factory, sensors can also collect data from all points along the supply chain (Bai et al. 2020). By integrating this data with other I5.0 technologies, a more complete and accurate picture of a company's social and environmental profile can be created. Carbon management accounting and carbon trade decisions benefit from the data gathered from the growing number of sensors that measure carbon emissions (Burritt, Schaltegger, and Zvezdov 2011; Payer, Quelhas, and Bergiante 2024). This information is crucial for enhancing ESG 4 (Workforce Score), ESG 5 (Human Rights Score), ESG 6 (Community Score), and ESG 10 (CSR Strategy Score). The preceding considerations follow OIPT, which delineates three primary components: information processing demand, processing capability, and the alignment between processing requirements and capabilities (Ma et al. 2023). Aligned with OIPT, I5.0 can act as a link connecting the ESG information requirements of a company with the necessary capabilities. Research demonstrates that the technologies used in I5.0 also play a helpful role in many other situations, such as accounting audits (Dai and Vasarhelyi 2016), supplier socio-compliance audits (Asif, Searcy, and Castka 2022), sustainability (Ghobakhloo 2020), and enhancing governance (Schmidt and Wagner 2019). Hence, it is plausible that I5.0 can boost ESG disclosure by improving the information processing capabilities of firms. Based on the above discussion, the following propositions are made.

P1. *Industry 5.0 applications (e.g., Data collection at source, Advanced data analytical capabilities, Prospective insights, Authenticated transactions, Enhanced integration across devices and entities, Detecting non-compliance errors) will provide better ESG reporting (e.g., Authenticity, Retrospective reporting, Customizability, Scope of reporting, Cost and Efficacy).*

P2. *Enhanced ESG disclosure driven by I5.0 applications will improve Thomson Reuters ESG performance scores (Innovation (I), Resource Use (RU), Emissions (EM), Workforce (WF), Human Rights (HR), Community (CO), Product Responsibility (PR), Management (MG), Shareholders (SH), and Corporate Social Responsibility (CS)).*

Schaltegger and Burritt (2006) as well as Maas, Schaltegger, and Crutzen (2016) suggest that investors use I5.0-driven effective ESG reporting (financial materiality) to make smart decisions about allocating capital, while firms use stakeholder materiality for internal purposes (operational, strategic, and management control) and to inform other external stakeholders, such as investors, about meaningful sustainability risks and opportunities. One long-term goal of these initiatives is to create a system of positive feedback that will allow capitalism to thrive (Pucker 2021). This means that companies can innovate for growth and productivity (with risks and opportunities addressed) with the help of investor capital without causing harm to people or the environment. According to Chopra et al. (2024), after implementing various investment screening methods on a wide scale, only organizations that are strongly committed to the sustainable development goal would be granted permission to expand. Users, including governments and consumers, are encouraged to influence the activities of entities in this scenario when it is executed transparently. We can enjoy the potential beneficial effects by controlling the corporate impact. Therefore, ESG reporting has evolved from a mere corporate responsibility to a potent mechanism that promotes sustainable development (Kräussl, Oladiran, and Stefanova 2024). Organizations that integrate ESG reporting into their fundamental operations and strategic plans have the potential to make substantial contributions toward resolving the most urgent global issues while also safeguarding their sustainability in the long run (Delgado-Ceballos et al. 2023). Businesses can leverage the full potential of ESG reporting to foster innovation, establish transparent objectives, prioritize accountability and transparency, incorporate sustainability into their business strategies, assess impacts, and actively involve stakeholders (Wang et al. 2023). By encouraging SRI through a variety of investors, they will not only contribute to sustainable development but also become leaders in the global movement for a better world. Numerous investors, despite possessing only a rudimentary comprehension of social responsibility principles, opt to allocate their investments toward accountable companies by utilizing ESG scores as a determinant (Widyawati 2019). The primary advantage of ESG scores to investors is the time and money they save on acquiring and analyzing underlying information (Amel-Zadeh and Serafeim 2018). As a result, ESG scores have become the gold standard for evaluating and quantifying CSR performance (Gyönyörová, Stachoň, and Stašek 2023). Because they have invested in ESG dimensions, companies with high ESG ratings have access to a multitude of resources (Wang et al. 2023). They can improve their production processes and efficiency (Bocquet et al. 2013), use energy-efficient technologies to deliver products and services (Siebenhuener and Arnold 2010), optimize the efficiency of R&D investments, promote the firm's green innovation capabilities (Xu, Liu, and Shang 2020), all because of the knowledge and technological advantages they acquire.

Clear, consistent, and comparable ESG data is essential for investors to make better, more educated decisions. Corporations that disclose consistently strong ESG performance give investors faith in their capacity to show company resilience and long-term sustained value, which in turn accelerates climate action towards the UN SDGs (City Developments Limited 2022). Businesses that excel in ESG metrics will have an easier time securing the capital they need to take action as ESG funds and green financing continue to expand rapidly. With a 45% increase from 2020, sustainable bond issuance reached a record high of over USD 1 trillion in 2021 (Bhattacharyya 2021). A growing number of ESG investors are actively seeking out companies with strong climate policies, and those individuals who fail to meet this demand are being removed from board positions through shareholder resolutions (Clark and Dixon 2024). Businesses can adapt to reduce their environmental and social effect with the help of new technology. They must aim to follow the goal of a zero-carbon future (Kelly and Herweijer 2021; PwC 2022). Businesses must shift their focus from traditional compliance to a proactive strategic approach in managing ESG reporting, as technological applications demand substantial financial investments. Listed firms that disclose their ESG ratings, for instance, lessen their information risk and operational risk, which in turn lays the groundwork for sustainable development (Xiao et al. 2021). This is just one example of how better ESG practices can lower internal risks associated with operations and governance. Bloomberg Intelligence (2021) confirms this by projecting that environmentally conscious investments, measured by ESG ratings, will surpass USD 53 trillion by 2025, accounting for over one-third of the world's managed assets. Further support for this comes from legitimacy theory, which states that organizations should prioritize public interests over those of investors. If a company doesn't live up to people's expectations, it could face consequences including having its operations, resources, and product demand curbed (Del Gesso and Lodhi 2024).

