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Article

DIGITAL TRANSFORMATION AND ENVIRONMENTAL PERFORMANCE: THE MEDIATING ROLE OF GREEN INNOVATION AND THE MODERATING ROLE OF ORGANIZATIONAL LEARNING CAPABILITY

Vuong Thanh Long, Nguyen

School of Economics and Finance, Thu Dau Mot University, longnvt@tdmu.edu.vn
https://orcid.org/0009-0000-2885-9528

Abstract: This study examines how digital transformation affects environmental performance, with green innovation as a mediator and organizational learning capability (OLC) as a moderator. The theoretical framework draws on dynamic capability theory, resource-based view, and organizational learning theory. Survey data from 326 manufacturing firms in Vietnam were analysed using structural equation modelling and hierarchical regression. Digital transformation positively predicted both green innovation and Environmental Performance. Green innovation partially mediated the digital transformation-ESG relationship, meaning ESG gains are stronger when digital capabilities translate into environmentally sustainable products and processes. OLC strengthened the digital transformation-green innovation link: firms with stronger learning cultures converted digital resources into sustainable innovations more effectively. The findings extend the digitalization-ESG literature to an emerging-economy context and suggest that managers should treat organizational learning as a precondition for translating digital investment into sustainability outcomes.
Keywords: Digital transformation; Environmental Performance; Green innovation; Organizational learning capability; Sustainability; Vietnam.

1. INTRODUCTION

Over the past decade, environmental, social, and governance (ESG) performance has become a standard measure of corporate sustainability and competitiveness. The increasing emphasis on environmental, social, and governance (ESG) criteria reflects growing expectations from regulators, investors, and consumers for responsible corporate behavior. Stakeholders, including governments, investors, regulators, consumers, and the general public, are demanding greater accountability and transparency from firms regarding their environmental practices and social responsibilities. As a result, Environmental Performance is now a mandatory component of corporate strategy in many markets. Concurrently, digital transformation has reshaped business operations and organizational capabilities. The rapid adoption of advanced digital technologies, such as artificial intelligence (AI), Internet of Things (IoT), cloud computing, blockchain, big data analytics, and digital platforms, has enabled organizations to gather, analyze, and use data in ways previously unattainable (Vial, 2019). These technological advancements facilitate improvements in operational efficiency, cost reduction, resource optimization, and innovation capacity. Recent research indicates that digital transformation can also positively influence sustainability and ESG outcomes by enhancing environmental management systems, supporting green innovation, increasing transparency, and strengthening stakeholder engagement (Lyu et al., 2025). Digital technologies enable real-time monitoring of environmental impacts, optimize energy use, minimize waste, and improve supply chain sustainability. Also, digital transformation enhances

organizational agility and strategic responsiveness, allowing firms to adapt more effectively to evolving sustainability standards and expectations. Despite growing academic interest in the intersection of digitalization and Environmental Performance, the mechanisms underlying this relationship remain insufficiently explored. Most existing research emphasizes direct links between digitalization and sustainability outcomes, often neglecting the mediating and moderating factors that influence this relationship. Among these factors, green innovation has emerged as a key mediating mechanism. Green innovation involves the development and deployment of environmentally friendly products, processes, managerial systems, and technologies aimed at reducing ecological impacts while maintaining economic efficiency (Chen, 2008). Firms engaged in digital transformation tend to possess stronger technological capabilities, data analytics skills, and knowledge integration mechanisms, which collectively facilitate green innovation activities. Consequently, digital transformation may indirectly improve Environmental Performance through the promotion of environmentally sustainable innovations.

