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Empowering or Constraining? The Impact of Corporate Digitalization on Green Management Practices

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Abstract

The relationship between corporate digitalization and green management practices has received increasing scholarly attention, but existing empirical findings remain inconsistent. To clarify this relationship, this research conducts a meta-analysis based on 94 effect sizes from 82 empirical studies, adopting a multivariable research framework to integrate existing findings and explore the factors that contribute to the generation of heterogeneity. The findings indicate that corporate digitalization facilitates green management practices, a conclusion robust across three key dimensions: environmental performance, green innovation, and green supply chain management. Furthermore, the findings show that digitalization exerts a stronger positive effect in non-manufacturing firms, non-heavy-polluting firms, and high-tech firms, while measurement approaches emerge as a critical factor influencing empirical outcomes. These findings provide integrated evidence on the digitalization–green management relationship, clarify its key boundary conditions, and offer practical implications for firms seeking to advance low-carbon transformation through digital technologies.

Keywords: corporate digitalization; green management practices; meta-analysis; moderator analysis

1. Introduction

The global drive for net-zero emissions has intensified the strategic importance of green and low-carbon development for enterprises[1]. Corporate digitalization is increasingly recognized as a critical enabler, capable of enhancing environmental governance and promoting low-carbon circular operations [1,2]. Digital technologies facilitate data-driven decision-making, resource optimization, and green innovation, potentially yielding competitive advantages for firms [3]. At the same time, however, efficiency gains from digitalization may be partially offset by increased energy consumption and environmental externalities, highlighting the complex and sometimes paradoxical relationship between digital transformation and sustainable development.

Empirical research examining the impact of corporate digitalization on green management practices presents mixed and sometimes contradictory findings. A number of studies report positive effects, demonstrating that digitalization can enhance environmental performance, support green innovation, and strengthen green supply chain management [4–9]. These studies generally highlight the role of digital capabilities in enabling more effective monitoring, process optimization, and integration of environmental considerations into organizational routines [10–12]. Conversely, some research identifies negative or counterintuitive outcomes, suggesting that digital transformation may inadvertently increase energy

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consumption, carbon emissions, or operational complexity, particularly when firms prioritize economic performance over environmental objectives [13–16]. In addition, several studies report inconclusive or context-dependent findings, which appear to be influenced by differences in industry segments, firm characteristics, or methodological approaches [17–19]. These mixed results suggest that the effect of digitalization is not uniformly positive and may vary according to firm-level strategies, technological adoption stages, and external environmental factors [20,21]. Table 1 presents representative studies illustrating these diverse outcomes, emphasizing the empirical ambiguity in the literature without implying a quantified proportion.

Table 1. Mainstream research conclusions on corporate digitization and green management practices.

Opinion		Scholar (Year)
	Positive	Bendig et al. (2023); Tang et al. (2023) [11,12]
	Negative	Danish et al. (2018); Lee and Brahmasrene (2011) [15,16]
Uncertain	Due to segment-based conclusion differences	Wang et al. (2024); Andrea Chiarini (2021) [20,21]
	Due to sample population differences	Ye et al. (2023); Hernández et al. (2024) [22,23]

The presence of divergent findings raises important questions regarding the mechanisms through which digitalization influences green management practices. While individual studies contribute valuable insights, they often focus on specific industries, geographic regions, or sub-dimensions of green management, limiting their generalizability [22,23]. This fragmentation underscores the need for a systematic and integrative approach that can reconcile conflicting evidence and provide a more comprehensive understanding of corporate digitalization–green management relationship. Meta-analysis offers a rigorous methodology to address these challenges. Existing meta-analytic studies have provided valuable evidence on related topics, such as the effects of green product and process innovation on firm performance, the relationship between green supply chain management, green innovation, and carbon-neutral performance [24,25]. In addition, recent systematic reviews have discussed digital transformation and green innovation, digital technologies for green recovery, and sustainability transitions in specific contexts such as logistics and manufacturing [25,26]. Despite these advances, existing meta-analytic rarely examines how corporate digitalization influences firm-level green management practices or how differences in samples and measurements shape this relationship. To fill this gap, this study investigates three research questions: (RQ1) the overall relationship between corporate digitalization and green management practices; (RQ2) the effects of corporate digitalization on key sub-dimensions of green management practices, namely environmental performance, green innovation, and green supply chain management; and (RQ3) the moderating role of organizational and methodological factors, such as industry characteristics, firm size, and research design.

By integrating evidence across studies and considering both positive and negative outcomes, this research aims to provide robust and generalizable conclusions regarding the role of digitalization in promoting green development. Examining sub-dimensions and potential moderators further illuminates the mechanisms driving heterogeneous findings, thereby enhancing theoretical understanding and offering practical guidance for managers seeking to leverage digital technologies for sustainable transformation. The remainder of this paper is organized as follows: Section 2 presents the hypotheses and theoretical framework; Section 3 details the empirical methods; Section 4 summarizes the findings; and Section 5 discusses the implications of the results.

2. Theoretical Basis and Research Hypothesis

2.1. Resource-Based View

Scholars often employ the resource-based view to investigate the relationship between corporate digitalization and green management practices. From the perspective of the resource-based view, the influence of digitalization on green management practices depends not merely on the possession of digital technologies, but on whether firms can transform digital resources into organizational capabilities that support environmental management. Research in strategic management indicates that competitive advantage arises from the alignment between a firm's internal organizational capabilities and changes in the external environment [27]. Penrose (1959) noted that resource scarcity limits corporate growth [27]; Grant (1997) argued that heterogeneous knowledge bases and capabilities determine a firm's performance in knowledge-related activities [28]; Barney (1991) emphasized that the core issue of the resource-based view is to explain why some firms perform better than others [29]. Thus, the connotation of the resource-based view has been relatively well-defined, positing that firms are essentially collections of various production resources that work in synergy, and that the management process of a firm involves the combination and allocation of resources. Unique resources are crucial for forming a firm's capabilities and competitive advantages. In this sense, digitalization may therefore provide firms with new resource bases, such as data resources, digital platforms, information-processing capacity, and digitally enabled coordination mechanisms [30]. These resources can support green management practices by improving environmental information acquisition, resource allocation efficiency, operational monitoring, and cross-functional collaboration [11,31,32].

Moreover, the natural resource-based view (NRBV), as a branch of the resource-based view, serves as an important theoretical framework for explaining the impact of digitalization on the reallocation of natural resources. NRBV further emphasizes that pollution prevention, product stewardship, and sustainable development can become important sources of competitive advantage [10]. Previous studies suggest that under the demands of sustainable development, green management practices are adopted by firms as critical leverage for gaining competitive advantage. Consequently, in the context where digital technologies and data elements are extensively integrated into corporate practices, digitalization lays a vital foundation for green management practices.

Overall, RBV and NRBV provide a theoretical basis for expecting a positive relationship between corporate digitalization and green management practices. Nevertheless, this relationship should be understood as conditional rather than deterministic. Digitalization may also generate resource consumption, rebound effects, or efficiency-oriented practices that weaken environmental outcomes. Therefore, this study uses meta-analysis to examine whether accumulated empirical evidence supports an overall positive relationship and to identify the boundary conditions under which this relationship varies.

2.2. Hypotheses Development

Based on the logic of synthesizing literature through the meta-analysis method, this study categorizes green management practices into three key components: environmental performance, green innovation, and green supply chain management. Additionally, hypotheses are developed based on the insights derived from these dimensions.

2.2.1. Corporate Digitalization and Green Management Practice

Green management practices refer to the integration of environmental considerations into corporate management activities, including environmental performance improvement, green innovation, and green supply chain management. Rather than being limited to pollution reduction or compliance responses, green management practices reflect a broader managerial orientation through which firms incorporate sustainability goals into production, operations, innovation, and inter-organizational collaboration. With the growing importance of sustainable development, modern corporate governance theory and stakeholder theory suggest that firms are increasingly expected to balance economic value creation with environmental responsibility and social value [33–35].

Corporate digitalization provides important technological and organizational conditions for promoting green management practices [36]. Digitalization involves the adoption of digital technologies in production, management, marketing, and decision-making processes, enabling firms to improve information processing, resource allocation, operational transparency, and cross-functional coordination [37,38]. From the perspective of the natural resource-based view, digital technologies and data resources can become strategic resources that support firms in identifying environmental problems, optimizing resource use, and developing sustainability-oriented capabilities. Specifically, digitalization may promote green management practices through three broad mechanisms. First, digital technologies enhance firms' ability to collect, process, and analyze environmental and operational data, thereby supporting more accurate environmental decision-making. Second, digitalization improves resource orchestration by reducing information asymmetry and enabling firms to allocate financial, technological, and human resources more efficiently toward green activities. Third, digital platforms and data-sharing systems facilitate internal and external collaboration, helping firms coordinate green innovation activities and green supply chain practices with suppliers, customers, and other stakeholders. Therefore, corporate digitalization provides a systematic foundation for firms to transform environmental awareness into concrete green management actions [39].

However, the green effects of digitalization are not automatic. Some studies suggest that the extensive use of digital technologies may generate new environmental burdens, such as energy consumption, electronic waste, and operational emissions [40]. In addition, firms may prioritize the economic benefits of digital transformation while paying insufficient attention to its environmental implications [41]. Nevertheless, the dominant view in existing research suggests that corporate digitalization provides firms with valuable tools and capabilities for advancing green management practices. Therefore, this study proposes the following hypothesis:

H1. *Corporate digitalization can influence green management practices.*

2.2.2. Corporate Digitalization and Environmental Performance

Environmental performance refers, on the one hand, to pollution prevention behaviors, such as reducing negative environmental impacts, preventing environmental accidents, and decreasing energy consumption; on the other hand, it pertains to the reduction of carbon emissions.

