https://doi.org/10.59865/abacj.2025.31

DIGITAL TRANSFORMATION AND ESG RATING FOR INDUSTRY 5.0 IN THE CHINESE MANUFACTURING INDUSTRY

Bifeng Ren[1], Sutana Boonlua[2,*], and Sumittra Jirawuttinunt[3]

Abstract

With the introduction of Industry 5.0, which emphasizes greater social responsibility and sustainable development for companies, it is imperative to explore the intricate relationship between digital transformation (DT) and environmental, social, and governance (ESG) rating. This study aims to understand how DT impacts ESG rating, considering the evolving competitive advantage of firms from the perspectives of resource-based view theory (RBV) and knowledge management (KM) theory. This study examines the relationship between DT and ESG rating, as well as the mediating effect of green innovation (GI) in this relationship. Utilizing data from 360 Chinese manufacturing firms listed on the Shanghai Stock Exchange and Shenzhen Stock Exchange from 2010 to 2022, the findings reveal that with the exception of digital technology and data analysis, DT was shown to have significant impacts on corporate ESG rating. Specifically, digital business strategy and leadership, and human resource capabilities and culture showed positive relationships, while transformative organization and operations exhibited a negative relationship. Furthermore, GI was found to mediate the relationship between DT and ESG rating. By uncovering the internal mechanisms through which DT affects ESG rating, this study provides valuable insights for companies looking to enhance their sustainable practices within the framework of Industry 5.0.

Keywords: Digital Transformation, ESG Rating, Green Innovation, Industry 5.0

1. INTRODUCTION

In today's business environment, companies must pursue sustainable development that goes beyond mere economic efficiency; they must also consider their environmental, social, and governance (ESG) responsibilities. ESG represents an extension and enrichment of the concept of socially responsible investing (SRI) and serves as a crucial measure of corporate sustainability (Nekhili, Boukadhaba, Nagati, & Chtioui, 2021). In the past decade, companies have experienced significant changes in their core manufacturing operations, including areas such as product planning and development, supply chain management, procurement, and marketing. These transformations have been driven by substantial investments in Industry 4.0 technologies and practices (Chen, Gao, Mangla, Song, & Wen, 2020; Jabbour, de Sousa Jabbour, Sarkis, & Godinho Filho, 2017). Although the Industry 4.0 paradigm is still relatively young and evolving, both academia and major European policy bodies are now promoting a

[1] Assoc. Prof. Dr. Bifeng Ren is currently working as a lecturer in the Department of Finance, Guangzhou Polytechnic University, Guangdong, China. She obtained a Ph.D. in Modern Management from Mahasarakham Business School, Mahasarakham University, Thailand.

[2,*] Asst. Prof. Dr. Sutana Boonlua *(corresponding author)* is currently working as a lecturer in Department of International Business, Mahasarakham Business School, Mahasarakham University, Thailand. She obtained a Ph.D. in Economics from Lincoln University, New Zealand. *Email: sutana.t@acc.msu.ac.th*

[3] Asst. Prof. Dr. Sumittra Jirawuttinunt is currently working as a lecturer in Department of Management, Mahasarakham Business School, Mahasarakham University, Thailand. She obtained a Ph.D. in Management from Mahasarakham University, Thailand.

new wave of digital transformation (DT) known as Industry 5.0 (Ivanov, 2023). The unprecedented emergence of Industry 5.0 necessitates an exploration of the drivers behind the Industry 5.0 paradigm and an understanding of how this addresses prevailing socio-environmental concerns. Economic and socio-environmental crises and challenges, such as social inequality, environmental degradation, and the disruptions caused by the COVID-19 pandemic or the Ukraine-Russia conflict, underscore the need for a profound systemic transformation that enables humans to live in peace and prosperity, and in harmony with the planet. Initially introduced as the chronological successor to Industry 4.0, Industry 5.0 was driven by advancements in man-machine integration technologies (Longo, Padovano, & Umbrello, 2020; Nahavandi, 2019). However, more recent perspectives present Industry 5.0 as a complementary transformational movement to Industry 4.0, with a focus on sustainable development (Xu, Lu, Vogel-Heuser, & Wang, 2021).