Another important but underexplored factor is organizational learning capability (OLC). Organizational learning capability refers to the firm's ability to acquire, disseminate, interpret, and apply knowledge for strategic adaptation and innovation (Jerez-Gómez et al., 2005). Organizations with strong learning capabilities are more adept at integrating digital technologies to support green innovation, owing to their effective knowledge-sharing systems, adaptive cultures, and routines focused on innovation. While existing research emphasizes the significance of learning capacity in organizational innovation, empirical evidence on its moderating effect between digital transformation and green innovation remains limited, especially within emerging economies like Vietnam. Vietnam's rapid industrialization and digitalization make it a relevant context for examining these dynamics. Firms in Vietnam face growing pressure from global supply chains, foreign investors, and international consumers to improve environmental, social, and governance (ESG) performance. Understanding how digital transformation influences ESG outcomes through green innovation and organizational learning is therefore important for advancing both theoretical frameworks and practical applications. This investigation aims to fill the research gap by exploring these dynamics in Vietnam, providing insights relevant to policymakers and industry stakeholders committed to sustainable development.

This study therefore aims to answer the following research questions:

1. Does Digital transformation positively influence Environmental performance?
2. Does Green innovation play a role in mediating the relationship between Digital transformation and Environmental performance?
3. Does Organizational learning capability moderate the relationship between Digital transformation and Green innovation?

This research constructs an integrated conceptual framework based on dynamic capability theory, organizational learning theory, and the resource-based view. It utilizes data from 326 manufacturing firms, employing structural equation modeling and hierarchical regression to evaluate hypotheses. The study advances existing literature by shifting focus from financial to Environmental Performance outcomes in digital transformation. Also, it highlights green innovation as an important mediating factor that links digital transformation initiatives to improved Environmental Performance, thereby enriching understanding of the mechanisms underlying sustainable organizational development in the context of technological change. Third, it introduces organizational learning capability as a moderating factor that strengthens the effectiveness of digital transformation in promoting green innovation. Fourth, the study enriches sustainability research in emerging economies, particularly Vietnam.

2. Literature review and hypotheses development

2.1 Theory

The resource-based view (RBV) emphasizes that firms can attain sustainable competitive advantage by using unique, scarce resources such as digital technologies, organizational knowledge, and innovation capabilities. Integrating digital tools with green innovation strategies can significantly improve environmental, social, and governance (ESG) outcomes, thereby promoting long-term organizational resilience. The theory of dynamic capabilities highlights a firm's ability to assimilate, develop, and reconfigure internal and external competencies in response to rapid environmental changes (Teece et al., 1997). Digital transformation is recognized as a critical dynamic capability that facilitates adaptation to technological and sustainability shifts, while green innovation improves responsiveness to environmental challenges. Also, organizational learning theory shows the importance of knowledge acquisition and application in supporting adaptability and innovation. Developing organizational learning capabilities enables the conversion of digital resources into sustainable practices through knowledge sharing, experimentation, and continuous improvement, ultimately strengthening organizational resilience and competitive positioning.

2.2. Hypotheses development

2.2.1 Digital transformation and Environmental Performance

Digital transformation encompasses the strategic integration of digital technologies into organizational processes, structures, and business models to enhance performance and generate value (Vial, 2019). This process involves fundamental organizational changes driven by technologies such as artificial intelligence (AI), Internet of Things (IoT), cloud computing, blockchain, and big data analytics. The primary benefits include increased operational efficiency, improved decision-making, and a heightened capacity for organizations to adapt swiftly to environmental shifts. Digital technologies also enable data-driven approaches to sustainability management, resource optimization, and environmentally responsible operations. Recent empirical research indicates a positive correlation between digital transformation and corporate sustainability outcomes. For instance, Lyu et al. (2025) reported that digital transformation significantly boosts environmental, social, and governance (ESG) performance among Chinese firms. Similarly, Zhang et al. (2025) found that digitalization supports green innovation by enhancing environmental information processing and technological integration. These technological infrastructures and analytical capabilities enable firms to monitor energy consumption, optimize production processes, minimize waste, and develop eco-friendly products. Organizational learning capability refers to the organizational and managerial attributes that facilitate effective learning processes, including knowledge acquisition, sharing, experimentation, openness, dialogue, and participative decision-making (Jerez-Gómez et al., 2005). Organizations with strong learning capabilities tend to be more adaptable, innovative, and resilient. Such organizations are better equipped to integrate digital technologies into sustainable innovation initiatives, owing to their mechanisms for knowledge dissemination and collaborative learning. Supporting this, Zhang et al. (2025) demonstrated that digital transformation enhances green innovation by improving access to environmental information and technological resources. Similarly, Guo et al. (2023) confirmed that digital technologies underpin environmental innovation and sustainable manufacturing practices. Based on these findings, the following hypothesis is proposed:

H1: Digital transformation positively affects Environmental Performance.