These findings are consistent with CDL's "Disclosure and Communication" testimony, which strongly advocates the idea that what is assessed is effectively managed (City Developments Limited 2022). As the inaugural Singaporean company to release a specialized sustainability report in 2008, they claim to have gained advantages from the experience of creating 15 sustainability reports. CDL utilizes GRI Standards as their primary reporting standard to effectively identify significant matters, establish meaningful objectives, monitor progress, and identify areas for improvement. This has allowed management to promptly and strategically take action to enhance and safeguard the business, as well as increase operational efficiency. In 2017, CDL's Future Value 2030 plan was adopted, outlining their strategic objectives and ESG targets. This blueprint has been successfully incorporated into CDL's company strategy and operations. CDL's longstanding reporting processes have effectively communicated comprehensive and comparable data and information to their stakeholders, including investors and financiers. This enables them to make informed decisions. One outcome has been the pilot and research and development of DigiHub, a digital platform developed by CDL that specializes in integrated and predictive facilities management solutions (An 2023). By utilizing this, CDL became the inaugural Singaporean entity to obtain a discount on a loan linked to sustainability through implementation of this pioneering initiative that substantially advances the SDGs established by the UN. This innovation is consistent with the views of Maama (2021), who explains the relationship between ESG reporting and the financial sustainability of institutions using legitimacy theory. Reber, Gold, and

Gold (2022) also employ this theory to support their claims regarding the legitimacy of sustainable business conduct by illustrating how voluntary ESG disclosure aids in the mitigation of firm-specific risks. ESG scores serve as a reliable indicator of the extent to which a company pursues legitimacy and transmits a significant message regarding transparency (Del Gesso and Lodhi 2024). Based on the above discussion, the following propositions are made:

P3. *Value-enhanced ESG disclosure (ESG data related to financial materiality) driven by Industry 5.0 will guide investor decisions towards socially responsible investment (SRI) to achieve sustainable development.*

P4. *Better ESG performance scores (ESG data related to stakeholder materiality) driven by value-enhanced ESG disclosure will guide investor decisions towards socially responsible investment (SRI) to achieve sustainable development.*

P5. *Better ESG performance scores (ESG data related to stakeholder materiality) driven by value-enhanced ESG disclosure will guide firms' decisions or strategies toward sustainable practices to achieve sustainable development.*

P6. *Investors' decisions towards socially responsible investment (SRI) will further facilitate firms' decisions or strategies towards sustainable practices to achieve sustainable development, thus completing the double materiality concept of ESG-based sustainability.*

Based on the above discussion and propositions formulated, Figure 4 depicts the conceptual framework to achieve SDGs driven by Industry 5.0 ESG reporting, as well as firms' and investors' decisions.

5.1 | Managerial and Social Implications

Our research suggests that managers and firms may not be included in investment portfolios, and not only because of their ESG performance. It's also possible that their ESG disclosure methods are slow or non-existent. Investors should be able to effectively manage ESG-related risks and make sustainable investments if comprehensive disclosure material is prioritized (KPMG 2022). Researchers can use the M pillar as a proxy for the existing ESG disclosure quality, adjusted for sectorial differences, just as the other pillars. It also shows organizational capacity to publish missing ESG information. This research provides managers with insights into the factors that cause organizations to be deficient in ESG data, as well as how this data is distributed across different categories and geographical regions (Greenly 2022). To measure ESG performance and the responsible investment of companies accurately, the present research may also shed light on which ESG information should be released, and how, following Industry 5.0. This study also advises business leaders and managers to disclose accurate information regarding their company's ESG obligations, as well as to implement ESG efforts to boost non-financial corporate performance (Financial Times 2020). According to these findings, ESG performance and transparency concerns are two aspects of corporate ESG practices that encompass both public rhetoric and real measures aimed at promoting the sustainable development of organizations as a whole.

The findings of this study have several practical implications for policymakers, regulators, and other interested parties. A more optimal level of ESG disclosure from a company is possible if upper management realizes the significance of ESG disclosure (Greenly 2022). It would be beneficial for managers of companies, in particular non-financial organizations, to realize that

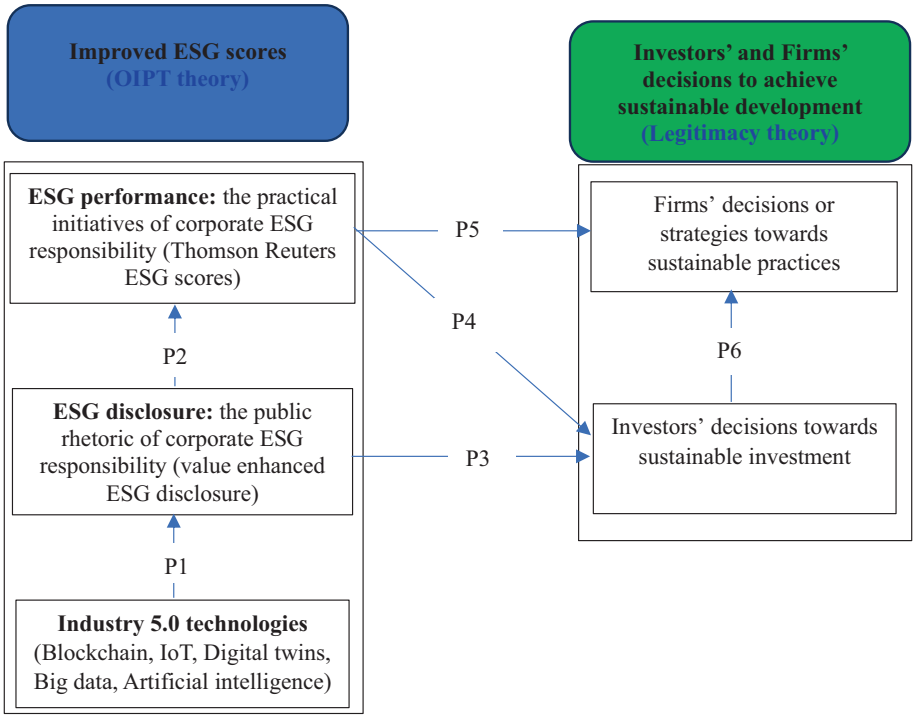

FIGURE 4 | Conceptual framework to achieve SDGs driven by Industry 5.0 ESG reporting, firms' and investors' decisions.