In terms of pollution prevention, the support of digital technologies such as Internet of Things (IoT) technology enhances the intelligent monitoring of green production processes and end-of-pipe pollution emissions [6], increasing transparency across various stages of production operations. This enables comprehensive internal green governance throughout the production process, improves inefficient and high-energy-consuming structures, and helps prevent environmental accidents [42]. Furthermore, the decentralized advantages of digital technologies facilitate firms in releasing redundant resources, allowing them to allocate more resources to projects that require high green resource input and have long investment payback periods, thereby advancing the green governance process on multiple levels. It is evident that corporate digitalization can promote pollution prevention behaviors and reduce the occurrence of environmental accidents [43,44].

In terms of carbon reduction, firm's carbon emissions primarily stem from direct emissions resulting from the combustion of fossil fuels during production processes and indirect emissions associated with electricity consumption during operations [45]. In the production process, digital technologies introduced by corporate digitalization, such as the Internet of Things (IoT) and satellite remote sensing, can identify the primary sources of carbon emissions, improving the prediction, monitoring, analysis, and management of carbon emissions in the production process [46]. This enables the development of targeted emission reduction measures for high-energy-consuming points and helps improve energy efficiency [18]. Companies can also optimize their energy structures through energy management systems, strategically utilizing clean energy to replace traditional fossil fuels [20,47], thereby driving production activities in a more environmentally friendly manner and reducing reliance on non-clean energy. Digital technologies like AI and virtual reality assist firms in optimizing production processes [48]. For example, AI can more accurately estimate a company's electricity and heat demand, reducing energy consumption during peak periods and balancing supply and demand, thereby minimizing the use of fossil fuels.

In the operational process, digital tools make corporate operations and management more digitized, reducing unnecessary carbon emissions within internal processes and enabling net-zero emissions during operations [31]. Additionally, digital tools such as video conferencing software, collaboration platforms, and cloud computing make remote work possible, reducing carbon emissions from employee travel and the use of meeting spaces. Remote collaboration across locations is also facilitated, reducing commuting needs and lowering carbon emissions from transportation [49]. Based on the resource-based view and existing literature, this study proposes the following hypothesis:

H2. *Corporate digitalization can influence pollution control behaviors (H2a) and can reduce firms' carbon emissions (H2b).*

2.2.3. Corporate Digitalization and Green Innovation

Green innovation refers to innovations in green products, technologies, and processes within enterprises. It facilitates the coordination among economic, resource, and environmental objectives, serving as a key driver for solving pollution issues and implementing sustainable green management practices. According to the natural resource-based view, the data elements and digital technologies provided by corporate digitalization fundamentally alter both the processes and outcomes of green innovation, thereby shaping unique competitive advantages [50].

From the perspective of enhancing the quantity of green innovation, digitalization expands the channels through which enterprises can acquire resources. Digital technologies such as cloud computing, IoT, and blockchain facilitate precise interactions of green information, accelerating the circulation of green information resources [37,49]. This allows companies to obtain large volumes of heterogeneous information at a low cost, thereby improving resource acquisition and orchestration [51,52] and alleviating the high-cost dilemma that previously hindered green innovation [53]. In terms of stimulating the quality of green innovation, digitalization helps companies reduce R&D costs, overcome technical challenges, and minimize the risks of innovation failure associated with initial green explorations, ultimately increasing the success rate of green innovations [54]. Additionally, high-quality green innovations often require substantial investment in innovation. The application of digital technologies and data elements enables companies to enhance investment in R&D [55], and ease financial constraint alleviation [12], thereby freeing up more redundant resources for substantial green innovation and enhancing the quality of green innovations [50,56]. Furthermore, corporate digitalization optimizes green innovation models, like remote collaborative innovation, simulated experiments. These new models derived from digital technologies mitigate the high transaction costs and information asymmetry associated with spatial distance, reduces the localized nature of knowledge exchange, and facilitates a broader search for cooperation opportunities [57]. Thus, it can promote the exploration of cutting-edge technologies and enhance technological integration capabilities, increasing the quantity and quality of green innovation.

Moreover, some scholars categorize green innovation into green product innovation and green process innovation based on innovation factors [58,59], and consider the impact of corporate digitalization on green innovation from this perspective. digital technologies provide a solid technical foundation for green product innovation. Research from the value co-creation perspective reveals that digitalization offers vital tools for customer value co-creation, enabling firms to leverage data to track users and build user profiles, thereby uncovering market trends and potential demands [60]. This, in turn, allows for targeted green product innovation based on customer needs. At the same time, corporate digitalization releases redundant resources and saves time, helping firms allocate more effort to the design of green products and services, thereby enhancing product environmental performance and sustainability. Furthermore, by leveraging digital technologies to improve process design, production, and recycling, firms can achieve green optimization and refined management of end-to-end information, promoting the adoption of circular production models and enhancing resource efficiency [50]. Digital technologies such as artificial intelligence and cloud computing, along with data feedback from operations, enable firms to identify sources of pollution and unnecessary waste, facilitating corrective adjustments to operational processes and fostering an efficient, science-based environmental management system. This allows firms to establish a sustainable, circular production and business model.

Based on the resource-based view and existing literature, this study proposes the following research hypotheses.

H3. *Corporate digitalization can influence the quantity of green innovation (H3a), the quality of green innovation (H3b), green product innovation (H3c), green process innovation (H3d).*

2.2.4. Corporate Digitalization and Green Supply Chain

The green supply chain refers to the integration of economic, environmental, and social development in the processes of procurement, production, and sales, achieving coordinated management of resources, information, and capital. The management process of green supply chain involves the entire flow from suppliers to producers and consumers, including the complete cycle of reverse logistics [61,62]. According to the natural resource-based view, corporate digitalization spurs the rapid application of digital technologies within the supply chain, providing essential tools for achieving green supply chain ecological design and collaborative governance [1]. Currently, two key areas of focus are green supply chain management and green supply chain integration.

Green supply chain management can be divided into two components: inter-organizational environmental management, which includes green procurement, green recycling, and upstream and downstream cooperation, and intra-organizational environmental management, which encompasses internal environmental management and ecological design [63,64]. Digital technologies facilitate collaborative supervision and logistics management within the supply chain, promoting the realization of green supply chain management [65,66]. Specifically, technologies such as blockchain, knowledge graphs, and IoT provide tools for external governance, allowing firms to track the carbon actions and footprints of supply chain partners and suppliers [67]. This enhances supply chain transparency and traceability, enabling collaborative supervision and integrated development of the green supply chain [68], thus facilitating comprehensive green supply chain management [69]. Additionally, big data, cloud computing, and simulation technologies enable dynamic monitoring of enterprises, allowing for better demand forecasting and inventory optimization through resource orchestration [66]. This mitigates resource waste and environmental burdens during logistics processes and helps predict potential risks, allowing firms to adjust in response to emergencies, ensuring supply chain continuity and stability, thereby reducing environmental impacts associated with disruptions.

Green supply chain integration emphasizes addressing environmental issues through strategic collaboration among suppliers, manufacturers, and customers [70]. Enterprises digital transformation enables a shift from a traditional linear supply chain structure to a networked structure, thereby achieving green ecology. This transformation relies on new business models and innovations derived from corporate digitalization, serving as a catalyst for the supply chain's transition toward eco-friendliness. By leveraging digital resources and technologies, companies can achieve coordinated management of digital resources, fostering intelligent supply chain management. This continuous effort aims to create a net-zero ecosystem involving stakeholders such as customers and employees [9], thereby enhancing environmental sustainability practices and extending low-carbon transformation throughout the supply chain [71]. A case study by Cao et al. (2023) demonstrates that leading manufacturing enterprises can leverage their own resources and capabilities to drive the green transformation of the supply chain through their digital capabilities, ultimately leading the ecosystem toward enhanced green value [72]. Based on the resource-based view and existing literature, this study proposes the following hypothesis:

H4a. *Corporate digitalization can influence green supply chain management (H4a) and green supply chain integration (H4b).*

2.3. Potential Moderators of Corporate Digitalization and Green Management Practice Relationship

In order to systematically examine the possible factors affecting the relationship between digitalization and green management practice, this paper selects moderating variables from the industry level, enterprise level and measurement method to study the relationship.

2.3.1. Industry Level

(1) The moderating role of industry type

Different industries exhibit significant variations in production processes, service strategies, and value creation approaches. Manufacturing enterprises are key actors in achieving energy conservation and emission reduction, focusing their digitalization efforts on further optimizing production processes, driving paradigm shifts in manufacturing, and enhancing operational efficiency [48,73]. Non-manufacturing enterprises, including resource-based and service-oriented firms, concentrate their digitalization on meeting personalized consumer demands and improving user experiences. The digitalization demands of manufacturing and non-manufacturing enterprises differ significantly, and the impact of industry type differences on the digitalization pathways and outcomes of enterprises requires further investigation. Therefore, this study categorizes the digitalization of enterprises into two moderating variables—manufacturing and non-manufacturing enterprises—and proposes a non-directional hypothesis.