2.2.2 Digital transformation and green innovation

Digital transformation has become an important organizational capability, significantly contributing to innovation, operational flexibility, and environmental sustainability. By integrating advanced technologies such as artificial intelligence (AI), cloud computing, Internet of Things (IoT), blockchain, and big data analytics, organizations are increasingly capable of redesigning production systems, optimizing resource use, and enhancing environmental management practices. The relationship between digital transformation and green innovation can be understood through the lenses of resource-based view and dynamic capability theory. These frameworks suggest that digital transformation provides firms with valuable technological resources and adaptive capabilities, which are important for supporting environmentally sustainable innovation activities. Specifically, digital technologies enable organizations to efficiently collect and analyse environmental data, monitor energy consumption in real time, reduce waste, and identify opportunities for sustainable product and process innovations.

Empirical studies support the positive impact of digital technologies on green innovation capabilities. For example, Zhang et al. (2025) found that digital transformation improves firms' access to environmental information, facilitates technological integration, and promotes environmentally responsible innovation. Their research indicates that digital tools assist organizations in identifying environmental inefficiencies and developing greener production solutions more effectively. Similarly, Guo et al. (2023) demonstrated that digital technologies enhance operational transparency, technological coordination, and sustainability-oriented decision-making, thereby positively influencing green innovation. The application of AI-based systems and big data analytics allows firms to optimize production processes, reduce environmental impacts, and improve innovation performance simultaneously. Additional evidence from emerging economies further supports this relationship. Liu et al. (2025) observed that firms with higher levels of digital transformation tend to demonstrate stronger green innovation performance, driven by improved knowledge integration and environmental responsiveness. Likewise, Khin and Ho (2019) emphasized that digital capabilities significantly improve organizational innovation and strategic flexibility. In the Vietnamese context, manufacturing firms are increasingly adopting digital technologies to meet international sustainability standards and comply with environmental regulations. As Vietnam becomes more integrated into global supply chains, these firms face mounting pressure to implement green production practices. Consequently, digital transformation is a critical mechanism for achieving green innovation objectives. Based on these findings, the following hypothesis is proposed:

H2: Digital transformation positively affects green innovation.

2.2.3 Green innovation and Environmental Performance

Green innovation encompasses technological and managerial advancements aimed at minimizing environmental impacts while enhancing organizational efficiency and sustainability (Chen et al., 2006). It involves the development of eco-friendly products, sustainable manufacturing methods, energy-efficient technologies, waste reduction strategies, and environmentally responsible management practices. Such innovations play an important role in advancing corporate sustainability and improving Environmental, Social, and Governance (ESG) performance. Empirical studies demonstrate that green innovation contributes to reduced resource consumption, increased environmental efficiency, and strengthened corporate social responsibility (Xie et al., 2019). Recent research by Liu et al. (2024) indicates that green innovation significantly improves ESG outcomes among Chinese publicly listed firms. Digital transformation acts as a facilitator for green innovation by improving access to information, enabling environmental monitoring, improving research and development capabilities, and supporting knowledge integration. Firms using advanced digital technologies are better equipped to develop environmentally sustainable products and processes. Environmental Performance measures a company's effectiveness in managing environmental, social, and governance responsibilities. Environmental performance focuses on resource efficiency, emission reductions, and environmental protection initiatives. Social performance encompasses employee welfare, diversity, community engagement, and stakeholder relations. Governance performance pertains to transparency, accountability, ethical conduct, and compliance with regulations. Strong Environmental Performance correlates with enhanced corporate reputation, increased investor confidence, stakeholder trust, and sustained competitive advantage (Friede et al., 2015). Consequently, organizations are increasingly integrating ESG considerations into strategic decision-making. Green innovation contributes to improved Environmental Performance by reducing environmental impacts, optimizing resource use, strengthening stakeholder relationships, and promoting transparent governance. Liu et al. (2024) found that green innovation positively influences both environmental and social dimensions of ESG. Similarly, Xie et al. (2019) reported that green process and product innovations are instrumental in supporting corporate sustainability. Overall, integrating green innovation within corporate strategies is important for achieving sustainable development goals and maintaining long-term competitiveness. Based on these findings, the following hypothesis is proposed:

H3: Green innovation positively affects Environmental Performance.