Following the agenda set by the European Commission in 2021, this study defines Industry 5.0 as a paradigm shift in the management of digital industrial transformation aimed at achieving sustainable economic and socio-environmental development. The current Industry 5.0 framework, as outlined by the European Commission in 2021, is closely aligned with the sustainable development agenda of the United Nations. The European Commission is actively pursuing economic resilience, social development, environmental protection, human-centric approaches, and a more equitable distribution of wealth. Industry 5.0 sets ambitious sustainability goals that necessitate a significant transformation of business models, value structures, consumption norms, and public engagement (Sindhwani, Afridi, Kumar, Banaitis, Luthra, & Singh, 2022).

In 2020, China introduced the "dual-carbon" strategy, intending to reach a "carbon peak" by 2030 and achieve "carbon neutrality" by 2060. The carbon peak target describes China's aim to have national carbon dioxide emissions peak by 2030, immediately followed by decreasing emissions. Meeting the carbon neutrality goal will involve offsetting carbon emissions through various measures to achieve a net-zero carbon footprint by 2060. The "dual-carbon" strategy requires companies to focus not only on technological innovation but also on innovation driven by a sense of responsibility. In 2022, the State-owned Assets Supervision and Administration Commission of the State Council (SASAC) established the Bureau of Science and Technology Innovation and the Bureau of Social Responsibility, indicating that companies should integrate technological innovation with the fulfillment of social responsibilities in their operations. Achieving the "dual carbon" goals requires that scientific and technological innovation be a precursor to promoting high-quality development that prioritizes ecological balance and fosters green, low-carbon growth.

The widely recognized ESG investment concept provides a clear direction for corporate innovation, advocating that companies focus on non-financial performance alongside financial outcomes. The ESG framework guides companies to assume environmental responsibility, improve social performance, and enhance corporate governance throughout their development. ESG principles align closely with China's current national strategies and new development priorities, offering a framework for companies to pursue innovative activities.

Sustainability in the context of Industry 5.0 extends beyond the sustainability of individual companies to encompass the environment, ecology, society, and people. This broader perspective aligns closely with the emphasis on environmental stewardship, social responsibility, and corporate governance found in ESG ratings. Therefore, ESG rating serves as an appropriate measure of how well companies are achieving the goals of "Sustainability for Industry 5.0".

Digital transformation, which involves integrating digital technologies into all aspects of organizational operations (Westerman, Bonnet, & McAfee, 2014), can lead to improvements in efficiency, productivity, and innovation, thereby enhancing the overall sustainability of

organizations and economies (Kagermann et al., 2017). Moreover, the implementation of digital technologies can lead to the creation of new business models and the streamlining of processes, both of which have important implications for sustainable development (Yoo, 2010). Therefore, it is crucial to understand the potential effects of DT on sustainable development, particularly with the goals of Industry 5.0 in mind.

As Industry 5.0 encourages companies to take on greater social responsibility and prioritize sustainable development, the focus of companies must go beyond economic performance. Thus, further research on the complex relationship between DT and ESG rating is necessary to understand DT's specific impact on ESG performance within the context of Industry 5.0. This study explores how corporate DT affects ESG ratings, reflecting how digitalization shapes competitive advantages and empowers development from the perspectives of RBV and KM theory, thus opening the "black box" of how DT affects corporate sustainability at the micro level.

DT can have an 'innovation effect' (Liu, Liu, & Ren, 2023; Ning, Jiang, & Luo, 2023; Ardito, Raby, Albino, & Bertoldi, 2021), enhancing the fulfillment of corporate ESG responsibilities (Yang & Han, 2024; Hao, Li, Ren, Wu, & Hao, 2023; Wang, Hong, & Long, 2023; Wu, Hu, & Hu, 2023). While pursuing business development and economic growth, green innovation emphasizes improvement in the utilization of natural resources and reducing environmental pollution through innovation and upgrading of technology, products, or processes (Wu & Hua, 2021). The contribution of GI to economic benefits, environmental protection, and social value makes it a vital approach to strengthening corporate ESG responsibilities (Yang & Han, 2024; Wu et al., 2023). Therefore, this study investigates GI as a mediator, influencing the relationship between DT and ESG rating (Wu et al., 2023).

Through DT and GI, Chinese manufacturing companies will meet national environmental goals and also enhance their global competitiveness and brand image. Driven by government policies and market demand, manufacturing companies are poised to improve their ESG performance, attract greater investor interest, and achieve long-term sustainable development. As Industry 5.0 progresses, China's manufacturing industry will continue to advance on the path of digital and green development, contributing to the global transition towards sustainable industrial practices.