H5. *Industry type significantly moderates the relationship between digitalization and green development.*

(2) The moderating role of industry pollution intensity

Enterprises in highly polluting industries are key actors in transitioning from high-emission production models to achieving green upgrades. These companies are typically characterized by large volumes of waste emissions, wide pollution diffusion, and high resource dependency. By adopting digital technologies, companies in heavily polluting industries can mitigate abnormal losses and improve the efficiency of recycling waste and defective products [74]. This may result in these companies exhibiting greater sensitivity to the relationship between digitalization and green management practices. Moreover, these industries are often the focus of environmental regulatory agencies and attract significant attention from public media and society, which puts external pressure on them to quickly adapt to new regulatory requirements, pursue green transformations, and leverage digitalization to enhance both the quality and quantity of green innovation. Therefore, this study classifies companies into highly polluting and non-highly polluting industries to examine the moderating effect of pollution intensity and proposes the following hypothesis:

H6. *Compared to non-highly polluting industries, the effect of digitalization on green development is stronger in highly polluting industries.*

(3) The moderating role of industry technology intensity

High-tech industries typically allocate a higher proportion of resources to innovation inputs and outputs and are characterized by high risks and potential high returns. These industries rely on technological innovation to enhance total factor productivity and foster comprehensive industrial linkages, requiring a coordinated pool of innovative resources, such as skilled talent, advanced technology, and supportive policies. Digitalization can enrich a company's innovation resources, providing access to digital technologies and diverse resources that encourage the flow of productive factors into the enterprise. Regarding the relationship between digitalization and green development in non-high-tech industries, two competing perspectives exist. One view suggests that non-high-tech industries, often labor-intensive, can use digitalization to replace repetitive tasks, release redundant resources, and advance green development [75]. Moreover, the relative concentration of technological fields within labor-intensive industries may lead to more significant marginal benefits from digitalization. Conversely, the alternative view posits that due to a generally lower innovation sensitivity in non-high-tech industries, the potential for disruptive innovation through digitalization is limited, resulting in a comparatively modest impact of digital transformation. Accordingly, this study categorizes the digitalized enterprise sample into high-tech and non-high-tech industries to examine the moderating role of industry technology intensity and proposes a non-directional hypothesis:

H7. *Industry technology intensity significantly moderates the relationship between digitalization and green development.*

2.3.2. The Moderating Role of Firm Size

The digitalization of enterprises requires substantial organizational resources for support, and firm size often reflects the resources available and the capacity to respond to internal and external environmental changes. Scholars have analyzed the moderating role of firm size from two perspectives. On one hand, some researchers argue that digitalization requires significant financial investment, with most digital activities relying on digital infrastructure and platforms. Large firms are better equipped to sustain more comprehensive digitalization initiatives. Additionally, large organizations have stable and complete organizational structures, robust talent pools, and extensive social networks, allowing them to access more internal and external resources, achieve economies of scale, and enhance their innovation capacity and performance. On the other hand, some scholars believe that small and medium-sized enterprises (SMEs), being among the most dynamic and prevalent business groups, demonstrate a stronger correlation between technological change and innovation. Moreover, due to their lean organizational structures and relatively simple member compositions, SMEs can respond more swiftly to environmental changes, fostering digital innovation vitality. Given these contrasting viewpoints, this study investigates the moderating role of firm size by categorizing the sample of digitalized enterprises into SMEs and large enterprises, and proposes the following non-directional hypothesis:

H8. *Firm size significantly moderates the relationship between digitalization and green development.*

2.3.3. The Influence of Measurement Method

In terms of research design, the measurement method is a critical factor influencing research outcomes. Utilizing meta-analysis models to statistically analyze differences in measurement methods can enhance the understanding of variations in academic research conclusions and help build a systematic understanding of the relationship between digitalization and green development. Existing research on the measurement of digitalization and green development typically employs two main approaches: objective measurement and subjective measurement.

Objective measurement methods often involve using Python software to scrape publicly available information, such as annual reports of listed companies, to indirectly reflect the effects of digitalization. This approach is transparent and free from subjective bias, but proxy variables may fail to fully capture the specific extent of digitalization. On the other hand, subjective measurement methods invite respondents to fill out questionnaires about the current state of digitalization and green development in their organizations. While survey-based methods can address the representativeness issues of objective measurements, they may suffer from respondent bias [76]. For instance, executives and organizational members might exhibit overconfidence in the effectiveness of digital transformation, or employees might beautify the effects of digitalization to protect the company's image [77], leading to measurement bias in evaluating digitalization and green development.

Given these distinctions, objective and subjective measurement methods may introduce different biases when assessing the relationship between digitalization and green development. Therefore, this study categorizes the measurement of digitalization and green development into two types—objective and subjective—and explores their moderating effects.

H9. *Compared to objective measurement methods, the effect of digital transformation on sustainable development is stronger when using subjective measurement methods.*

The analytical framework of this study is illustrated in Figure 1.

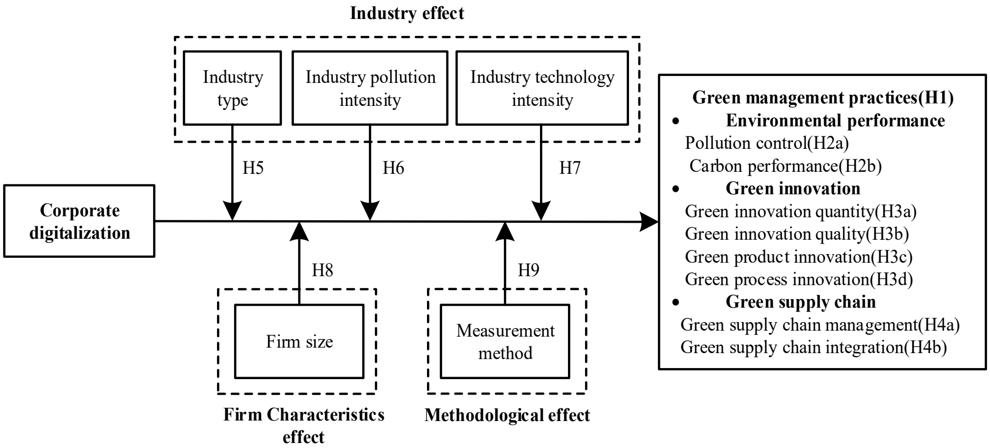

Figure 1. Analytical framework.

3. Results Design

3.1. Method Selection

This study employs meta-analysis for empirical testing. Meta-analysis originates from psychological and medical research, synthesizes previous research findings to derive conclusions. Due to its high objectivity, rigor, and inductiveness, it is widely recognized and applied in scientific research across fields such as strategic management, human resource management, and entrepreneurship management. In this study, meta-analysis is used to compile the divergent conclusions on the relationship between digital transformation and green management practices, and to identify the relevant factors influencing this relationship, thereby deepening the understanding the relationship of "digital transformation–green management practices".

3.2. Literature Collection

To enhance transparency and reproducibility, the literature search, screening, eligibility assessment, and inclusion process followed the PRISMA 2020 reporting logic. The search protocol first defined the data sources, keyword combinations, and inclusion/exclusion criteria, and then screened the retrieved records stage by stage before effect sizes were extracted for meta-analysis.

In the identification stage, we searched publications released between 2010 and 2025 in Web of Science, EBSCO, Elsevier, Wiley, Emerald, Springer, JSTOR, MDPI, APA PsycNET, and Google Scholar. Search terms combined digital-transformation keywords with green-management-practice keywords, including "environment", "green", "low-carbon", "green innovation", "carbon emissions", "green supply chain", and "digital", "Industry 4.0", "Artificial Intelligence", "Big Data", and "IoT". These terms were applied to article titles, abstracts, and keywords. To reduce the risk of missing relevant studies, we also manually searched journals closely related to the topic, including Journal of Business Ethics, Journal of Business Research, Business Strategy and the Environment, European Journal of Innovation Management, Journal of Cleaner Production, and Sustainability.

In the screening and eligibility assessment stage, duplicate and irrelevant records were first removed. The remaining titles, abstracts, keywords, and full texts were then reviewed according to the inclusion and exclusion criteria. Studies were retained if they examined the relationship between corporate digitalization and green management practices and provided a correlation coefficient or sufficient statistical information for effect-size calculation. After applying the PRISMA-based screening procedure, 82 articles containing 94 correlation coefficients were included in the final meta-analysis. The screening process is summarized in Figure 2.

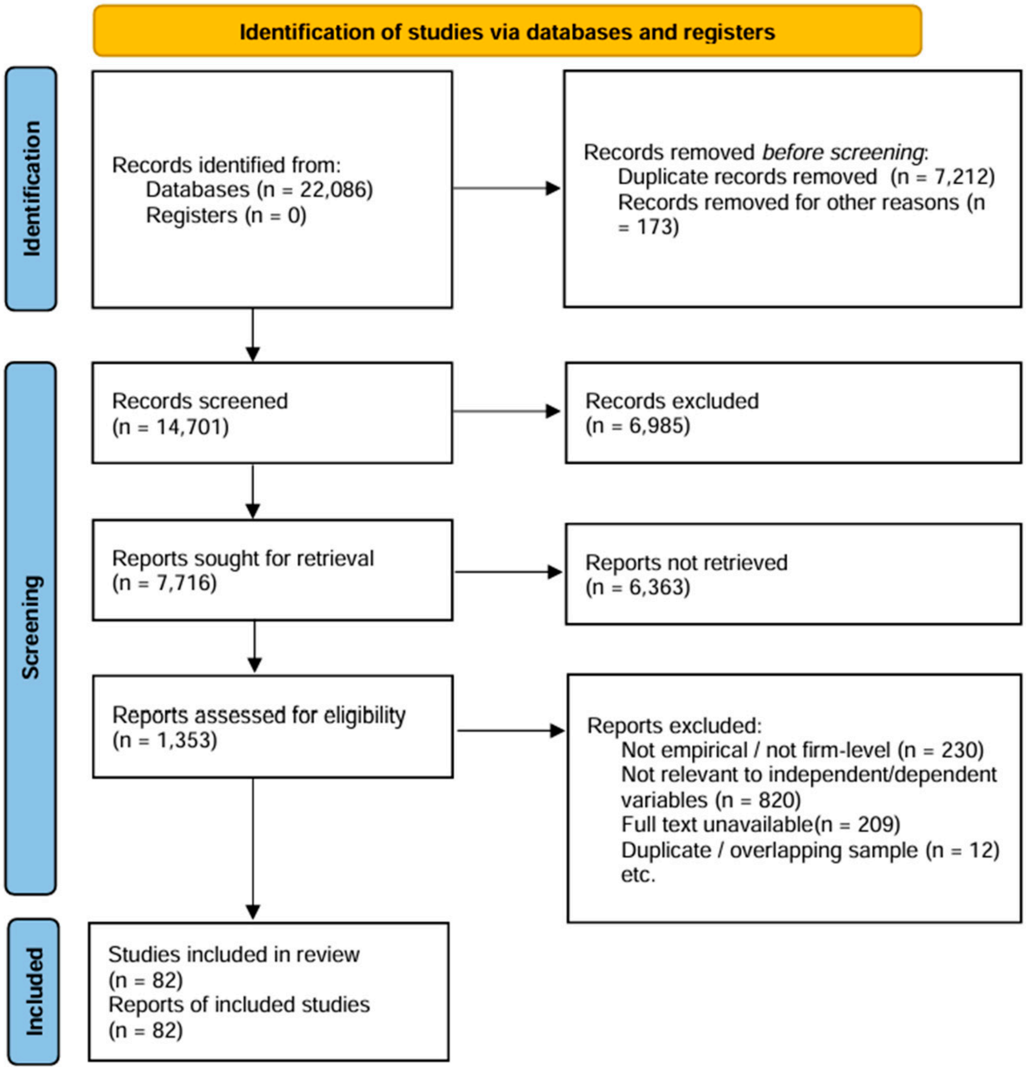

Figure 2. PRISMA framework for paper screening and eligibility process mapping.