TABLE 4 | Potential questions for future research exploration to achieve SDGs driven by Industry 5.0 ESG reporting, firms' and investors' decisions.

Present research questions	Unexplored themes	Future research questions
RQ1: How will Industry 5.0 applications facilitate better ESG reporting?	Industry 5.0 applications in ESG reporting	• What avenues can be pursued for further investigation into the potential use of I5.0 or other technologies in ESG disclosure? • How can researchers include generative AI technologies like ChatGPT, blockchain, and AI into ESG reporting in their future work? • How will I5.0 technologies (cloud computing, artificial intelligence, digital twins, etc.) be evaluated generally by ESG-related research in the future, regarding their suitability, feasibility, accuracy, and stage of advancement? • How can automated information gathering be made possible by sensors and RFID, minimizing inaccuracies and lowering the requirement for human assistance? • How will future work conform to established methods, such as prioritizing and ranking difficulties in I5.0-based ESG reporting? • How can blockchain guarantee transaction monitoring if a buyer's procurement history contradicts a supplier's sales record?
	Enhancing Industry 5.0 Utility	• How do numerous stakeholders work together to guarantee that the ESG principles underlying I5.0 are implemented? • What is the optimal method for establishing data platforms (or other collaborative platforms)? • Which guiding principles ought to regulate these platforms? • How do digital twins furnish a digital copy of actual processes, representing the most current version of processes and making ESG disclosure instantaneous? • How do digital twins provide an immediate digital replica of real operations, reflecting the most recent iteration of the procedures and facilitating ESG disclosure? • In what ways do cloud computing applications facilitate online services and combine information to create ESG reports?
	Analyzing the impact of Industry 5.0 on ESG reporting	• How will future researchers determine if I5.0 has helped companies improve their ESG disclosure performance? • What are the distinctions in the extent and caliber of ESG disclosure that arise from the implementation of I5.0 technologies? • How can sensors, RFID, and IoT enable real-time data collecting? How does blockchain ensure transaction security? How do machine learning and artificial intelligence simplify and enhance ESG reporting?

(Continues)

TABLE 4 | (Continued)

Present research questions	Unexplored themes	Future research questions
RQ2: How will the disclosed ESG information based on Industry 5.0 improve ESG scores?	Interlinking between ESG disclosure and ESG scores	• How will future research verify that ESG ratings accurately reflect disclosure levels related to ESG concerns? • What can future research on the different ESG score definitions reveal about the variable that ESG disclosure is most useful for measuring? • How can missing (M) scores or information based on value-enhanced ESG reporting be connected to ESG scores to obtain aggregate MESG scores? • How will the incorporation of ESG reporting prompted by the behaviors of green-washing corporations enhance ESG scores? • How might different theoretical frameworks facilitate the establishment of an association between ESG reporting, specifically in the context of I5.0, and ESG scores?
RQ3: How will the disclosed ESG information and better ESG scores further facilitate investors' and firms' decisions to achieve sustainable development?	ESG reporting driving investors' strategies toward sustainable investment	• What steps may be taken to make sustainable investment strategies more data-driven, optimized, integrated, and operationalized? • How do ESG reports and sustainable investing strategies relate to one another, and what is the theory behind this? Are there any cause-and-effect relationships? If there are any, what are the primary factors that have a substantial impact on these relationships? • What strategies can be employed to address the limitations associated with social and environmental data, metrics, and ratings to facilitate informed decisions regarding sustainable investments? • How would the risk of green-washing in ESG reporting be addressed by investors? • How can companies adapt their business models driven by ESG reporting to incorporate sustainable investment? • How can governments combine different sustainable investment policy instruments to tackle the most salient sustainability-related challenges revealed by improved ESGM scores?
	ESG performance-driven firms' strategies toward sustainable practices	• How can companies that are committed to ESG performance access a multitude of services due to their ESG performance scores? • How does a company's access to information and technical advantages through ESGM scores support its innovation efforts across the board, including the development of environmentally friendly goods and services through the application of energy-saving technology? • In what ways will missing scores improve the firm's capacity for green innovation by making R&D investments more efficient? • How will ESG scores influence industries with different product attributes given the different levels of contact with various stakeholders? • How will industry sensitivity, which can assess the degree of sustainable difficulties in a company's production operations, be impacted by ESG scores?

ESG disclosure can boost competitive advantage. Management must accept that a higher competitive edge can make the firm more viable and successful. The findings of this study can be useful for policymakers and the financial services authority, among others, as they work to codify requirements for businesses to disclose more information about ESG factors, particularly those outside of the financial sector. Disclosure of ESG components is the responsibility of companies. Lastly, it is envisaged that stakeholders, such as creditors, investors and the public at large, can contribute valuable insights and deepen their understanding when it comes to assessing upcoming economic decisions, particularly those concerning ESG transparency, competitive advantage, and the value of a firm. This can lead to practitioners making better decisions and implementing better systems.

6 | Conclusion, Limitations, and Future Directions

This article discusses how I5.0 could improve the credibility of ESG reports, make them more customizable, make them applicable to more supply chains, lower disclosure costs, and enable real-time reporting and future insights. The level of implementation of I5.0 technologies will determine the extent to which these benefits are realized. This research demonstrates how businesses may improve ESG by implementing certain aspects of I5.0. To accommodate a company's capacity to disclose missing ESG information, this study suggests a new pillar score, the so-called Missing (M) pillar score, driven by I5.0. A new Environmental, Social, Governance, and Missing (ESGM) score is therefore introduced. Furthermore, our research develops an optimization strategy that correlates the risk for corporations with their ESGM scores. The aim of this plan is to encourage businesses to be more transparent about their ESG practices and to assess how this transparency affects their financial risk. In addition, investors and firms can utilize it to create personalized scores that will guide their strategies toward sustainable development (the double materiality notion). I5.0 is the driving force behind the present study's proposed twofold materiality approach, which enables companies to involve shareholders and investors in ESG integration while also aiding in sustainable development and the attainment of the SDGs. Double materiality functions as a framework that enables a company to develop its sustainability practices by considering the concerns of all stakeholders and resolving the conflicting viewpoints of investors (financial materiality) and other stakeholders (stakeholder materiality) regarding sustainability.