The primary research question of this study is "what is the impact mechanism of DT on ESG rating within the context of Industry 5.0?" Additionally, specific research questions are as follows:

1. How does each dimension of DT influence ESG rating?
2. To what extent does GI mediate the relationship between DT and ESG rating?

2. LITERATURE REVIEW

The rapid growth of digital technology is increasing turbulence in the external environment in which companies operate, leading to increased uncertainty in corporate growth. Currently, companies must effectively allocate resources and transform business models to quickly adapt to the digital economy. Digital resources, compared to traditional factors of production, are considered a new type of resource. Scholars such as Jin & Wu (2024) and Li, Pan, & Yuan (2022) argue that leveraging digital technology effectively, presents a new avenue to overcome existing physical resource barriers and resolve resource constraints. As companies gain access to more resources, they are better equipped to develop, adjust, and integrate strategies for DT, ultimately impacting corporate performance.

The Resource-Based View (RBV) theory posits that companies must integrate, build, and reconfigure digital resources to adapt to rapid environmental changes, thereby enhancing their sustainable competitive advantage (Teece et al., 1997). This study extends the application

of RBV by applying it to DT dimensions at the organizational level, including transformative organization & operation, digital technology and data analysis, digital business strategy and leadership, and human resource capability and culture. Additionally, this study connects RBV to GI and sustainability, specifically focusing on ESG performance to analyze the theoretical linkages between these concepts.

Knowledge Management (KM) systems have the ability to optimize the utilization of tangible resources by leveraging data to enhance performance and process management. Establishing a robust cognitive architecture that ensures efficient information utilization and protection through intelligent infrastructure and collaborative technology supports corporate innovation processes (Santoro, Vrontis, Thrassou, & Dezi, 2018). KM systems can significantly impact corporate performance by promoting innovation and bolstering a company's competitive advantage (Costa & Monteiro, 2016).

Utilizing the diverse knowledge accumulated by a company (Lee, Choi, & Lee, 2020) has proven advantageous for leveraging existing information as a catalyst for innovation and merging it with new knowledge resulting from innovative performance (Ferraris, Santoro, & Dezi, 2017). This underscores the importance of KM systems in enhancing the efficiency of internal and external knowledge allocation processes while unleashing the innovation potential across various levels of companies (Shujahat et al., 2019). KM systems influence business models, facilitate dialogue among stakeholders, and align strategies and capabilities (including resources).

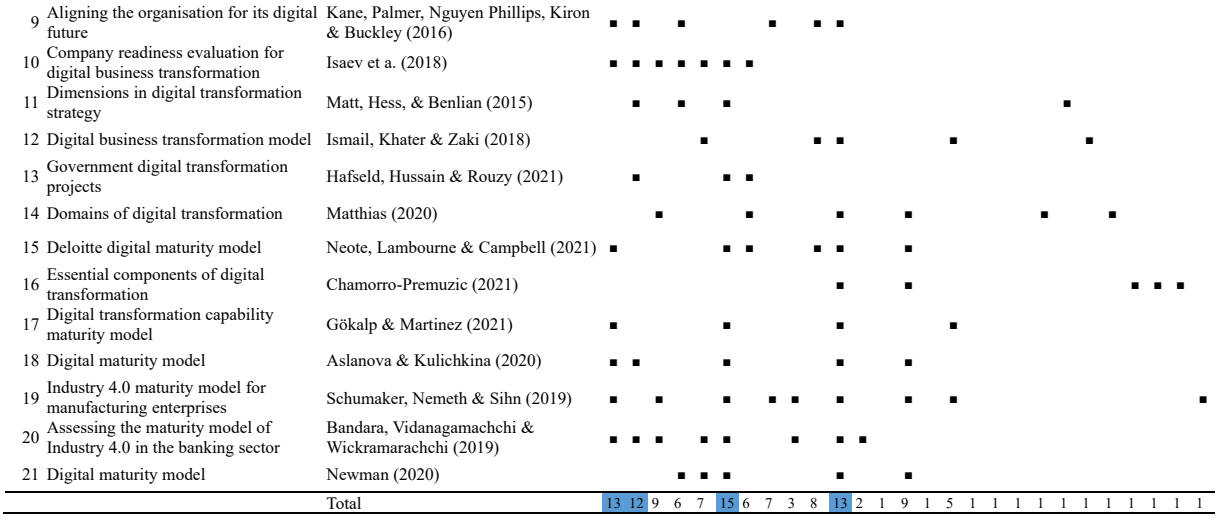
DT encompasses all aspects of an organization, from business philosophy to corporate culture, production to sales, and management to employees, all requiring a comprehensive transformation to achieve sustainable corporate development (Ma & Li, 2020).