3.3. Literature Coding

This study conducted literature coding based on the variable definitions presented in Table 2 and the coding manual provided in the Appendix A. For each included study, the coding process captured both the variable information (independent, dependent, and moderating variables) and essential study characteristics, such as author(s), publication year, journal, country, and industry type. Following the method suggested by Lipsey and Wilson (2001) [78], two authors independently conducted the coding for all studies. Any discrepancies were reviewed and resolved through discussion with additional authors to finalize the coding. All coders performed the coding blind to the study authorship and journal source to reduce subjective bias.

The inter-coder reliability was assessed using Cohen's kappa coefficient, which yielded a value of 0.97, indicating excellent agreement. The coding discrepancies identified during the process mainly arose from the coding of moderator variables, where some study characteristics required further interpretation and confirmation. These discrepancies were discussed among the authors and resolved through consensus, ensuring the consistency and reliability of the final coding results.

Table 2. Description of variables.

Variable	Description
1. Independent variable	
Corporate digitalization	Corporate digitalization relies on a suite of digital technologies to drive disruptive innovation in areas such as research and development, production, business processes, and business models, thereby digitally reshaping and optimizing existing organizational practices.
2. Dependent variable	
Pollution control	Whether the company has had environmental accidents, received environmental penalties, obtained environmental certification, and spent money on the treatment and recycling of waste gas, wastewater, smoke and dust.
Carbon performance	The company has reduced its carbon emissions.
Green innovation quantity	Number of patent applications.
Green innovation quality	Number of green invention patents with high technical content.
Green product innovation	Pay attention to company's active development of new green products and services.
Green process innovation	Carry out green transformation of the company's production and operation processes.
Green supply chain management	Company's promotion of energy recovery in the procurement, manufacturing, packaging, sales and marketing processes to help organizations reduce waste.
Green supply chain integration	Supply chain members carry out green management practices through strategic cooperation, information sharing and group decision-making.
Moderating variables	
3. Industry type	
(a) Manufacture	Dummy variable equal to 1 if belonging to industries such as electronic information product manufacturing, machinery manufacturing, or pharmaceutical manufacturing.
(b) Non-manufacturing	Dummy variable equal to 0 if belonging to resource-based and service-oriented firms.
4. Industry pollution level	
(a) Heavy pollution	Dummy variable equal to 1 if belonging to industries with high energy consumption and high emissions, such as steel, cement, oil, natural gas, electricity, and chemical industries.
(b) Non-heavy pollution	Dummy variable equal to 0 if not belonging to industries with high energy consumption and high emissions.
5. Industry technology intensity	
(a) High-tech	Dummy variable equal to 1 if belonging to high-tech industries as defined by OECD standards.
(b) Non-high-tech	Dummy variable equal to 0 if not belonging to high-tech industries as defined by OECD standards.
6. Enterprise size	
(a) SME	Dummy variable equal to 1 if belonging to SME as defined by World Bank's classification.
(b) Large enterprises	Dummy variable equal to 0 if belonging to large enterprises as defined by World Bank's classification.
7. Measurement method	
(a) Subjective	Dummy variable equal to 1 if questionnaires are used to collect data.
(b) Objective	Dummy variable equal to 0 if data collection is done using annual report data, second-hand data, etc.

4. Data Analysis Results

4.1. Publication Bias Test

Publication bias was assessed using the fail-safe N method, funnel plot, Begg and Mazumdar's rank correlation test, Egger's regression test, and Trim-and-Fill method. As shown in Table 3, the fail-safe N value was 84,861, which is far greater than the threshold of 5K + 10, indicating that the overall effect is unlikely to be overturned by unpublished or missing studies. The funnel plot in Figure 3 shows that most effect sizes are distributed on both sides of the pooled effect and are generally symmetrical, suggesting no obvious visual evidence of publication bias. In addition, Begg and Mazumdar's rank correlation test was not statistically significant ($p = 0.08977$), and Egger's regression test was also not significant ($p = 0.67231$). This study further employed the Trim-and-Fill method to examine the potential influence of publication bias on the overall effect. The results showed that, after imputing 11 potentially missing studies, the effect size under the random-effects model remained positive and statistically significant, with an adjusted effect size of 0.21134 and a 95% confidence interval of [0.14185, 0.27875]. This indicates that although the included literature may be subject to a certain degree of publication bias, such bias does not substantially alter the positive relationship between corporate digitalization and green management practices, suggesting that the main conclusion of this study is robust.

Table 3. Results of publication bias test.

Test Name	5K + 10	Fail-Safe N	*p* Value
Fail-Safe N	420	84,861	
Begg and Mazumdar Rank Correlation			0.08977
Egger's Regression			0.67231

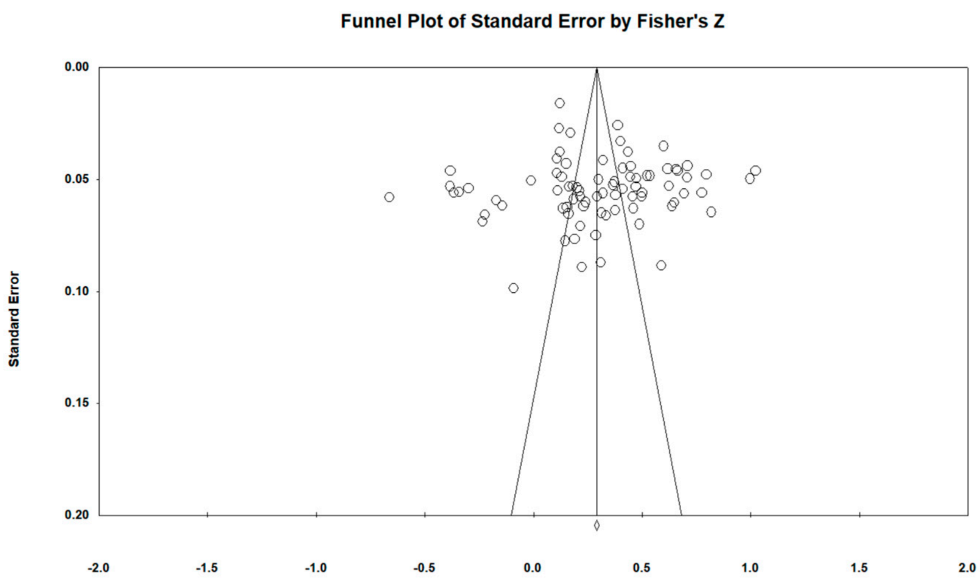

Figure 3. Funnel plot.

4.2. Heterogeneity Test and Main Effect Test

Using CMA 3.0 software (Biostat, Inc., Englewood, NJ, USA), this study process the coded data, yielding the results of the heterogeneity test for the effect sizes between corporate digitalization and various dimensions of green management practices, as shown in Table 4. To reduce potential dependence among effect sizes, when multiple effect sizes were reported within the same study for the same analytical model, we averaged these effect sizes and retained one study-level effect size for the corresponding analysis. The heterogeneity test yielded a p-value < 0.01, with I^2 values exceeding 90% and Q > K − 1, indicating that the empirical samples included in the meta-analysis are heterogeneous, with substantial intergroup differences among the independent samples. Therefore, random effects model is selected for the meta-analysis. For evaluating the strength of relationships between variables, this study adopted Cohen's (1988) guidelines [79]: if the correlation coefficient $|r| < 0.1$, the correlation is considered weak; if $0.1 < |r| < 0.3$, the correlation is moderate; and if $0.3 < |r| < 0.5$, the correlation is strong. The results of the heterogeneity test and main effect analysis for corporate digitalization and green management practices are shown in Table 4. The study found that the effect size of corporate digitalization on green management practices is significant at 0.327, indicating a positive correlation.

Table 4. Meta-analysis results on corporate digitalization and green management practices.

Independent Variable	Hypothesis	K	N	r	95%CI	Z	Q	Df	I^2
Green management practices	H1	82	14,372	0.327 ***	[0.273–0.379]	11.189	4957.569 ***	81	98.366

Note: *** indicates $p < 0.01$.

To reduce potential dependence among effect sizes, when multiple effect sizes were reported within the same study for the same analytical model, we averaged these effect sizes and retained one study-level effect size for the corresponding analysis. In addition, we conducted a further sensitivity analysis by excluding studies that reported multiple correlation coefficients. The results based on 70 independent studies remained consistent with the main analysis. Under the random-effects model, the pooled effect size was positive and significant (r = 0.331, 95% CI [0.275, 0.385], Z = 10.824, $p < 0.001$), which is very close to the main-effect estimate (r = 0.327). This suggests that the main conclusion is not substantially driven by studies contributing multiple effect sizes.

Subsequently, this study categorizes green management practices into three major dimensions—environmental performance, green innovation, and green supply chain management—based on the variable connotations and measurement methods reported in the literature. A subgroup analysis was then conducted for each dimension to obtain more objective, comprehensive, and consistent conclusions.