The current study does have some limitations, but it also makes some important contributions. The correlation between the I5.0 adoption rate and ESG performance is not explored in the current literature. The question of whether or not I5.0 has enhanced companies' ESG disclosure performance may be the subject of future research. There are a few missing scores or pieces of information for ESG reporting, which limits our analysis. It would be beneficial for future research to incorporate data from more companies when calculating our M pillar score and ESGM ratings. The study has certain caveats due to its reliance on secondary data on the ESG performances of corporations from Thomson Reuters, as this is based on their appraisal of 10 sustainability themes. In future, other sustainability scores for firms will be available, such as the Dow Jones sustainability indices and Bloomberg disclosure scores. Also, a comparative study of these relations among various rating sources can be conducted as a potential direction for future work.

This research does not deeply analyze the episodic events and dynamic components that change the relationships between ESG practices and corporate sustainable-value creation in a phase where companies are facing an increasingly complex internal or external environment. Therefore, in future, the impact of the COVID-19 outbreaks on the economic consequences shaped by corporate ESG practices can be monitored on an ongoing basis to provide sound advice for companies to achieve a sustainable transition in the post-epidemic era.

Finally, Table 4 provides future research avenues based on past literature limitations.

Conflicts of Interest

The authors declare no conflicts of interest.

References

Aheleroff, S., H. Huang, X. Xu, and R. Y. Zhong. 2022. "Toward Sustainability and Resilience With Industry 4.0 and Industry 5.0." *Frontiers in Manufacturing Technology* 2: 951643.

Aheleroff, S., X. Xu, R. Y. Zhong, and Y. Lu. 2021. "Digital Twin as a Service (DTaaS) in Industry 4.0: An Architecture Reference Model." *Advanced Engineering Informatics* 47: 101225.

Ahmad, H., M. Yaqub, and S. H. Lee. 2024. "Environmental-, Social-, and Governance-Related Factors for Business Investment and Sustainability: A Scientometric Review of Global Trends." *Environment, Development and Sustainability* 26: 2965–2987.

Ali, O., A. Jaradat, A. Kulakli, and A. Abuhalimeh. 2021. "A Comparative Study: Blockchain Technology Utilization Benefits, Challenges and Functionalities." *IEEE Access* 9: 12730–12749.

Alkaraan, F., K. Albitar, K. Hussainey, and V. Venkatesh. 2022. "Corporate Transformation Toward Industry 4.0 and Financial Performance: The Influence of Environmental, Social, and Governance (ESG)." *Technological Forecasting and Social Change* 175: 121423.

Amel-Zadeh, A., and G. Serafeim. 2018. "Why and How Investors Use ESG Information: Evidence From a Global Survey." *Financial Analysts Journal* 74, no. 3: 87–103.

An, E. 2023. "Accelerating Sustainability Through Better Reporting." *Sustainability Accounting, Management and Policy Journal* 14, no. 4: 904–914.

Anselmi, D., I. D'Adamo, M. Gastaldi, and G. V. Lombardi. 2023. "A Comparison of Economic, Environmental and Social Performance of European Countries: A Sustainable Development Goal Index." *Environment, Development and Sustainability* 26, no. 8: 20653–20677. https://doi.org/10.1007/s10668-023-03496-3.

Appelbaum, D., and R. A. Nehmer. 2017. "Using Drones in Internal and External Audits: An Exploratory Framework." *Journal of Emerging Technologies in Accounting* 14, no. 1: 99–113.

Asif, M. 2019. "Supplier Socioenvironmental Compliance: A Survey of the Antecedents of Standards Decoupling." *Journal of Cleaner Production* 246: 118956.

Asif, M., C. Searcy, and P. Castka. 2022. "Exploring the Role of Industry 4.0 in Enhancing Supplier Audit Authenticity, Efficacy, and Cost Effectiveness." *Journal of Cleaner Production* 331: 129939.

Asif, M., C. Searcy, and P. Castka. 2023. "ESG and Industry 5.0: The Role of Technologies in Enhancing ESG Disclosure." *Technological Forecasting and Social Change* 195: 122806.

Assaf, C., J. Monne, L. Harriet, and L. Meunier. 2024. "ESG Investing: Does One Score Fit all Investors' Preferences?" *Journal of Cleaner Production* 443: 141094.

Bai, C., P. Dallasega, G. Orzes, and J. Sarkis. 2020. "Industry 4.0 Technologies Assessment: A Sustainability Perspective." *International Journal of Production Economics* 229: 107776.

Bekaert, G., R. Rothenberg, and M. Noguer. 2023. "Sustainable Investment – Exploring the Linkage Between Alpha, ESG, and SDGs." *Sustainable Development* 31, no. 5: 3831–3842. https://doi.org/10.1002/sd.2628.

Bensaou, M., and N. Venkatraman. 1995. "Configurations of Interorganizational Relationships: A Comparison Between US and Japanese Automakers." *Management Science* 41, no. 9: 1471–1492.

Berg, F., J. Koelbel, and R. Rigobon. 2022. "Aggregate Confusion: The Divergence of ESG Ratings." *Review of Finance* 26, no. 6: 1315–1344.

Bhattacharyya, R. 2021. "Green Finance for Energy Transition, Climate Action and Sustainable Development: Overview of Concepts, Applications, Implementation and Challenges." *Green Finance* 4, no. 1: 1–35.

Bloomberg Intelligence. 2021. "ESG Assets May Hit $53 Trillion by 2025, a Third of Global AUM." Bloomberg Professional Services. Accessed 29 April, 2024. https://www.bloomberg.com/professional/blog/esg-assets-may-hit-53-trillion-by-2025-a-third-of-globalaum/.

Bocquet, R., C. Le Bas, C. Mothe, and N. Poussing. 2013. "Are Firms With Different CSR Profiles Equally Innovative? Empirical Analysis With Survey Data." *European Management Journal* 31, no. 6: 642–654.

Burritt, R. L., S. Schaltegger, and D. Zvezdov. 2011. "Carbon Management Accounting: Explaining Practice in Leading German Companies." *Australian Accounting Review* 21, no. 1: 80–98.