After conducting a literature review, this study has compiled nearly a hundred articles on digital maturity models and frameworks. A digital maturity model serves as a framework to assess an organization's current digital maturity level and assist in planning its DT journey (Deloitte, 2018). Only articles from peer-reviewed journals with dimensions validated through research were considered for analysis. In total, 21 articles were collected for the study.

Table 1 presents a summary of the models/frameworks and their corresponding dimensions/actions. The analysis highlights the four most commonly used dimensions/action fields, namely technology (15), people (13), strategy (13), and organization/structure (12).

Table 1 Comparison of Existing Digital Transformation Models and Frameworks (own illustration)

No.	Article focus	Author(s)	Strategy	Organization/Structure	Customer/User	Ecosystem/Value Chain	Operations	Technology	Innovation	Leadership	Products	Culture	People (Capabilities/skills)	Governance	Transformation Management	Cloud & Data	Insights	Process	Monitoring & Control	Digital Marketing	Digital Business Development	Value	Final Aspects	Decision-making	Competitors	Insights	Actions	Results	Corporate Standard
1	Digital maturity model for telecommunications service providers	Valdez-De-Leon (2016)	■	■	■	■	■	■	■																				
2	Digital transformation framework	Bumann & Peter (2019)	■	■	■			■				■	■																
3	Maturity model for industry 4.0 readiness & maturity	Schumaker, Erol & Sihn (2016)	■		■		■	■		■	■	■	■	■															
4	Structuring digital transformation	Gimpel et al. (2018)	■	■	■	■	■			■					■	■													
5	The digital maturity model 4.0	Gill & Vanboskirk (2016)	■	■				■				■				■	■												
6	Maturity model for assessing the digital readiness of manufacturing companies	De Carolis, Macchi, Negri, & Terzi (2017)		■				■										■	■										
7	Action fields of digital transformation	Peter (2017)			■			■		■		■				■		■			■	■							
8	Organisational agility maturity model	Gunsberg et al. (2018)	■	■					■	■		■	■																



9	Aligning the organisation for its digital future	Kane, Palmer, Nguyen Phillips, Kiron & Buckley (2016)	
10	Company readiness evaluation for digital business transformation	Isaev et a. (2018)	
11	Dimensions in digital transformation strategy	Matt, Hess, & Benlian (2015)	
12	Digital business transformation model	Ismail, Khater & Zaki (2018)	
13	Government digital transformation projects	Hafseld, Hussain & Rouzy (2021)	
14	Domains of digital transformation	Matthias (2020)	
15	Deloitte digital maturity model	Neote, Lambourne & Campbell (2021)	
16	Essential components of digital transformation	Chamorro-Premuzic (2021)	
17	Digital transformation capability maturity model	Gökalp & Martinez (2021)	
18	Digital maturity model	Aslanova & Kulichkina (2020)	
19	Industry 4.0 maturity model for manufacturing enterprises	Schumaker, Nemeth & Sihn (2019)	
20	Assessing the maturity model of Industry 4.0 in the banking sector	Bandara, Vidanagamachchi & Wickramarachchi (2019)	
21	Digital maturity model	Newman (2020)	
		Total	13 12 9 6 7 15 6 7 3 8 13 2 1 9 1 5 1 1 1 1 1 1 1 1 1 1

As indicated by the comparative analysis, four dimensions are prominent in the potential universal cross-industry DT framework. This study identifies the dimensions of transformative organization and operation (OO), digital technology and data analysis (TD), digital business strategy and leadership (SL), and human resource capabilities and culture (HRC).

McKinsey (2021) asserts that companies can utilize digital technology and data analytics to promote sustainable practices and enhance ESG performance. Digital technologies enable transparency and accountability in reporting ESG-related information (Wang, Song, & Xue, 2023). Niu, Park, & Jung (2022) discovered that companies can enhance organizational sustainability by proactively adapting to changing environments through the application of ESG management strategies under strong digital leadership. Jorgji et al. (2024) contend that companies that invest in sustainable human capital management practices, such as training expenses, workforce diversity and inclusion, and employee benefits, are more likely to achieve favorable ESG outcomes. Meanwile, Sassen, Hinze, & Hardeck (2016) have stressed the importance of an innovative organizational culture which promotes ESG initiatives, in generating fresh ideas, building knowledge, and positioning the company as a leader in global markets. Friede, Busch, & Bassen (2015) claim that an innovative culture among organizational members should be accompanied by changes in the company's structure to embrace new developments and advance ESG management. Therefore, the following hypotheses are proposed:

H1a: Transformative organization and operation is positively related to ESG ratings.