(1) Relationship between corporate digitalization and environmental performance

The effect test results of corporate digitalization on environmental performance and its two sub-dimensions, carbon performance and pollution control, are presented in Table 5. Carbon Performance refers to reductions in corporate carbon emissions, while the metrics for pollution control include increased pollution control expenditures and a decrease in environmental incidents. The empirical results indicate that corporate digitalization has a significant effect on environmental performance, carbon emissions reduction, and pollution control, with effect values of 0.381, 0.322, and 0.335, respectively. All demonstrate a high positive correlation, and point estimates are statistically significant (with a 95% confidence interval that does not include zero), supporting H2a, and H2b.

Table 5. Meta-analysis results on Corporate Digitalization and Environmental Performance.

Environmental Performance	Hypothesis	K	N	r	95%CI	Z	Q	Df	I^2
Pollution control	H2a	15	7189	0.335 ***	[0.156–0.492]	3.570	744.864 ***	14	98.120
Carbon performance	H2b	5	7183	0.322 ***	[0.074–0.532]	2.519	379.328 **	4	98.946

Note: *** indicates $p < 0.01$, ** indicates $p < 0.05$.

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(2) Relationship between corporate digitalization and green innovation

The main effect test results of corporate digitalization on green management practices and its sub-dimensions are shown in Table 6. This study categorizes the existing green innovation literature into four dimensions: green innovation quantity, green innovation quality, green product innovation, and green process innovation. The empirical results indicate that corporate digitalization has a significant effect on green innovation (effect size = 0.300), green innovation quantity (effect size = 0.133), and green innovation quality (effect size = 0.160), demonstrating a moderate positive correlation. Additionally, corporate digitalization has a significant effect on green product innovation (effect size = 0.527) and green process innovation (effect size = 0.607), showing a positive correlation. The point estimates for corporate digitalization and green innovation, along with each sub-dimension, are significant (the 95% confidence intervals do not include 0), thus validating H2a, H2b, H2c, and H2d.

Table 6. Meta-analysis results on corporate digitalization and green innovation.

Green Innovation	Hypothesis	K	N	r	95%CI	Z	Q	Df	I^2
Green innovation quantity	H3a	22	28,893	0.133 ***	[0.088–0.177]	5.726	302.372 ***	21	93.055
Green innovation quality	H3b	6	10,469	0.160 ***	[0.086–0.231]	4.225	73.607 ***	5	93.207
Green product innovation	H3c	7	1853	0.527 ***	[0.378–0.648]	6.129	99.025 ***	6	93.941
Green process innovation	H3d	5	1478	0.607 ***	[0.355–0.777]	4.144	167.952 ***	4	97.618

Note: *** indicates $p < 0.01$.

(3) The relationship between corporate digitalization and green supply chain

The main effect test results of corporate digitalization on green management practices and its sub-dimensions, green supply chain management and green supply chain integration, are shown in Table 7. Empirical results indicate that corporate digitalization has a significant effect on green supply chain, green supply chain management, and green supply chain integration, with effect values of 0.414, 0.393, and 0.471, respectively, indicating a positive correlation. Furthermore, the point estimates are all significant (95% confidence intervals do not include 0), thus confirming hypotheses H3, H3a, and H3b.

Table 7. Meta-analysis results on corporate digitalization and green supply chain.

Green Supply Chain	Hypothesis	K	N	r	95%CI	Z	Q	Df	I^2
Green supply chain management	H4a	12	6050	0.393 ***	[0.242–0.527]	4.808	433.670 ***	11	97.464
Green supply chain integration	H4b	4	1167	0.472 ***	[0.273–0.632]	4.333	47.225 ***	3	93.647

Note: *** indicates $p < 0.01$.

4.3. Moderation Effect Testing

This study further examines how industry attributes, firm size, and measurement methods impact the relationship between digital transformation and green management practices. The moderation effect test results are shown in Table 8. The specific empirical findings are as follows:

Table 8. Results of moderating effects.

Moderator Variable	Hypothesis	K	N	r	95%CI	Z	QB
Industry type							
Manufacture industry	H5	47	25,695	0.349 ***	[0.276–0.419]	8.757	13.084 ***
Non-manufacturing industry		6	1378	0.496 ***	[0.321–0.637]	5.060	
Industry pollution level							
Heavy pollution industry	H6	12	6192	0.179 ***	[0.029–0.321]	2.337	4.894 *
Non-heavy pollution		23	26,934	0.370 ***	[0.277–0.457]	7.274	
Industry technology intensity							
High-tech industry	H7	10	3121	0.426 ***	[0.313–0.528]	6.776	4.992 *
Non-high-tech industry		9	3042	0.369 ***	[0.192–0.523]	3.929	
Enterprise size							
SME	H8	4	14,958	0.376 ***	[0.069–0.618]	2.378	0.122
Large enterprises		20	13,422	0.323 ***	[0.216–0.421]	5.703	
Measurement method							
Subjective	H9	41	25,500	0.156 ***	[0.093–0.218]	4.792	49.165 ***
Objective		36	46,541	0.481 ***	[0.385–0.567]	8.660	

Note: *** indicates $p < 0.01$, * indicates $p < 0.1$.

(1) Industry Characteristics: Industry type, pollution intensity, and technological intensity all moderate the relationship between digital transformation and green management practices, confirming hypotheses H5, H6, and H7. Non-manufacturing firms show a stronger effect size (r = 0.496) compared to manufacturing firms (r = 0.349). Firms in less-polluting industries have a higher effect size (r = 0.370) than those in heavily polluting industries (r = 0.179). Likewise, high-tech industry firms exhibit a stronger effect (r = 0.426) compared to non-high-tech firms (r = 0.369). Thus, non-manufacturing firms, low-pollution industries, and high-tech firms demonstrate a stronger promoting effect of digital transformation on green management practices.

(2) Firm size: Firm size does not exert a statistically significant moderating effect on the relationship between digital transformation and green management practices; thus, H8 is not supported. Although the estimated effect size for SMEs (r = 0.376) is slightly higher than that for large firms (r = 0.323), the between-group difference is not statistically significant. Nevertheless, given the relatively limited number of studies focusing on SMEs, the subgroup result should be interpreted with caution. Future research is encouraged to further examine the role of firm size by incorporating more empirical evidence on SMEs and comparing their digitalization-enabled green transformation mechanisms with those of large firms.

(3) Measurement Methods: Using subjective measurement methods (r = 0.481) reveals a stronger positive relationship compared to objective measurement methods (r = 0.156), thereby confirming hypothesis H9. This result suggests that measurement approaches may systematically influence the estimated relationship between corporate digitalization and green management practices. Specifically, when both variables are measured through questionnaire data, the observed correlation may be amplified by common method bias or social desirability bias, whereas objective measures based on panel or secondary data may provide relatively more conservative estimates.

5. Main Research Conclusions and Implications

5.1. Findings

Using meta-analysis, this study examines the mechanisms and impacts of corporate digitalization in driving green management practices, yielding the following conclusions:

(1) Main effects analysis

In terms of environmental performance, digitalization has a positive effect on both carbon performance and pollution control. The carbon emissions of enterprises mainly come from direct carbon emissions from the combustion of fossil fuels in the production process and indirect carbon emissions from electricity consumption during operations. Digitalization enhances real-time monitoring and dynamic optimization of these emissions, effectively reducing the environmental issues caused by carbon emissions. As regards pollution control, corporate digitalization promotes internal green regulation across the entire production and operational process, improving high-energy-consuming structures, and preventing environmental accidents.

Regarding green innovation, corporate digitalization can improve both the quantity and quality of green innovations, and foster innovations in green products and green processes. Digitalization enables enterprises to access heterogeneous innovation resources and, through digital technologies such as simulation experiments and virtual reality, facilitates innovation activities in different locations, reducing the risk of innovation failure. This effectively enhances the quantity and quality of green innovations. Furthermore, digitalization plays a key role in promoting targeted product innovation and optimizing management processes, driving green product innovation and green process innovation.

In the area of green supply chains, corporate digitalization promotes green supply chain management and green supply chain integration. Digitalization in enterprises leads the supply chain towards informatization and intelligence, providing essential tools for tracking carbon footprints, carbon behaviors, and collaborative supervision, thus strengthening the full-process management of the green supply chain. The deep development of digitalization also drives the supply chain to evolve from a linear structure to an ecological, networked structure, achieving a green value upgrade through deep collaboration in the supply chain. This transformation makes the integration of green supply chains and the resolution of environmental issues a norm in supply chain management.

(2) Moderating effects analysis

The moderation effect test of industry attributes revealed that digitalization in non-manufacturing enterprises has a stronger effect on promoting green management practices. This may be due to the differing digital transformation needs between manufacturing and non-manufacturing enterprises, which result in differentiated performance outcomes. Non-manufacturing enterprises focus on optimizing organizational operations and human resource structures, with lower thresholds for digital transformation and higher initial marginal returns.

The moderation effect test of industry pollution intensity found that digitalization in non-heavy-pollution industries has a better incentive effect on green management practices, which aligns with previous studies [80]. One possible explanation is that firms in heavy-polluting industries face stricter environmental regulation and lower managerial discretion, making digitalization more likely to serve compliance-oriented functions, such as pollution monitoring, environmental reporting, and regulatory control. In this context, digitalization may be absorbed by mandatory compliance requirements rather than transformed into proactive green management practices. By contrast, firms in non-heavy-polluting industries face relatively weaker regulatory constraints and enjoy

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greater strategic flexibility, allowing digitalization to better support green innovation and sustainability-oriented decision-making.

The moderation effect test of industry technological intensity revealed that digital transformation in high-tech enterprises can better promote green management practices, which aligns with previous study [81]. This may be due to the high innovation sensitivity of high-tech industries, where corporate digitalization has a stronger incentive effect on green innovation. Additionally, high-tech enterprises are better able to quickly capture new technologies within their industries, thereby advancing green management practices and green supply chain practices.

The moderation effect test of firm size found that firm size does not moderate the relationship between digitalization and green management practices. Both small and medium-sized enterprises (SMEs) and large enterprises can promote green management practices through digital transformation. However, the relationship is stronger in SMEs. SMEs have greater flexibility in the transformation process, allowing them to adapt rapidly to actual conditions and development demands. In contrast, large enterprises leverage their resource advantages through economies of scale, enabling the integration of digital and green resources, which accelerates the learning and development of new technologies and lays a crucial foundation for green management practices.