Cao, Y., L. Tao, and Y. Zhang. 2024. "Does Environmental Credit Rating Policy Improve Corporate ESG Performance?" *Sustainable Development* 32, no. 5: 4329–4337. https://doi.org/10.1002/sd.2901.

Capelle-Blancard, G., and S. Monjon. 2012. "Trends in the Literature on Socially Responsible Investment: Looking for the Keys Under the Lamppost." *Business Ethics: A European Review* 21, no. 3: 239–250.

Castka, P., C. Searcy, and J. Mohr. 2020. "Technology-Enhanced Auditing: Improving Veracity and Timeliness in Social and Environmental Audits of Supply Chains." *Journal of Cleaner Production* 258: 120773.

Chen, L., L. Zhang, J. Huang, H. Xiao, and Z. Zhou. 2021. "Social Responsibility Portfolio Optimization Incorporating ESG Criteria." *Journal of Management Science and Engineering* 6, no. 1: 75–85.

Cho, C. H., G. Michelon, D. M. Patten, and R. W. Roberts. 2015. "CSR Disclosure: The More Things Change...?" *Accounting, Auditing and Accountability Journal* 28, no. 1: 14–35.

Chopra, S. S., S. S. Senadheera, P. D. Dissanayake, et al. 2024. "Navigating the Challenges of Environmental, Social, and Governance (ESG) Reporting: The Path to Broader Sustainable Development." *Sustainability* 16, no. 2: 606.

City Developments Limited. 2022. "Integrated Sustainability Report 2022." http://cdlsustainability.com/pdf/CDL_ISR_2022.pdf.

Clark, G. L., and A. D. Dixon. 2024. "Legitimacy and the Extraordinary Growth of ESG Measures and Metrics in the Global Investment Management Industry." *Environment and Planning A: Economy and Space* 56, no. 2: 645–661.

Clément, A., É. Robinot, and L. Trespeuch. 2023. "The Use of ESG Scores in Academic Literature: A Systematic Literature Review." *Journal of Enterprising Communities: People and Places in the Global Economy*. https://doi.org/10.1108/JEC-10-2022-0147.

Coindesk. 2020. "Digital Voting Is Coming. Let's Do It Right." Coindesk. Accessed April 28, 2024. https://www.coindesk.com/markets/2020/11/10/digital-voting-is-coming-lets-do-it-right/.

Colasante, A., I. D'Adamo, A. De Massis, and S. Italiano. 2024. "An Exploratory Study of Stakeholder Views on the Sustainable Development of Mountain Tourism." *Sustainable Development* 32, no. 4: 3722–3735. https://doi.org/10.1002/sd.2878.

Cort, T., and D. Esty. 2020. "ESG Standards: Looming Challenges and Pathways Forward." *Organization and Environment* 33, no. 4: 491–510.

D'Adamo, I., C. Di Carlo, M. Gastaldi, and A. F. Uricchio. 2024. "Equitable and Sustainable Well-Being Indicators: A Study of Italian Regional Disparities Towards Sustainable Development." *Sustainable Development* 32, no. 5: 5538–5549. https://doi.org/10.1002/sd.2985.

D'Adamo, I., M. Gastaldi, and P. Morone. 2022. "Economic Sustainable Development Goals: Assessments and Perspectives in Europe." *Journal of Cleaner Production* 354: 131730. https://doi.org/10.1016/j.jclepro.2022.131730.

D'Adamo, I., and E. N. Rossi. 2024. "Impact of Regional Investment on the Sustainable Development Goals: A Group Analysis of Economic and Territorial Development." *Sustainable Development*. https://doi.org/10.1002/sd.3215.

Dai, J., and M. A. Vasarhelyi. 2016. "Imagineering Audit 4.0." *Journal of Emerging Technologies in Accounting* 13, no. 1: 1–15.

De Silva Lokuwaduge, C. S., and K. M. De Silva. 2022. "ESG Risk Disclosure and the Risk of Green Washing." *Australasian Accounting, Business and Finance Journal* 16, no. 1: 146–159.

de Villiers, C., E. R. Venter, and P.-C. K. Hsiao. 2017. "Integrated Reporting: Background, Measurement Issues, Approaches and an Agenda for Future Research." *Accounting and Finance* 57, no. 4: 937–959.

Deegan, C. M. 2019. "Legitimacy Theory: Despite Its Enduring Popularity and Contribution, Time Is Right for a Necessary Makeover." *Accounting, Auditing and Accountability Journal* 32, no. 8: 2307–2329.

Del Gesso, C., and R. N. Lodhi. 2024. "Theories Underlying Environmental, Social and Governance (ESG) Disclosure: A Systematic Review of Accounting Studies." *Journal of Accounting Literature*. https://doi.org/10.1108/JAL-08-2023-0143.

Delgado-Ceballos, J., N. Ortiz-De-Mandojana, R. Antolín-López, and I. Montiel. 2023. "Connecting the Sustainable Development Goals to Firm-Level Sustainability and ESG Factors: The Need for Double Materiality." *Business Research Quarterly* 26, no. 1: 2–10.

Dillard, J., and E. Vinnari. 2019. "Critical Dialogical Accountability: From Accounting-Based Accountability to Accountability-Based Accounting." *Critical Perspectives on Accounting* 62: 16–38.

Drempetic, S., C. Klein, and B. Zwergel. 2020. "The Influence of Firm Size on the ESG Score: Corporate Sustainability Ratings Under Review." *Journal of Business Ethics* 167: 333–360.

Eccles, R. G., L. E. Lee, and J. C. Stroehle. 2020. "The Social Origins of ESG: An Analysis of Innovest and KLD." *Organization and Environment* 33, no. 4: 575–596.

Escrig-Olmedo, E., M. A. Fern_andez-Izquierdo, I. Ferrero-Ferrero, J. M. Rivera-Lirio, and M. J. Muñoz- Torres. 2019. "Rating the Raters: Evaluating How ESG Rating Agencies Integrate Sustainability Principles." *Sustainability* 11, no. 3: 915.

European Commission. 2020. "EUROPE 2020 A European Strategy for Smart, Sustainable and Inclusive Growth." Accessed 10 November, 2024. https://ec.europa.eu/eu2020/pdf/COMPLET%20EN%20BARROSO%20%20%20007%20-%20Europe%202020%20-%20EN%20version.pdf.