H1b: Digital technology and data analysis is positively related to ESG ratings.

H1c: Digital business strategy and leadership is positively related to ESG ratings.

H1d: Human resource capabilities and culture is positively related to ESG ratings.

Green innovation is frequently cited as having two primary dimensions: green product innovation (Kammerer, 2009) and green process innovation (Qi, Zeng, Li, & Tam, 2012). Burki, Ersoy, & Dahlstrom (2018) proposed green management innovation as a new dimension of GI. This study specifically focuses on green management innovation and green process innovation (Junaid, Zhang, & Syed, 2022), while excluding green product innovation as not all companies can pursue green product innovation; this capability is often determined by the nature of a company's products.

During the process of DT, the improved company environmental information transparency boosts stakeholders' positive expectations and has positive effects on corporate green innovation through beneficial information and resource feedback (Hu, Zhang, Ji, &

Zhang, 2023). Digital technology enhances GI performance through effects such as green technology upgrading, cost reduction, and optimized green resource allocation (Zhao & Qian, 2024). The primary objective of digital business strategy and leadership, as articulated by Mittal & Dhar (2016), is to empower employees with a clear vision, inspiration, and motivation, fostering their development to achieve organizational goals while encouraging the acquisition and application of new knowledge in green processes and product innovation (Le & Lei, 2018; Han, Seo, Li, & Yoon, 2016). This approach not only facilitates the successful market launch of eco-friendly products and services (Andriopoulos & Lewis, 2010), enhancing environmental performance (Dranev, Izosimova, & Meissner, 2018; Martinez-Conesa, Soto-Acosta, & Carayannis, 2017), but also signals strong development prospects to external stakeholders, attracting the additional investments (Xie, Ye, Zhong, & Wan, 2024) vital for green innovation. HRM (human resource management) practices that foster a culture of commitment, rather than mere compliance, positively influence corporate innovation orientation (Verburg, Den Hartog, & Koopman, 2007), while strategic alignment of HRM with innovation goals, as per the RBV, enhances innovation capabilities, though their impact on administrative and process innovation remains less significant compared to product and technological innovation (Seeck & Diehl, 2017).

Therefore, this study proposes the following hypotheses:

H2a: Transformative organization and operation is positively related to green innovation.

H2b: Digital technology and data analysis is positively related to green innovation.

H2c: Digital business strategy and leadership is positively related to green innovation.

H2d: Human resource capability and culture is positively related to green innovation.

Given the significant investment required for GI and the potential for higher uncertainty (Polzin & Sanders, 2020), various sectors are striving to accelerate the pace of low-carbon innovation. Previous studies (Kratzer, Meissner, & Roud, 2017; Lin, Tan, & Geng, 2013; de Burgos-Jiménez, Vázquez-Brust, Plaza-Úbeda, & Dijkshoorn, 2013) have suggested that GI should not be seen merely as a response to external pressure but as an active organizational strategy to enhance environmental performance. Drawing on the RBV and KM, this study predicts that GI is an essential organizational resource for improving environmental performance and achieving key business objectives. Therefore, this study proposes the hypothesis:

H3: GI mediates the relationship between DT and corporate ESG rating.

This study contributes significantly to knowledge by integrating and applying various theoretical frameworks, namely resource-based theory, stakeholder theory, and sustainable development theory, in the study of the relationship between digital transformation (DT), green innovation (GI), and environmental, social, and governance (ESG) performance in the context of Industry 5.0.

First, regarding resource-based view theory (RBV), which conceptualizes digital transformation as a strategic resource that enhances a firm's dynamic capabilities, this study allows for development of the theory by identifying specific dimensions of digital transformation (DT) (such as strategic leadership and HR capabilities). This demonstrates how digital capabilities contribute to sustainability outcomes through green innovation, helping to narrow the gap between IT capabilities and non-financial performance indicators such as ESG rankings.

Second, we consider the stakeholder theory perspective that ESG performance is not only a result of internal operations, but also a response to pressures and expectations from a variety of stakeholder groups. The inclusion of ESG as a dependent variable suggests that digital and green innovation strategies play a role in aligning organizational performance with

stakeholder demands for transparency, accountability, and sustainability in long-term value creation.