2.2.3 Mediating role of green innovation

Digital transformation may improve Environmental Performance indirectly through green innovation. Digital technologies facilitate environmental data collection, knowledge integration, and sustainable product development. These capabilities enhance green innovation, which subsequently improves ESG outcomes. This mediating mechanism aligns with dynamic capability theory, which suggests that organizational capabilities translate strategic resources into performance outcomes. Accordingly:

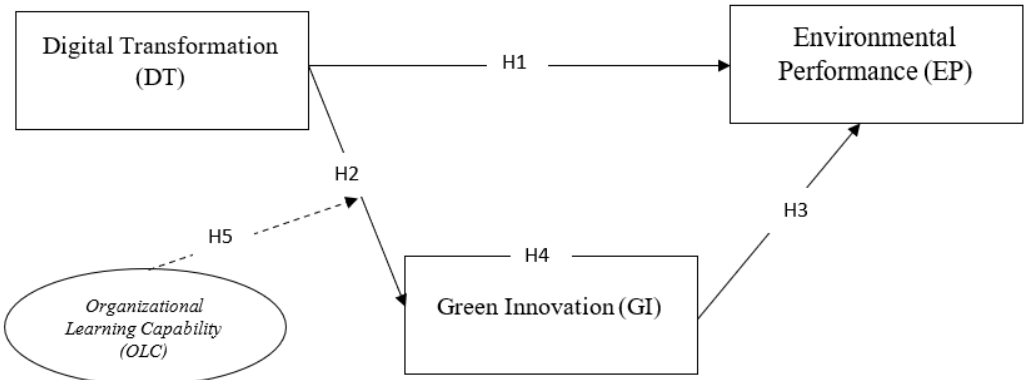
H4: Green innovation mediates the relationship between digital transformation and Environmental Performance.

2.2.4 Moderating role of Organizational learning capability

Organizational learning capability enhances firms' ability to leverage digital technologies for innovation. Firms with strong learning cultures are better able to acquire, assimilate, and exploit knowledge generated through digital technologies, thereby improving innovation outcomes. Consistent with organizational learning theory, digital transformation facilitates green innovation by strengthening firms' absorptive capacity, which represents a critical learning capability for recognizing and utilizing external knowledge (Zhou & Feng, 2024). Likewise, organizational learning capability has been shown to significantly improve innovation performance by fostering experimentation, dialogue, and knowledge sharing within organizations (Alegre & Chiva, 2008). Therefore:

H5: Organizational learning capability moderates the relationship between digital transformation and green innovation.

2.2.5 Research model



In there:

- Independent variable: Digital transformation (DT)
- Mediating variable: Green innovation (GI)
- Dependent variable: Environmental Performance (ESG)
- Moderating variable: Organizational learning capability (OLC)

3. Research methodology

3.1 Research design

This study adopts a quantitative research design using survey methodology. Quantitative research is appropriate because the study seeks to test causal relationships among latent variables using statistical techniques. The study uses cross-sectional data collected from manufacturing firms in Vietnam. Structural equation modelling (SEM) and hierarchical regression analysis were employed to test the proposed hypotheses.

3.2 Population and sample

The study focuses on medium and large manufacturing enterprises in Vietnam, chosen due to their significance in digital transformation and environmental sustainability. The dataset comprises 326 valid observations, ensuring strongness and reliability in the research findings.

Table 1. Characteristics of respondents' demographics in study.

Characteristics	Frequency	Percentage
Medium firms	148	45.4%
Large firms	178	54.6%
Manufacturing	326	100%
Firms older than 10 years	201	61.7%
Firms implementing ERP systems	259	79.4%
Firms using AI technologies	183	56.1%

3.3 Measurement scales

All constructs were measured using five-point Likert scales ranging from 1 (strongly disagree) to 5 (strongly agree).