Ferrero-Ferrero, I., R. León, and M. J. Munoz-Torres. 2021. "Sustainability Materiality Matrices in Doubt: May Prioritizations

of Aspects Overestimate Environmental Performance?" *Journal of Environmental Planning and Management* 64, no. 3: 432–463.

Financial Times. 2020. "Ethical Investors Want More Proof of Good Deeds." Financial Times. Accessed September 19, 2024. https://www.ft.com/content/5c943b66-5a22-11ea-abe5-8e03987b7b20.

Friede, G. 2019. "Why don't We See More Action? A Meta Synthesis of the Investor Impediments to Integrate Environmental, Social, and Governance Factors." *Business Strategy and the Environment* 28, no. 6: 1260–1282.

Galbraith, J. R. 1974. "Organization Design: An Information Processing View." *Interfaces* 4, no. 3: 28–36.

Galbraith, J. R. 2014. "Organizational Design Challenges Resulting From Big Data." *Journal of Organization Design* 3, no. 1: 2–13.

Ghobakhloo, M. 2020. "Industry 4.0, Digitization, and Opportunities for Sustainability." *Journal of Cleaner Production* 252: 119869.

Ghobakhloo, M., M. Iranmanesh, M. Fathi, A. Rejeb, B. Foroughi, and D. Nikbin. 2024. "Beyond Industry 4.0: A Systematic Review of Industry 5.0 Technologies and Implications for Social, Environmental and Economic Sustainability." *Asia-Pacific Journal of Business Administration*. https://doi.org/10.1108/APJBA-08-2023-0384.

Global Sustainable Investment Alliance. 2018. "2018 Global Sustainable Investment Review."

Greenly. 2022. "What is ESG Reporting, and Should You Be Doing It?" Greenly. Accessed September 18, 2024. https://www.greenly.earth/blog-en/what-is-esg-reporting-and-should-you-be-doing-it.

Gupta, A., U. Sharma, and S. K. Gupta. 2021. "The Role of ESG in Sustainable Development: An Analysis Through the Lens of Machine Learning." In *Proceedings of the 2021 IEEE International Humanitarian Technology Conference (IHTC), Virtual*, 1–5. IEEE.

Gyönyörová, L., M. Stachoň, and D. Stašek. 2023. "ESG Ratings: Relevant Information or Misleading Clue? Evidence From the S&P Global 1200." *Journal of Sustainable Finance and Investment* 13, no. 2: 1075–1109.

Hahn, T., and M. Tampe. 2021. "Strategies for Regenerative Business." *Strategic Organization* 19, no. 3: 456–477.

Helfaya, A., R. Morris, and A. Aboud. 2023. "Investigating the Factors That Determine the ESG Disclosure Practices in Europe." *Sustainability* 15, no. 6: 5508.

Höchstädter, A. K., and B. Scheck. 2015. "What's in a Name: An Analysis of Impact Investing Understandings by Academics and Practitioners." *Journal of Business Ethics* 132, no. 2: 449–475.

In, S. Y., D. Rook, and A. Monk. 2019. "Integrating Alternative Data (Also Known as ESG Data) in Investment Decision-Making." *Global Economic Review* 48, no. 3: 237–260.

International Accounting Standard Board. 2010. "Conceptual Framework for Financial Reporting 2010." https://www.ifrs.org/projects/completed-projects/2010/conceptual-framework-2010.

ISO Focus. 2018. "The New Industrial Revolution." International Organization for Standardization. Accessed April 29, 2024. https://issuu.com/isostandards/docs/isofocus_131-en.

Jiang, Z., Y. Guo, and Z. Wang. 2021. "Digital Twin to Improve the Virtual-Real Integration of Industrial IoT." *Journal of Industrial Information Integration* 22: 100196.

Jonsdottir, B., T. O. Sigurjonsson, L. Johannsdottir, and S. Wendt. 2022. "Barriers to Using ESG Data for Investment Decisions." *Sustainability* 14, no. 9: 5157.

Kang, A. S., and S. Arikrishnan. 2024. "Sustainability Reporting and Total Quality Management Post-Pandemic: The Role of Environmental, Social, Governance (ESG), and Smart Technology Adoption." *Journal of Asia Business Studies* 18: 1308–1343. https://doi.org/10.1108/JABS-03-2022-0080.

Kelly, C., and C. Herweijer. 2021. "How Business Can Bridge the Gap and Achieve Net Zero." PwC. www.pwc.com/gx/en/issues/reinventing-the-future/take-on-tomorrow/businessachieving-net-zero.htm.

Khamisu, M. S., R. A. Paluri, and V. Sonwaney. 2024. "Environmental Social and Governance (ESG) Disclosure Motives for Environmentally Sensitive Industry: An Emerging Economy Perspective." *Cogent Business and Management* 11, no. 1: 2322027.

Khan, M., G. Serafeim, and A. Yoon. 2016. "Corporate Sustainability: First Evidence on Materiality." *Accounting Review* 91, no. 6: 1697–1724.

KPMG. 2022. "Mandatory ESG Reporting Is Here, and Finance Needs to Get Ready." KPMG. Accessed September 18, 2024. https://home.kpmg/uk/en/blogs/home/posts/2022/05/mandatory-esg-reporting.html.

Kräussl, R., T. Oladiran, and D. Stefanova. 2024. "A Review on ESG Investing: Investors' Expectations, Beliefs and Perceptions." *Journal of Economic Surveys* 38, no. 2: 476–502.

Lai, A., G. Melloni, and R. Stacchezzini. 2016. "Corporate Sustainable Development: Is 'Integrated Reporting' a Legitimation Strategy?" *Business Strategy and the Environment* 25, no. 3: 165–177.

Lee, M. S. 2023. "The Relationship Between Green Innovation and Sustainable Growth in Korean Companies: Moderated Mediation Effect of ESG Score by Industry." *Sustainable Development* 32, no. 3: 2797–2810. https://doi.org/10.1002/sd.2807.

Lee, O., H. Joo, H. Choi, and M. Cheon. 2022. "Proposing an Integrated Approach to Analyzing ESG Data via Machine Learning and Deep Learning Algorithms." *Sustainability* 14, no. 4: 8745.