Thirdly, sustainable development theory is used to address the broader societal imperatives of the Industry 5.0 transition, in which technological advances must be balanced with environmental sustainability and human-centered values. This study supports this discourse by empirically demonstrating that innovation-driven and sustainability-aligned digital strategies are positively associated with ESG performance, underscoring the role of technology as a mediator not only of performance but also of responsible corporate behavior.

In conclusion, this study extends theoretical understanding by positioning green innovation as a mediating mechanism and provides an empirical examination of how strategic digital transformation helps companies meet evolving sustainability expectations. It also supports the connection between theory and practice by offering a structural framework that scholars and practitioners can use to align technology investments with ESG goals in the Industry 5.0 era.

3. METHODOLOGY

3.1 Data Collection

Referring to the industry classification results of listed companies in the first half of 2023 as conducted by the China Association of Listed Companies, there are a total of 3,452 Chinese manufacturing firms listed on the Shanghai Stock Exchange and Shenzhen Stock Exchange. This study identifies all 3,452 of these listed firms from 2010 to 2022 as the research population. The decision to start the research sample in 2010 is based on the rapid development of China's digital economy since 2010 (Wang, Yang, He, & Liao, 2023). Referring to Yamane's (1973) sampling formula, with e = 0.05, results in an appropriate sample size of 360.

$$n = \frac{N}{1 + N(e^2)} = \frac{3452}{1 + 3452(0.05^2)} \approx 360$$

Actual data utilized in this study consist of panel data from 4,680 firm-year observations of 360 firms over the 13-year period, where these observations are stored across firms over time. The panel regression of the fixed effect model (FEM) and random effect model (REM) methodology is specifically designed for this structure, allowing control for unobservable differences between firms, such as firm-specific governance patterns or regional regulation, that do not change over time. Stata 14.0 software was used to complete the regression and test the relevant models (Zhou, Liu, & Luo, 2022). Table 2 provides a summary of the key variables in the study, along with their definitions.

Table 2 Summary of Variables

Variable	Measurement	Source
Environmental, social, and governance (ESG)	The CSI ESG rating, where AAA rating = 9, C rating = 1.	CSI ESG rating system, 2022
Transformative organization and operation (OO) Digital technology and data analysis (TD) Digital business strategy and leadership (SL)	The sum of keywords frequency statistics from the listed companies'	The official websites of Shenzhen Stock

Human resource capabilities and culture (HRC)	annual reports (see Appendix A).	Exchange and Shanghai Stock Exchange, 2022
Green Innovation (GI)	The number of green patent applications for inventions and utility models of a listed company.	The China National Intellectual Property Administration, 2022
Low-Carbon City Pilot Policy (LCCP)	A dummy variable where 1 = a firm locates in a low-carbon city in the given year; 0 = a firm does not locate in a low-carbon city in the given year.	The National Development and Reform Commission, 2022

3.2 Methods

To test the hypotheses proposed above, this study first establishes relationship models for the impact of the four dimensions of DT (OO, TD, SL, and HRC) on ESG performance and green innovation, respectively. Following the three-step method proposed by Baron & Kenny (1986) to test the mediating effect, the green innovation variable was added to the latter model, and changes in regression results were observed to verify the mediating effect.

Based on the above analysis, this study uses the following model to verify hypotheses H1a to H1d, which examine the influence of the four dimensions (OO, TD, SL, and HRC) of DT on corporate ESG performance, using the following equation:

$$ESG_{i,t} = \alpha_1 + \beta_1 OO_{i,t} + \beta_2 TD_{i,t} + \beta_3 SL_{i,t} + \beta_4 HRC_{i,t} + \beta_5 LCCP_{i,t} + \varepsilon \quad \text{Eq. (1)}$$

Second, equation 2 was constructed to test hypotheses H2a - H2d respectively, namely the relationships between the four dimensions of DT (OO, TD, SL and HRC) and GI.

$$GI_{i,t} = \alpha_2 + \beta_6 OO_{i,t} + \beta_7 TD_{i,t} + \beta_8 SL_{i,t} + \beta_9 HRC_{i,t} + \beta_{10} LCCP_{i,t} + \varepsilon \quad \text{Eq. (2)}$$