Table 2. Measuring scale

Item	Scale	Source

Digital Transformation (DT)	The company integrates digital technologies into operational processes. The company uses AI and big data analytics in decision-making. The company has implemented integrated ERP systems.	Khin & Ho (2019)
Green Innovation (GI)	The company develops environmentally friendly products. The company invests in green technologies. The company improves production processes to reduce waste.	Chen (2008) and Xie et al. (2019
The Environmental Performance (ESG)	Our company actively reduces carbon emissions and environmental pollution. Our company efficiently uses energy and natural resources. Our company adopts environmentally friendly production processes. Our company invests in environmental protection and waste management systems. Our company continuously improves environmental sustainability practices.	Fatemi, Glaum, & Kaiser (2018)
Organizational Learning Capability (OLC)	Employees share knowledge across departments. The company encourages experimentation and learning. The organization continuously learns from experience.	Jerez-Gómez et al. (2005).

4. Results

4.1 Descriptive statistics

Descriptive statistics provide an overview of the characteristics and distributions of the variables included in the study.

Table 3. Descriptive Statistics

Variable	Mean	SD	Minimum	Maximum
Digital Transformation	3.74	0.71	1.00	5.00
Green Innovation	3.58	0.68	1.00	5.00
Environmental Performance	3.69	0.65	1.00	5.00
Organizational Learning Capability	3.81	0.62	1.00	5.00

Means range from 3.58 to 3.81, indicating that sampled firms report moderate to high engagement across all four constructs.

4.2 Reliability and validity analysis

Table 4. Reliability and convergent validity

Variable	Cronbach's Alpha	Composite Reliability	AVE
Digital Transformation	0.892	0.901	0.641
Green Innovation	0.887	0.896	0.632
Environmental Performance	0.908	0.915	0.654
Organizational Learning Capability	0.880	0.888	0.611

All Cronbach's alpha values exceed the recommended threshold of 0.70, indicating satisfactory internal consistency reliability. Composite reliability exceeds 0.70, indicating strong construct reliability, while AVE values above 0.50 confirm the presence of convergent validity, supporting the measurement model's validity.

4.3 Correlation analysis

Table 5. Correlation matrix

Variable	DT	GI	ESG	OLC
Digital Transformation	1.000			
Green Innovation	0.612**	1.000		
Environmental Performance	0.545**	0.671**	1.000	
Organizational Learning Capability	0.488**	0.534**	0.469**	1.000

**p < 0.01

4.4 Regression analysis

Table 6. Regression results for green innovation

Variable	Model 1	Model 2	Model 3
DT	0.530***	0.487***	0.462***
OLC	0.221**	0.236**	0.201**
DT × OLC		0.220*	0.225*
R^2	0.381	0.429	0.441

*p < 0.05; **p < 0.01; ***p < 0.001

The regression analysis confirms hypothesis H1, demonstrating that digital transformation has a positive effect on green innovation. Also, the significant positive interaction between digital transformation and organizational learning capacity supports hypothesis H5.

4.5 Regression results for Environmental Performance

Table 7. Regression results for Environmental Performance

Variable	Coefficient	p-Value
DT	0.150	0.045
GI	0.580	<0.001
R^2	0.517	

The results support H2, H3, indicating that digital transformation and green innovation positively influence Environmental Performance.

4.6 Mediation analysis

Bootstrapping analysis demonstrates that the indirect effect of digital transformation on Environmental Performance through green innovation is significant.

Table 8. Mediation results

Path	Indirect effect	95% ci
DT → GI → ESG	0.307	[0.214, 0.401]

Because the confidence interval does not include zero, H4 is supported.

5. Discussion and conclusion

Drawing from the empirical results of hierarchical regression and bootstrapping analysis applied to 326 manufacturing firms in Vietnam, this study proposes an integrated set of implications for three distinct stakeholder groups, namely policymakers and regulatory agencies, professional and industry associations, and manufacturing firms themselves, aimed at maximizing the sustainability returns of digital transformation in the Vietnamese manufacturing sector.