The test of the impact of measurement methods found that the measurement approach is an important factor influencing the relationship between digitalization and green management practices in enterprises. This may be because respondents might be overly optimistic about the outcomes of their company's development or may be inclined to convey information that maintains a positive company image, which leads to a stronger relationship between digitalization and green management practices when using subjective measurement methods. Currently, meta-analysis methods used in academic research to examine corporate strategy implementation outcomes have also confirmed that the incentive relationships between variables derived from subjective measurements are stronger than those obtained from objective measurement methods [82].

5.2. Theoretical Contributions

In examining the relationship between corporate digitalization and green management practices, scholars often apply the resource-based view (RBV) to analyze this connection. However, some researchers, from alternative perspectives, have discovered that corporate digitalization may lead to increased pollution. Additionally, due to the strong externalities associated with green investments and their relatively slow returns, the positive impact of digitalization on green management practices may not be universally applicable. Regarding the current state of research, this study makes several theoretical contributions to corporate digitalization and green management practice literature.

First, this study empirically tests the contradictory research findings between corporate digitalization and green management practices, a more stable positive research conclusion is drawn through large-sample testing. The study clarifies the methodological limitations of previous research that failed to explain the contradictory relationship between digital transformation and sustainable development, thus advancing green research within the digitalization theoretical framework and providing strong evidence for the natural resource-based view. Second, this research further examines the relationship between corporate digitalization and the sub-dimensions of green management practices, thereby overcoming the limitations of previous studies that discussed these relationships in a fragmented manner. Third, the paper systematically discusses the boundary conditions impacting digitalization's effect on green management practices, such as industry characteristics, organizational context factors, and measurement differences on the complex relationship between the two. This provides a multi-level theoretical explanation for existing differentiated research findings and classifies the factors that lead to result variations into the categories of industry heterogeneity and firm characteristics.

5.3. Managerial Implications

For firms, digitalization should be embedded into concrete green management activities. Enterprises should use digital tools to improve environmental data collection, energy consumption monitoring, emission tracking, process optimization, and green supply chain coordination. Since the effect of digitalization is stronger in non-manufacturing, non-heavy-polluting, and high-tech firms, these firms should further use their flexibility and technological advantages to promote green innovation, low-carbon operations, and sustainability-oriented decision-making. By contrast, manufacturing, heavy-polluting, and low-tech firms should avoid limiting digitalization to production control or regulatory compliance. They need to strengthen digital absorptive capacity and apply digital technologies to cleaner production, energy-efficiency improvement, green product design, and supplier environmental collaboration. In addition, the non-significant moderating effect of firm size suggests that the green value of digitalization does not simply depend on organizational scale, but on whether digital tools are effectively applied to substantive green management practices.

For governments, policy support should be more differentiated and result-oriented. Governments should encourage non-manufacturing and high-tech firms to expand digital applications in green service innovation, low-carbon business models, and sustainable supply chains. For heavy-polluting and low-tech industries, policy instruments should guide firms to move beyond compliance-based digital monitoring and promote cleaner production, green technology upgrading, and energy-saving transformation. Since firm size does not significantly change the digitalization–green management relationship, support should not be limited to large firms; small and medium-sized enterprises also need accessible digital tools, technical training, shared data platforms, and financial support. Finally, given the significant influence of measurement methods, firms and governments should combine self-reported assessments with objective indicators, such as carbon-emission accounting, energy-use records, environmental performance data, and green innovation outputs, to evaluate the real green effects.

5.4. Limitations and Future Research Directions

This study has several limitations. Firstly, some studies were excluded because they did not report correlation coefficients or other convertible statistical information required for meta-analysis, which may lead to potential sample selection bias. In addition, the included studies showed high heterogeneity and measurement inconsistency due to differences in research contexts, samples, indicators, data sources, and operational definitions. Although this study conducted publication bias tests and robustness checks, future research could further apply PET-PEESE, the Vevea-Hedges selection model, robust variance estimation, or three-level meta-analytic models to better address publication bias, effect-size dependence, and heterogeneity. Secondly, certain moderator subgroup analyses had small sample sizes ($K = 4$ or $K = 5$), which may affect the representativeness and statistical power of the findings. Thirdly, meta-analysis is mainly suitable for examining overall linear associations, whereas curvilinear relationships, threshold effects, configuration effects, and set-theoretic relations may also be valuable for management research. Future research could explore additional moderators, such as national culture, firm age, and sample size. Studies could also investigate digitalization's impact on sustainable development from different perspectives, such as employee and industry levels, to evaluate its contribution to carbon-reduction goals.

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Appendix A

Table A1. Coding Scheme for the meta-analysis.

Coding Field	Allowed Values/Examples	Coding Rule
Study ID	1; 2; 3; etc.	The studies were numbered sequentially according to the order in which they entered the meta-analysis, beginning with 1.
Literature ID	Author-year format, e.g., Zhang et al. (2021); Li and Wang (2022)	Literature information was recorded in the author-year format. If the same author had multiple studies in the same year, they were distinguished using letters such as a, b, and c.
Corporate digitalization	digital transformation; digital technology application; digital innovation; digital investment; digital capability	If the variable reflected enterprise-level digital technology application, digital transformation, digital investment, or digital capability, it was coded as corporate digitalization.
Green management practices	environmental performance; pollution control; carbon performance; green innovation; green supply chain management	If the dependent variable reflected corporate environmental governance, green innovation, or green supply chain practices, it was included in green management practices.
Pollution control	environmental certification; environmental penalties; environmental accidents; waste gas; wastewater; solid waste treatment	If the variable involved environmental penalty, environmental certification, pollutant discharge, or pollution treatment, it was coded as pollution control.
Carbon performance	carbon emission reduction; carbon intensity; low-carbon performance	If the variable directly reflected carbon emission reduction, carbon intensity reduction, or low-carbon performance improvement, it was coded as carbon performance.
Green innovation quantity	green patent applications; number of green patents	If the variable reflected the number of green patent applications, authorizations, or other measures of green innovation quantity, it was coded as green innovation quantity.
Green innovation quality	green invention patents; high-value green patents; patent citations	If the variable reflected the technical value, invention attribute, or citation frequency of green innovation, it was coded as green innovation quality.
Green product innovation	green product development; eco-product design; new green products and services	If the variable reflected green product development, eco-design, or green service innovation, it was coded as green product innovation.

Table A1. *Cont.*

Coding Field	Allowed Values/Examples	Coding Rule
Green process innovation	cleaner production; green process transformation; energy-saving process innovation	If the variable reflected clean production, energy-saving processes, production process greening, or process improvement, it was coded as green process innovation.
Green supply chain management	green purchasing; green manufacturing; green packaging; green logistics; green supply chain integration	If the variable reflected green management or cross-organizational green collaboration in supply chain activities, it was coded as green supply chain management.
Industry type	manufacturing; non-manufacturing; unclear	Manufacturing samples were coded as manufacturing; service industries, resource-based industries, or other non-manufacturing samples were coded as non-manufacturing; samples that could not be clearly identified were coded as unclear.
Pollution intensity	heavy-pollution; non-heavy-pollution; mixed; unclear	Industries such as steel, cement, petroleum, natural gas, electric power, and chemicals were coded as heavy-pollution; other industries were coded as non-heavy-pollution; samples that could not be clearly identified were coded as unclear.
Technology intensity	high-tech; non-high-tech; mixed; unclear	According to the OECD standard or original classification, industries such as electronic information, pharmaceuticals, aerospace, computers, and communication equipment were coded as high-tech; other industries were coded as non-high-tech; samples that could not be clearly identified were coded as unclear.
Enterprise size	SME; large enterprise; mixed; unclear	Samples composed mainly of SMEs were coded as SME; samples composed mainly of large enterprises or listed companies were coded as large enterprise; samples that could not be clearly identified were coded as unclear.
Measurement method	subjective; objective; mixed; unclear	Questionnaire-based or perceptual data were coded as subjective; annual reports, patents, financial data, environmental disclosures, and database data were coded as objective; samples that could not be clearly identified were coded as unclear.
Effect size extraction	r; β; t; F; OR	Pearson correlation coefficients were extracted preferentially; if not reported, effect sizes were converted based on statistics such as β, t, F, or OR.
Multiple effect sizes	Digitalization → green innovation; digitalization → environmental performance	In the overall effect analysis, if multiple effect sizes came from the same sample, the average value was taken; in subgroup analyses, they were assigned to the corresponding categories according to the dependent variable type.

Note

[1] The International Energy Agency (IEA) released the Energy Technology Perspectives 2020, which explores the feasible pathways for achieving global net-zero emissions (carbon neutrality) by 2050 under the accelerated deployment of low-carbon energy technologies. The full text can be found here: https://www.iea.org/reports/energy-technology-perspectives-2020 (accessed on 21 April 2026).