Third, this study follows Zhou et al. (2022) and Baron & Kenny's (1986) in testing the mediating effect of GI on the relationship between DT and corporate ESG rating. Green innovation (GI) is hypothesized to mediate the relationship between digital transformation (DT) and ESG performance by acting as a strategic resource, similar to what Zhou et al. (2022) identified as a channel linking ESG to firm value. DT enhances operational transparency and efficiency, thus promoting GI, which results in stronger ESG outcomes aligned with sustainability goals. The changes of regression results were observed again to verify the mediating effect, using the following equation:

$$ESG_{i,t} = \alpha_3 + \beta_{11} OO_{i,t} + \beta_{12} TD_{i,t} + \beta_{13} SL_{i,t} + \beta_{14} HRC_{i,t} + \beta_{15} GI_{i,t} + \beta_{16} LCCP_{i,t} + \varepsilon \quad \text{Eq. (3)}$$

The methodology used allows this study to contribute significantly to empirical research on digital transformation and sustainability by applying a longitudinal panel data design with fixed effects model (FEM) and Baron and Kenny's (1986) mediation test on a large sample of listed manufacturing companies in China over a 13-year period (2010–2022). This robust quantitative design addresses a major gap in the literature, as most previous studies have

used cross-sectional data or limited time frames, which lack the ability to detect dynamic changes and causal patterns over time.

The use of panel data enhances the internal validity of the findings by controlling for time-invariant firm-specific differences (such as industry effects, organizational culture). The use of a fixed effects model (FEM), selected after appropriate Hausman tests, ensures that the estimates reflect within-firm variability rather than cross-sectional differences, strengthening the causal interpretation. This approach provides a deeper understanding of how changes in digital transformation strategies within the same firm affect ESG outcomes over time. This is a detail that a cross-sectional design cannot account for.

Another strength of the research methodology lies in the implementation of digital transformation across four dimensions: transformative organization and operation (OO), digital technology and data analysis (TD), digital business strategy and leadership (SL), and human resource capabilities and culture (HRC). This separation allows for a deeper analysis of how specific strategic and technological aspects of DT relate to green innovation and ESG performance. Rather than viewing DT as a holistic construct, this multidimensional modeling increases the precision with which we identify the different aspects of DT that drive sustainability and innovation outcomes, enabling greater insights for executives and policymakers.

Using Baron and Kenny's (1986) three-step approach, this article tests the mediating effect of green innovation (GI) on the relationship between DT and ESG. The study identifies an indirect path which explains how DT capabilities affect ESG performance by incorporating GI, measured by green patent filings. This mediation analysis increases theoretical clarity by revealing causal mechanisms. It shows that DT improves ESG not only directly but also indirectly through GI. This analysis advances empirical modeling in sustainability research by explicitly testing partial mediation.

The study's large sample size and long time-horizon which utilizes a dataset covering 4,680 company-year observations across 360 companies from 2010 to 2022 increases statistical power and enables reliable identification of long-term trends in ESG performance. The long time-horizon is particularly valuable for assessing sustainability-related outcomes, which often take several years to materialize, increasing the reliability and relevance of the results.

Therefore, the analytical methodology of this study demonstrates the rigor by combining panel econometric data, multidimensional structural analysis, and mediation modeling, establishing a strong benchmark for future empirical studies on the link between digital transformation and sustainability.

4. RESULTS AND DISCUSSION

4.1 Statistical Results

The descriptive statistical analysis of this study is presented in Table 3. It is evident that none of the sample corporations achieved the AAA level, which is scored as 9 in this study. The data ranges for the four dimensions are close together, but the means for DT (lowest) and HRC (highest) differ, indicating that most of the sample corporations do not actively engage in transformative activities related to DT, but show a high level of passion for HRC.

Table 3 Variable descriptions

VARIABLE	OBS.	MEAN	STD. DEV.	MIN.	MAX.
VARIABLES					
ESG	4680	4.205	1.062	1	8

OO	4680	13.312	11.180	0	154
TD	4680	8.801	29.787	0	364
SL	4680	19.273	23.938	0	313
HRC	4680	68.289	50.390	0	551
GI	4680	8.157	32.664	0.2	951
CONTROL VARIABLE					
LCCP	4680	0.506	0.500	0	1

Table 4 displays the correlation matrix among the independent and control variables. These findings suggest that there are no high correlations among the variables. Additionally, Table 4 indicates that the variance inflation factor (VIF) for each variable is less than 2, indicating the absence of multidisciplinary issues.