All five hypotheses were supported by the empirical evidence, confirming a multi-step pathway in which digital transformation drives Environmental Performance both directly ($\beta = 0.150$, $p = 0.045$) and indirectly through green innovation (indirect effect = 0.307, 95% CI [0.214, 0.401]), with organizational learning capability amplifying the digital transformation-to-green innovation conversion (interaction $\beta = 0.220$, $p < 0.05$). The substantially stronger effect of digital transformation on green innovation ($\beta = 0.530$, $p < 0.001$) relative to its direct effect on Environmental Performance ($\beta = 0.150$) indicates that digital technologies primarily reshape ESG outcomes by enabling firms to develop environmentally sustainable products, processes, and management systems rather than through direct operational reporting improvements, consistent with dynamic capability theory (Teece et al., 1997) holding that technological resources generate performance advantages only when converted into capability-based innovation outputs. Green innovation's strong direct effect on Environmental Performance ($\beta = 0.580$, $p < 0.001$) and the finding that the indirect DT–GI–ESG path (0.307) exceeds the direct DT–ESG path (0.150) together confirm that green innovation is not merely a correlate but the dominant channel through which digitalization translates into measurable sustainability gains, corroborating Liu et al. (2024) and Xie et al. (2019) and extending this finding to Vietnamese manufacturing, where digital transformation pressure from international supply chains increasingly co-occurs with ESG disclosure expectations from foreign investors and export regulators. The moderating effect of OLC suggests that firms possessing stronger learning cultures are better able to transform digital resources into green innovation outcomes. This finding is consistent with Alegre and Chiva (2008), who argued that organizational learning capability enhances innovation performance through knowledge sharing, experimentation, and continuous learning. It also supports Zhou and Feng (2025), who found that organizational learning mechanisms facilitate the conversion of digital transformation into green innovation by strengthening firms' knowledge absorption and utilization capabilities.

First, for Vietnamese policymakers, particularly the Ministry of Science and Technology and the Ministry of Natural Resources and Environment, the finding that digital transformation's dominant ESG pathway runs through green innovation (indirect path 0.307) rather than through direct reporting (direct path 0.150) implies that government programs designed to improve Environmental Performance in manufacturing should be structured as integrated digital–green innovation packages rather than treating digital transformation support and green innovation incentives as separate policy instruments; specifically, the Ministry of Science and Technology should revise eligibility requirements under the National Digital Transformation Program (Decision 749/QD-TTg) to require that beneficiary firms document at least one green innovation output within a defined period after receiving support, thereby converting digital transformation subsidies into a green innovation pipeline rather than a technology adoption program alone. For the State Securities Commission and the Ministry of Finance, the significant OLC moderation effect ($\beta = 0.220$, $p < 0.05$) suggests that mandatory ESG disclosure frameworks, if applied uniformly without regard to firm-level variation in learning capacity, will generate compliance-driven reporting among learning-deficient firms rather than genuine ESG improvement, because firms that lack effective knowledge-sharing routines and experimentation cultures cannot productively convert digital environmental data into actionable sustainability innovations regardless of their disclosure obligations; a more effective regulatory design would therefore tier ESG requirements according to a firm's assessed

level of digital maturity combined with an organizational learning readiness indicator, beginning with basic environmental data reporting for firms at early stages and progressively requiring integrated green innovation disclosures as firms develop the organizational capacity to support them. Regarding the 20.6% of sampled firms without ERP systems and the 43.9% without AI technologies, the Ministry of Natural Resources and Environment should establish a phased regulatory roadmap that begins with basic digital infrastructure requirements before imposing comprehensive ESG data standards, because imposing advanced disclosure obligations on firms that lack the foundational digital systems to generate the required data will increase compliance cost without improving actual environmental performance.