References

1. Nguyen, N.M.; Hoai, T.T.; Vo, H.V.; Nguyen, N.P. Digital Approach toward Environmental Sustainability in Supply Chains: Evidence from Vietnamese Firms. *Sustain. Dev.* **2023**, *31*, 3303–3317. [CrossRef]
2. Yang, S.; Jahanger, A.; Usman, M. Examining the Influence of Green Innovations in Industrial Enterprises on China's Smart City Development. *Technol. Forecast. Soc.* **2024**, *199*, 123031. [CrossRef]
3. Khan, S.A.R.; Piprani, A.Z.; Yu, Z. Digital Technology and Circular Economy Practices: Future of Supply Chains. *Oper. Manag. Res.* **2022**, *15*, 676–688. [CrossRef]

4. Nguyen, T.T.; Pham, T.A.T.; Tram, H.T.X. Role of Information and Communication Technologies and Innovation in Driving Carbon Emissions and Economic Growth in Selected G-20 Countries. *J. Environ. Manag.* **2020**, *261*, 110162. [CrossRef]
5. Awan, U.; Sroufe, R.; Shahbaz, M. Industry 4.0 and the Circular Economy: A Literature Review and Recommendations for Future Research. *Bus. Strat. Environ.* **2021**, *30*, 2038–2060. [CrossRef]
6. Chauhan, A.S.; Cuzzocrea, A.; Fan, L.; Harvey, J.D.; Leung, C.K.; Pazdor, A.G.M.; Wang, T. Predictive Big Data Analytics for Service Requests: A Framework. *Procedia Comput. Sci.* **2022**, *198*, 102–111. [CrossRef]
7. Ren, S.; He, D.; Yan, J.; Zeng, H.; Tan, J. Environmental Labeling Certification and Corporate Environmental Innovation: The Moderating Role of Corporate Ownership and Local Government Intervention. *J. Bus. Res.* **2022**, *140*, 556–571. [CrossRef]
8. Ågerfalk, P.J.; Axelsson, K.; Bergquist, M. Addressing Climate Change through Stakeholder-Centric Information Systems Research: A Scandinavian Approach for the Masses. *Int. J. Inf. Manag.* **2022**, *63*, 102447. [CrossRef]
9. Mehmood, K.; Kiani, A.; Rehman, H.; Alshibani, S.M.; Piccardi, P. Can Platform Leadership Drive Twin Transitions in Greening SMEs? Exploring the Nexus Between AI Infrastructure Flexibility, Information Effects, and Green Sustainable Practices. *Bus. Ethic-Environ. Responsib.* **2024**, *34*, 2274–2292. [CrossRef]
10. Hart, S.L. A Natural-Resource-Based View of the Firm. *Acad. Manag. Rev.* **1995**, *20*, 986–1014. [CrossRef]
11. Bendig, D.; Schulz, C.; Theis, L.; Raff, S. Digital Orientation and Environmental Performance in Times of Technological Change. *Technol. Forecast. Soc.* **2023**, *188*, 122272. [CrossRef]
12. Tang, L.; Jiang, H.; Hou, S.; Zheng, J.; Miao, L. The Effect of Enterprise Digital Transformation on Green Technology Innovation: A Quantitative Study on Chinese Listed Companies. *Sustainability* **2023**, *15*, 10036. [CrossRef]
13. Alcott, B. Jevons' Paradox. *Ecol. Econ.* **2005**, *54*, 9–21. [CrossRef]
14. Avom, D.; Nkengfack, H.; Fotio, H.K.; Totouom, A. ICT and Environmental Quality in Sub-Saharan Africa: Effects and Transmission Channels. *Technol. Forecast. Soc.* **2020**, *155*, 120028. [CrossRef]
15. Danish; Khan, N.; Baloch, M.A.; Saud, S.; Fatima, T. The Effect of ICT on CO_2 Emissions in Emerging Economies: Does the Level of Income Matters? *Environ. Sci. Pollut. Res.* **2018**, *25*, 22850–22860. [CrossRef]
16. Lee, J.W.; Brahmasrene, T. ICT, CO_2 Emissions and Economic Growth: Evidence from a Panel of ASEAN. *Glob. Econ. Rev.* **2014**, *43*, 93–109. [CrossRef]
17. Xiao, Y.; Xiang, R.; Sun, Y.; Chen, J.; Hao, Y. Digital Disruption, Knowledge and Collaborative Networks and Green Innovation in China Manufacturing Transformation. *Technol. Forecast. Soc.* **2025**, *216*, 124120. [CrossRef]
18. Liu, Y.; Zhang, X.; Shen, Y. Technology-Driven Carbon Reduction: Analyzing the Impact of Digital Technology on China's Carbon Emission and Its Mechanism. *Technol. Forecast. Soc.* **2024**, *200*, 123124. [CrossRef]
19. Cardinali, P.G.; De Giovanni, P. Responsible Digitalization through Digital Technologies and Green Practices. *Corp. Soc. Responsib. Environ.* **2022**, *29*, 984–995. [CrossRef]
20. Wang, B.; Wang, J.; Dong, K.; Nepal, R. How Does Artificial Intelligence Affect High-Quality Energy Development? Achieving a Clean Energy Transition Society. *Energy Policy* **2024**, *186*, 114010. [CrossRef]
21. Chiarini, A. Industry 4.0 Technologies in the Manufacturing Sector: Are We Sure They Are All Relevant for Environmental Performance? *Bus. Strategy Environ.* **2021**, *30*, 3194–3207. [CrossRef]
22. Ye, F.; Ouyang, Y.; Li, Y. Digital Investment and Environmental Performance: The Mediating Roles of Production Efficiency and Green Innovation. *Int. J. Prod. Econ.* **2023**, *259*, 108822. [CrossRef]
23. Hernández, V.; Revilla, A.; Rodríguez, A. Digital Data-driven Technologies and the Environmental Sustainability of Micro, Small, and Medium Enterprises: Does Size Matter? *Bus. Strat. Environ.* **2024**, *33*, 5563–5582. [CrossRef]
24. Zhao, F.; Li, M.; Xie, X.; He, L. Green product and process innovation and firm performance: A meta-analytic review. *Sustainability* **2026**, *18*, 1640. [CrossRef]
25. Öztürk, R.; Öztürk, M.; Kızılkan, Z.; Dumitrașcu, C.; Cîrțînă, D.; Ghimiși, S.S.; Ianăși, C.A.; Nioață, A. Green Supply Chain Management, Green Innovation, and Carbon-Neutral Performance: A Meta-Analytic Examination of the Moderating Role of Sustainability Metrics. *Sustainability* **2026**, *18*, 681. [CrossRef]
26. Song, C.; Teh, S.Y.; Alnoor, A.; Shao, M. Trends of the digital transformation and green innovation using PRISMA and biblio-metric analysis review. *Discov. Sustain.* **2025**, *6*, 1010. [CrossRef]
27. Penrose, E. *The Theory of the Growth of the Firm*; Oxford University Press: Oxford, UK, 1995.
28. Grant, R.M. The Knowledge-Based View of the Firm: Implications for Management Practice. *Long Range Plan.* **1997**, *30*, 450–454. [CrossRef]
29. Barney, J.B. Firm Resources and Sustained Competitive Advantage. *J. Manag.* **1991**, *17*, 99–120. [CrossRef]
30. Cuthbertson, R.W.; Furseth, P.I. Digital Services and Competitive Advantage: Strengthening the Links between RBV, KBV, and Innovation. *J. Bus. Res.* **2022**, *152*, 168–176. [CrossRef]
31. Yadav, S.; Samadhiya, A.; Kumar, A.; Majumdar, A.; Garza-Reyes, J.A.; Luthra, S. Achieving the Sustainable Development Goals through Net Zero Emissions: Innovation-Driven Strategies for Transitioning from Incremental to Radical Lean, Green and Digital Technologies. *Resour. Conserv. Recycl.* **2023**, *197*, 107094. [CrossRef]