Liu, X., H. Wu, W. Wu, Y. Fu, and G. Q. Huang. 2021. "Blockchain-Enabled ESG Reporting Framework for Sustainable Supply Chain." In *Sustainable Design and Manufacturing*. Singapore: Springer.

Lokuwaduge, C. S. D. S., and K. Heenetigala. 2016. "Integrating Environmental, Social and Governance (ESG) Disclosure for a Sustainable Development: An Australian Study." *Business Strategy and the Environment* 26, no. 4: 438–450.

Lynch, J., M. Maslin, H. Balzter, and M. Sweeting. 2013. "Choose Satellites to Monitor Deforestation." *Nature* 496: 293–294.

Ma, Y. M., Z. Deng, Y. Teng, Z. Yang, and X. Zheng. 2023. "Firms' Multi-Sided Platform Construction Efforts and ESG Performance: An Information Processing Theory Perspective." *Industrial Marketing Management* 115: 455–469.

Maama, H. 2021. "Achieving Financial Sustainability in Ghana's Banking Sector: Is Environmental, Social and Governance Reporting Contributive?" *Global Business Review*: 1–13. https://doi.org/10.1177/09721509211044300.

Maas, K., S. Schaltegger, and N. Crutzen. 2016. "Integrating Corporate Sustainability Assessment, Management Accounting, Control, and Reporting." *Journal of Cleaner Production* 136: 237–248.

MacNeil, I., and I. M. Esser. 2022. "From a Financial to an Entity Model of ESG." *European Business Organization Law Review* 23, no. 1: 9–45.

Macpherson, M., A. Gasperini, and M. Bosco. 2021. "Implications for Artificial Intelligence and ESG Data." Accessed April 28, 2024. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3863599.

Milne, M. J., and R. Gray. 2013. "W(h)ither Ecology? The Triple Bottom Line, the Global Reporting Initiative, and Corporate Sustainability Reporting." *Journal of Business Ethics* 118: 13–29.

Mourtzis, D., J. Angelopoulos, and N. Panopoulos. 2022. "A Literature Review of the Challenges and Opportunities of the Transition From Industry 4.0 to Society 5.0." *Energies* 15: 6276.

Nielsen, C. 2023. "ESG Reporting and Metrics: From Double Materiality to Key Performance Indicators." *Sustainability* 15, no. 24: 16844.

Nirino, N., G. Santoro, N. Miglietta, and R. Quaglia. 2021. "Corporate Controversies and Company's Financial Performance: Exploring the Moderating Role of ESG Practices." *Technological Forecasting and Social Change* 162: 120341.

Olsen, C. 2022. "Toward a Digital Sustainability Reporting Framework in Organizations in the Industry 5.0 Era: An Accounting Perspective." In *From the Internet of Things to the Internet of Ideas: The Role of Artificial Intelligence, Proceedings of EAMMIS 2022*. Switzerland: Springer.

Olsen, T. L., and B. Tomlin. 2020. "Industry 4.0: Opportunities and Challenges for Operations Management." *Manufacturing and Service Operations Management* 22, no. 1: 113–122.

Pagano, M. S., G. Sinclair, and T. Yang. 2018. "Understanding ESG Ratings and ESG Indexes." In *Research Handbook of Finance and Sustainability*, edited by S. Boubaker, D. Cumming, and D. K. Nguyen, vol. 18, 339–370. Cheltenham: Edward Elgar.

Page, M. J., J. E. McKenzie, P. M. Bossuyt, et al. 2021. "The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews." *BMJ* 10, no. 1: 1–11.

Paolone, F., M. Pozzoli, M. Chhabra, and A. Di Vaio. 2024. "Cultural and Gender Diversity for ESG Performance Towards Knowledge Sharing: Empirical Evidence From European Banks." *Journal of Knowledge Management* 28, no. 11: 106–131.

Payer, R. C., O. L. G. Quelhas, and N. C. R. Bergiante. 2024. "Framework to Supporting Monitoring the Circular Economy in the Context of Industry 5.0: A Proposal Considering Circularity Indicators, Digital Transformation, and Sustainability." *Journal of Cleaner Production* 466: 142850.

Principles for Responsible Investment. 2017. "The SDG Investment Case."

PRISMA. 2023. "Preferred Reporting Items for Systematic Reviews and Meta-Analyses." http://www.prisma-statement.org/.

Pucker, K. P. 2021. "Overselling Sustainability Reporting." *Harvard Business Review* 99: 134–143.

PwC. 2022. "PwC's US Investor Survey: The Economic Realities of ESG."

Rajesh, R., and C. Rajendran. 2019. "Relating Environmental, Social, and Governance Scores and Sustainability Performances of Firms: An Empirical Analysis." *Business Strategy and the Environment* 29, no. 3: 1247–1267.

Reber, B., A. Gold, and S. Gold. 2022. "ESG Disclosure and Idiosyncratic Risk in Initial Public Offerings." *Journal of Business Ethics* 179, no. 3: 867–886.

Refinitiv. 2021a. "Environmental, Social and Governance (ESG) Scores from Refinitiv."

Refinitiv. 2021b. "The Refinitiv Business Classification." Accesses 28 April, 2024. https://www.refinitiv.com/content/dam/marketing/en_us/documents/quickreference-guides/trbc-business-classification-quick-guide.pdf.

Rehman, A., and T. Umar. 2024. "Literature Review: Industry 5.0. Leveraging Technologies for Environmental, Social and Governance Advancement in Corporate Settings." *Corporate Governance*. https://doi.org/10.1108/CG-11-2023-0502.

Reid, J., and P. Castka. 2023. "The Impact of Remote Sensing on Monitoring and Reporting – The Case of Conformance Systems." *Journal of Cleaner Production* 393: 136331.

Rekker, S. A. C., J. E. Humphrey, and K. R. O'Brien. 2021. "Do Sustainability Rating Schemes Capture Climate Goals?" *Business and Society* 60, no. 1: 125–160.

Respol. 2023. "Blockchain Technology for the Energy Sector." Respol. Accessed April 29, 2024. https://www.repsol.com/en/press-room/repsol-news/32/index.cshtml.

Rezaee, Z. 2016. "Business Sustainability Research: A Theoretical and Integrated Perspective." *Journal of Accounting Literature* 36, no. 1: 48–64.