Second, for professional bodies such as the Vietnam Chamber of Commerce and Industry and sector-specific manufacturing associations, the sample composition reveals two structurally distinct firm populations requiring differentiated capacity-building strategies: large manufacturing firms (54.6%, n = 178), the majority of which have already implemented ERP systems (79.4% of total sample) and adopted AI technologies (56.1%), and medium manufacturing firms (45.4%, n = 148), many of which have not yet reached the digital infrastructure threshold needed to activate the full DT–GI pathway. For large manufacturing enterprises, since these firms already possess the digital infrastructure that makes the DT–GI relationship technically feasible, the binding constraint is not more digital investment but organizational learning capability; industry associations should therefore design training programs for large firms that build integrated knowledge management platforms connecting environmental data from ERP systems to green product development teams, establish cross-functional sustainability innovation committees with representation from operations, research and development, and ESG reporting units, and introduce performance metrics that incentivize operational managers to generate and share environmental improvement insights rather than treating ESG as a disclosure function isolated from production decisions. For medium-sized manufacturing firms, where the combination of lower digital maturity and weaker learning infrastructure simultaneously constrains both the DT–GI and GI–ESG pathways, capacity-building programs should be sequenced rather than comprehensive: the first phase should build knowledge-sharing routines and learning culture within the existing management structure, since the moderation evidence shows that strengthening OLC raises the green innovation return from every subsequent level of digital investment, while the second phase introduces targeted digital tools beginning with environmental data collection and ERP–ESG integration into organizations that have already developed the learning culture needed to productively use them.

Finally, for manufacturing firms themselves, the central practical lesson is that the highest-return strategy for improving Environmental Performance is not to invest in digital reporting technology per se but to direct digital capabilities toward green innovation and simultaneously ensure that organizational learning infrastructure is in place to maximize the innovation yield of those digital tools; this follows directly from the finding that digital transformation's indirect effect on Environmental Performance through green innovation (0.307) more than doubles its direct effect (0.150), and that green innovation itself is the strongest predictor of Environmental Performance in the model ($\beta = 0.580$). The OLC moderation finding carries a specific sequencing implication: firms that already score high on knowledge sharing, experimentation, and cross-departmental learning, which is more common among large, ERP-equipped firms older than ten years (61.7% of the sample), should pursue aggressive digital transformation investment knowing that their learning infrastructure will amplify the green innovation return, and their strategic priority should be to systematically channel digital analytics outputs into green product development and sustainable process redesign rather than using digital technologies only for efficiency gains; conversely, firms with low OLC scores, more prevalent among younger and medium-sized enterprises, should not expect significant ESG improvements from digital transformation alone and should instead invest first in structural learning mechanisms, including cross-functional sustainability teams, knowledge management systems connecting production data with innovation processes, and leadership development programs that build management commitment to environmental experimentation, because these investments serve as prerequisite conditions that determine how productively digital resources will subsequently convert into green innovation and Environmental Performance.

The cross-sectional design prevents causal inference, and the directional relationships confirmed here should be treated as consistent with the proposed theory rather than as definitive proof of causality. The sample covers only manufacturing firms in Vietnam, limiting generalizability to service industries, agricultural enterprises, or manufacturing sectors in other emerging economies with different digital infrastructure conditions, ownership structures, or regulatory environments. Future research should collect longitudinal panel data tracking digital transformation levels, green innovation outputs, and ESG scores across multiple periods to test whether period-t digital transformation predicts period-t+1 green innovation and ESG improvement; should extend the moderating analysis to examine whether the OLC amplification effect varies across firm ownership types, export orientation, and

environmental regulatory exposure, all sources of heterogeneity in Vietnamese manufacturing that this study's design did not permit to examine; and should investigate whether the DT–GI–ESG pathway strengthens or weakens across high-regulation versus low-regulation industry sub-sectors within manufacturing.

Conflicts of interest/Competing interests: The author declare that they have no conflict of interest

Declaration of Generative AI and AI-assisted Technologies in the Writing Process. During the preparation of this work, the authors used ChatGPT (OpenAI) in order to support language editing, improve clarity of academic writing, and refine the presentation of arguments. After using this tool, the authors carefully reviewed, revised, and edited the content as necessary and take full responsibility for the accuracy, originality, and integrity of the published article.

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