32. He, Q.; Ribeiro-Navarrete, S.; Botella-Carrubi, D. A Matter of Motivation: The Impact of Enterprise Digital Transformation on Green Innovation. *Rev. Manag. Sci.* **2024**, *18*, 1489–1518.
33. Schmidheiny, S. The business of sustainable development. *Financ. Dev.* **1992**, *29*, 24.
34. Mio, C.; Panfilo, S.; Blundo, B. Sustainable Development Goals and the Strategic Role of Business: A Systematic Literature Review. *Bus. Strategy Environ.* **2020**, *29*, 3220–3245. [CrossRef]
35. Martin, C.J.; Evans, J.; Karvonen, A. Smart and Sustainable? Five Tensions in the Visions and Practices of the Smart-Sustainable City in Europe and North America. *Technol. Forecast. Soc.* **2018**, *133*, 269–278. [CrossRef]
36. Filiou, D.; Kesidou, E.; Wu, L. Are Smart Cities Green? The Role of Environmental and Digital Policies for Eco-Innovation in China. *World Dev.* **2023**, *165*, 106212. [CrossRef]
37. Jiang, Z.; Zhang, X.; Zhao, Y.; Li, C.; Wang, Z. The Impact of Urban Digital Transformation on Resource Sustainability: Evidence from a Quasi-Natural Experiment in China. *Resour. Policy* **2023**, *85*, 103784. [CrossRef]
38. Wen, H.; Lee, C.-C.; Song, Z. Digitalization and Environment: How Does ICT Affect Enterprise Environmental Performance? *Environ. Sci. Pollut. Res.* **2021**, *28*, 54826–54841. [CrossRef]
39. Shen, Z.; Wang, S.; Boussemart, J.-P.; Hao, Y. Digital Transition and Green Growth in Chinese Agriculture. *Technol. Forecast. Soc.* **2022**, *181*, 121742. [CrossRef]
40. Kiddee, P.; Naidu, R.; Wong, M.H. Electronic Waste Management Approaches: An Overview. *Waste Manag.* **2013**, *33*, 1237–1250. [CrossRef] [PubMed]
41. Ertz, M.; Latrous, I.; Dakhlaoui, A.; Sun, S. The Impact of Big Data Analytics on Firm Sustainable Performance. *Corp. Soc. Responsib. Environ. Manag.* **2025**, *32*, 1261–1278.
42. Sasmoko, S.; Mihardjo, L.W.W.; Alamsjah, F.; Elidjen, E.; Tarofder, A.K. Investigating the Effect of Digital Technologies, Energy Consumption and Climate Change on Customer's Experience: A Study from Indonesia. *Int. J. Energy Econ. Policy* **2019**, *9*, 353–362. [CrossRef]
43. Lei, Y.; Zhou, X.; Xie, L. Emergency Monitoring and Disposal Decision Support System for Sudden Pollution Accidents Based on Multimedia Information System. *Multimed. Tools Appl.* **2019**, *78*, 11047–11071.
44. Cagno, E.; Accordini, D.; Neri, A.; Negri, E.; Macchi, M. Digital Solutions for Workplace Safety: An Empirical Study on Their Adoption in Italian Metalworking SMEs. *Saf. Sci.* **2024**, *177*, 106598. [CrossRef]
45. Xuchao, W.; Priyadarsini, R.; Siew Eang, L. Benchmarking Energy Use and Greenhouse Gas Emissions in Singapore's Hotel Industry. *Energy Policy* **2010**, *38*, 4520–4527. [CrossRef]
46. Long, Y.; Liu, L.; Yang, B. The Effects of Enterprise Digital Transformation on Low-Carbon Urban Development: Empirical Evidence from China. *Technol. Forecast. Soc.* **2024**, *201*, 123259. [CrossRef]
47. Wang, L.; Chen, Y.; Ramsey, T.S.; Hewings, G.J. Will Researching Digital Technology Really Empower Green Development? *Technol. Soc.* **2021**, *66*, 101638. [CrossRef]
48. Zhang, C.; Fang, J.; Ge, S.; Sun, G. Research on the Impact of Enterprise Digital Transformation on Carbon Emissions in the Manufacturing Industry. *Int. Rev. Econ. Financ.* **2024**, *92*, 211–227. [CrossRef]
49. Sun, Y. Digital Transformation and Corporates' Green Technology Innovation Performance–The Mediating Role of Knowledge Sharing. *Financ. Res. Lett.* **2024**, *62*, 105105. [CrossRef]
50. Liu, X.; Liu, F.; Ren, X. Firms' Digitalization in Manufacturing and the Structure and Direction of Green Innovation. *J. Environ. Manag.* **2023**, *335*, 117525. [CrossRef]
51. Subramaniam, M.; Youndt, M.A. The Influence of Intellectual Capital on the Types of Innovative Capabilities. *Acad. Manag. J.* **2005**, *48*, 450–463. [CrossRef]
52. Han, Y.; Li, Z.; Feng, T.; Qiu, S.; Hu, J.; Yadav, K.K.; Obaidullah, A.J. Unraveling the Impact of Digital Transformation on Green Innovation through Microdata and Machine Learning. *J. Environ. Manag.* **2024**, *354*, 120271. [CrossRef]
53. Su, J.; Wei, Y.; Wang, S.; Liu, Q. The Impact of Digital Transformation on the Total Factor Productivity of Heavily Polluting Enterprises. *Sci. Rep.* **2023**, *13*, 6386. [CrossRef] [PubMed]
54. Zhang, Y.; Sun, J.; Yang, Z.; Wang, Y. Critical Success Factors of Green Innovation: Technology, Organization and Environment Readiness. *J. Clean. Prod.* **2020**, *264*, 121701. [CrossRef]
55. Yuan, S.; Pan, X. Inherent Mechanism of Digital Technology Application Empowered Corporate Green Innovation: Based on Resource Allocation Perspective. *J. Environ. Manag.* **2023**, *345*, 118841. [CrossRef]
56. Song, Y.; Du, C.; Du, P.; Liu, R.; Lu, Z. Digital Transformation and Corporate Environmental Performance: Evidence from Chinese Listed Companies. *Technol. Forecast. Soc.* **2024**, *201*, 123159. [CrossRef]
57. Hussain, M.; Yang, S.; Maqsood, U.S.; Zahid, R.M.A. Tapping into the Green Potential: The Power of Artificial Intelligence Adoption in Corporate Green Innovation Drive. *Bus. Strategy Environ.* **2024**, *33*, 4375–4396. [CrossRef]
58. El-Kassar, A.-N.; Singh, S.K. Green Innovation and Organizational Performance: The Influence of Big Data and the Moderating Role of Management Commitment and HR Practices. *Technol. Forecast. Soc.* **2019**, *144*, 483–498. [CrossRef]

59. Rennings, K.; Ziegler, A.; Ankele, K.; Hoffmann, E. The Influence of Different Characteristics of the EU Environmental Management and Auditing Scheme on Technical Environmental Innovations and Economic Performance. *Ecol. Econ.* **2006**, *57*, 45–59. [CrossRef]
60. Tsai, K.-H.; Chou, C.; Kuo, J.-H. The Curvilinear Relationships between Responsive and Proactive Market Orientations and New Product Performance: A Contingent Link. *Ind. Mark. Manag.* **2008**, *37*, 884–894. [CrossRef]
61. Zhu, Q.; Sarkis, J. An Inter-Sectoral Comparison of Green Supply Chain Management in China: Drivers and Practices. *J. Clean. Prod.* **2006**, *14*, 472–486. [CrossRef]
62. Nureen, N.; Sun, H.; Irfan, M.; Nuta, A.C.; Malik, M. Digital Transformation: Fresh Insights to Implement Green Supply Chain Management, Eco-Technological Innovation, and Collaborative Capability in Manufacturing Sector of an Emerging Economy. *Environ. Sci. Pollut. Res.* **2023**, *30*, 78168–78181. [CrossRef]
63. Guang Shi, V.; Lenny Koh, S.C.; Baldwin, J.; Cucchiella, F. Natural Resource Based Green Supply Chain Management. *Supply Chain Manag. Int. J.* **2012**, *17*, 54–67. [CrossRef]
64. Trujillo-Gallego, M.; Sarache, W.; Sousa Jabbour, A.B.L.D. Digital Technologies and Green Human Resource Management: Capabilities for GSCM Adoption and Enhanced Performance. *Int. J. Prod. Econ.* **2022**, *249*, 108531. [CrossRef]
65. Ivanov, D.; Dolgui, A.; Sokolov, B.; Ivanova, M. Literature Review on Disruption Recovery in the Supply Chain*. *Int. J. Prod. Res.* **2017**, *55*, 6158–6174. [CrossRef]
66. Behl, A.; Sampat, B.; Gaur, J.; Pereira, V.; Laker, B.; Shankar, A.; Shi, Y.; Roohanifar, M. Can Gamification Help Green Supply Chain Management Firms Achieve Sustainable Results in Servitized Ecosystem? An Empirical Investigation. *Technovation* **2024**, *129*, 102915. [CrossRef]
67. Kumar, V.; Kumar, S.; Chatterjee, S.; Mariani, M. Optimizing the Digital Transformation Capability for Enhancing Economic Sustainability of Entrepreneurial Venture: The Moderating Role of Entrepreneurial Orientation. *IEEE Trans. Eng. Manag.* **2024**, *71*, 8517–8530. [CrossRef]
68. Gupta, A.; Deokar, A.; Iyer, L.; Sharda, R.; Schrader, D. Big Data & Analytics for Societal Impact: Recent Research and Trends. *Inf. Syst. Front.* **2018**, *20*, 185–194. [CrossRef]
69. Shahzad, F.; Zaied, Y.B.; Shahzad, M.A.; Mahmood, F. Insights into the Performance of Green Supply Chain in the Chinese Semiconductor Industry. *Int. J. Prod. Econ.* **2024**, *273*, 109286. [CrossRef]
70. Benzidia, S.; Makaoui, N.; Bentahar, O. The Impact of Big Data Analytics and Artificial Intelligence on Green Supply Chain Process Integration and Hospital Environmental Performance. *Technol. Forecast. Soc.* **2021**, *165*, 120557. [CrossRef]
71. Feng, S.; Chong, Y.; Li, G.; Zhang, S. Digital Finance and Innovation Inequality: Evidence from Green Technological Innovation in China. *Environ. Sci. Pollut. Res.* **2022**, *29*, 87884–87900. [CrossRef]
72. Cao, Y.; Li, X.; Hu, H.; Wan, G.; Wang, S. How Does Digitalization Promote Green Transformation in Manufacturing Enterprises? An Exploratory Case Study from the Perspective of Resource Orchestration Theory. *J. Manag. World* **2023**, *39*, 96–112, 126, 113.
73. Zhou, J.; Liu, W. Carbon Reduction Effects of Digital Technology Transformation: Evidence from the Listed Manufacturing Firms in China. *Technol. Forecast. Soc.* **2024**, *198*, 122999. [CrossRef]
74. Ashford, N. Understanding Technological Responses of Industrial Firms to Environmental Problems: Implications for Government Policy. In *Environmental Strategies for Industry: International Perspectives on Research Needs and Policy Implications*; Fischer, K., Schot, J.W., Eds.; Island Press: Washington, DC, USA, 1993; pp. 277–307.
75. Wang, J.; Liu, Y.; Wang, W.; Wu, H. How Does Digital Transformation Drive Green Total Factor Productivity? Evidence from Chinese Listed Enterprises. *J. Clean. Prod.* **2023**, *406*, 136954. [CrossRef]
76. Nadeem, M.; Bahadar, S.; Gull, A.A.; Iqbal, U. Are Women Eco-friendly? Board Gender Diversity and Environmental Innovation. *Bus. Strategy Environ.* **2020**, *29*, 3146–3161. [CrossRef]
77. Berrone, P.; Fosfuri, A.; Gelabert, L.; Gomez-Mejia, L.R. Necessity as the Mother of "green" Inventions: Institutional Pressures and Environmental Innovations. *Strateg. Manag. J.* **2013**, *34*, 891–909. [CrossRef]
78. Lipsey, M.W.; Wilson, D.B. *Practical Meta-Analysis*; SAGE Publications, Inc.: Thousand Oaks, CA, USA, 2001.
79. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed.; Lawrence Erlbaum Associates: Hillsdale, NJ, USA, 1988.
80. Yang, C.; Qi, H.; Jia, L.; Wang, Y.; Huang, D. Impact of Digital Technologies and Financial Development on Green Growth: Role of Mineral Resources, Institutional Quality, and Human Development in South Asia. *Resour. Policy* **2024**, *90*, 104699. [CrossRef]
81. Lu, Y.; Xu, C.; Zhu, B.; Sun, Y. Digitalization Transformation and ESG Performance: Evidence from China. *Bus. Strategy Environ.* **2024**, *33*, 352–368.
82. Oduro, S.; Umar, R.M.; De Massis, A.; Haylemariam, L.G. Corporate Social Responsibility and Family Firm Performance: A Meta-analytic Review. *Corp. Soc. Responsib. Environ. Manag.* **2024**, *32*, 1412–1443. [CrossRef]