Saad, A., S. Faddel, and O. Mohammed. 2020. "IoT-Based Digital Twin for Energy Cyber-Physical Systems: Design and Implementation." *Energies* 13, no. 8: 4762.

Sahin, O., K. Bax, C. Czado, and S. Paterlini. 2022. "Environmental, Social, Governance Scores and the Missing Pillar—Why Does Missing Information Matter?" *Corporate Social Responsibility and Environmental Management* 29, no. 5: 1782–1798.

Sarti, S., N. Darnall, and F. Testa. 2018. "Market Segmentation of Consumers Based on Their Actual Sustainability and Health-Related Purchases." *Journal of Cleaner Production* 192: 270–280.

Saxena, A., R. Singh, A. Gehlot, et al. 2023. "Technologies Empowered Environmental, Social, and Governance (ESG): An Industry 4.0 Landscape." *Sustainability* 15, no. 1: 309.

Schaltegger, S., and R. Burritt. 2006. "Corporate Sustainability Accounting. A Catchphrase for Compliant Corporations or a Business Decision Support for Sustainability Leaders?" In *Sustainability Accounting and Reporting*, 37–59. Berlin/Heidelberg, Germany: Springer.

Schmidt, C. G., and S. M. Wagner. 2019. "Blockchain and Supply Chain Relations: A Transaction Cost Theory Perspective." *Journal of Purchasing and Supply Management* 25, no. 4: 100552.

Schulz, K., and M. Feist. 2021. "Leveraging Blockchain Technology for Innovative Climate Finance Under the Green Climate Fund." *Earth System Governance* 7: 100084.

Selim, O. 2020. "ESG and AI: The Beauty and the Beast of Sustainable Investing." In *Sustainable Investing*. London: Routledge.

Serafeim, G., M. Kramer, B. M. E. Porter, G. Serafeim, and M. K. October. 2019. "Where ESG Fails." Institutional Investor. Accessed 28 April, 2024. www.institutionalinvestor.com/article/b1hm5ghqtxj9s7/Where-ESG-Fails.

Siebenhuener, B., and M. Arnold. 2010. "Organizational Learning to Manage Sustainable Development." *Business Strategy and the Environment* 16, no. 5: 339–353.

The Economist. 2022. "ESG Should Be Boiled Down To One Simple Measure: Emissions." The Economist. https://www.economist.com/leaders/2022/07/21/esg-should-be-boiled-down-to-one-simple-measure-emissions.

Thomson Reuters. 2019. "ESG Scores." https://www.refinitiv.com/content/dam/marketing/en_us/documents/methodology/esgscores-methodology.pdf.

Turner, C., and J. Oyekan. 2023. "Manufacturing in the Age of Human-Centric and Sustainable Industry 5.0: Application to Holonic, Flexible, Reconfigurable and Smart Manufacturing Systems." *Sustainability* 15, no. 13: 10169.

van Zanten, J. A., and R. van Tulder. 2021. "Improving companies' Impacts on Sustainable Development: A Nexus Approach to the SDGS." *Business Strategy and the Environment* 30, no. 8: 3703–3720.

Verdouw, C., B. Tekinerdogan, A. Beulens, and S. Wolfert. 2021. "Digital Twins in Smart Farming." *Agricultural Systems* 189: 103046.

Waheed, A., M. Alharthi, S. Z. Khan, and M. Usman. 2022. "Role of Industry 5.0 in Leveraging the Business Performance: Investigating Impact of Shared-Economy on Firms' Performance With Intervening Role of i5.0 Technologies." *SAGE Open* 12, no. 2: 1–14.

Wan Ismail, W. A., M. Madah Marzuki, and N. A. Lode. 2024. "Financial Reporting Quality, Industrial Revolution 4.0 and Social Well-Being

Among Malaysian Public Companies." *Asian Journal of Accounting Research* 9, no. 4: 294–308.

Wang, N., H. Pan, Y. Feng, and S. Du. 2023. "How Do ESG Practices Create Value for Businesses? Research Review and Prospects." *Sustainability Accounting, Management and Policy Journal* 15: 1155–1177. https://doi.org/10.1108/SAMPJ-12-2021-0515.

Waniak-Michalak, H., A. Sapkauskiene, and S. Leitoniene. 2018. "Do Companies Manipulate CSR Information to Retain Legitimacy?" *Engineering Economics* 29, no. 3: 352–360.

Wettstein, F., E. Giuliani, G. D. Santangelo, and G. K. Stahl. 2019. "International Business and Human Rights: A Research Agenda." *Journal of World Business* 54, no. 1: 54–65.

Widyawati, L. 2019. "A Systematic Literature Review of Socially Responsible Investment and Environmental Social Governance Metrics." *Business Strategy and the Environment* 29, no. 2: 619–637.

Xian, W., K. Yu, F. Han, L. Fang, D. He, and Q. Han. 2024. "Advanced Manufacturing in Industry 5.0: A Survey of Key Enabling Technologies and Future Trends." *IEEE Transactions on Industrial Informatics* 20, no. 2: 1055–1068.

Xiao, F., F. Y. Lan, W. Shi, H. Xiong, and H. Y. Shen. 2021. "Do ESG Ratings of Listed Companies Affect Audit Fees? – A Quasi-Natural Experiment Based on ESG Rating Events." *Audit Research* 3: 41–50.

Xu, J., F. Liu, and Y. Shang. 2020. "R&D Investment, ESG Performance and Green Innovation Performance: Evidence From China." *Kybernetes* 50, no. 3: 737–756.

Xu, X., Y. Lu, B. Vogel-Heuser, and L. Wang. 2021. "Industry 4.0 and Industry 5.0—Inception, Conception and Perception." *Journal of Manufacturing Systems* 61: 530–535.

Zhang, D., Z. Zhao, and C. K. M. Lau. 2022. "Sovereign ESG and Corporate Investment: New Insights From the United Kingdom." *Technological Forecasting and Social Change* 183: 121899.

Zhang, Y., and Y. Li. 2023. "Society 5.0 Versus Industry 5.0: An Examination of Industrialization Models in Driving Sustainable Development From a Normative Stakeholder Theory Perspective." *Sustainable Development* 31, no. 5: 1–10.