Table 4 Correlation matrix

	ESG	**OO**	**TD**	**SL**	**HRC**	**GI**	**LCCP**
ESG	1						
OO	-0.0349**	1					
TD	0.0580***	0.0349**	1				
SL	0.1074***	0.0905***	0.4673***	1			
HRC	0.1160***	0.1165***	0.1707***	0.3292***	1		
GI	0.1216***	0.0117	0.1762***	0.2567***	0.0872***	1	
LCCP	-0.0061	0.0651***	0.1455***	0.1924***	0.1854***	0.1259***	1
COLLINEARITY (VIF)		1.10	1.82	1.79	1.34	1.24	1.09

Note: * p < 0.1, ** p < 0.05, *** p < 0.01.

The Levin-Lin-Chu (LLC) panel unit root test was conducted to assess the stationarity properties (Levin, Lin, & Chu, 2002) of both ESG ratings and GI indices. The analysis utilized a balanced panel of 360 manufacturing firms with annual data spanning 13 years (2010-2022; N = 360, T = 13). The results demonstrate strong rejection of the unit root null hypothesis at the 1% significance level: the adjusted test statistics for ESG and GI were -45.65 ($p < 0.001$) and -42.30 ($p < 0.001$) respectively. Consistent with LLC asymptotes requiring $N/T \rightarrow 0$, the large cross-sectional dimension relative to the time periods (360 > 13) suggests reliable inference. These findings confirm stationarity requirements for subsequent panel data analyses.

4.2 Panel Regression

Results of the Hausman specification test (χ^2 (5) = 24.59, p = 0.0002) decisively reject the null hypothesis of orthogonality between firm effects and regressors at the 1% significance level, necessitating the use of fixed effects estimation (Hausman, 1978). The test detected systematic differences in coefficients for five key parameters between fixed and random effects specifications.

The results of the main effect regression analysis are summarized in Table 5, Model 1. It can be observed that the three dimensions of DT (OO, SL and HRC) are significantly related to ESG rating. Specifically, OO is significantly and negatively related to ESG rating (β = -0.0040, SE = 0.0014), while SL (β = 0.0039, SE = 0.0008), and HRC (β = 0.0025, SE = 0.0003) are significantly and positively related to ESG rating. Surprisingly, TD absolutely has no significant relationship with ESG rating. Therefore, hypotheses 1a and 1b are not supported, while hypotheses 1c and 1d are.

The results for Model 2, shown in Table 5 indicate that the three dimensions of DT (OO, TD and SL) are significantly associated with GI. Specifically, OO has a significant negative association, while TD and SL have significant positive associations with GI. HRC statistically has no significant relationship with GI. Thus, **hypotheses 2b and 2c are supported**, while hypotheses 2a and 2d are not supported.

As shown in Table 5, the results demonstrate partial mediation through GI, evidenced by persistent direct effects of DT drivers in both the initial (Model 1: OO β = -0.0040***, SL β = 0.0039***) and mediated models (Model 3: OO β = -0.0037***, SL β = 0.0030***), with GI exhibiting significant mediation (β = 0.0034***). The attenuated coefficients indicate GI accounts for 7.5% of the total effect ([(-0.0040) - (-0.0037)]/-0.0040) for OO and 23.1% for SL ([0.0039-0.0030]/0.0039), confirming complementary pathways per partial mediation criteria (Zhao et al., 2010). This dual-channel mechanism persists under firm fixed effects and after controlling for LCCP.

Table 5 Comparison of regression results of the models

	MODEL 1	**MODEL 2**	**MODEL 3**
	ESG	**GI**	**ESG**
OO	-0.0040***	-0.0706*	-0.0037***
	(0.0014)	(0.0424)	(0.0014)
TD	0.0003	0.0711***	-0.0001
	(0.0006)	(0.0175)	(0.0006)
SL	0.0039***	0.2773***	0.0030***
	(0.0008)	(0.0233)	(0.0008)
HMC	0.0025***	-0.0166	0.0025***
	(0.0003)	(0.0104)	(0.0003)
GI			0.0034***
			(0.0005)
LCCP	-0.0813***	4.8017***	-0.0975***
	(0.0318)	(0.9526)	(0.0317)
CONSTANT TERM	4.0507***	1.8287*	4.0445***
	(0.0361)	(1.0796)	(0.0359)
NO. OF OBS.	4680	4680	4680
F-STATISTICS	22.73***	60.56***	27.36***
R^2	0.0238	0.0610	0.0340
MODEL	FEM	FEM	FEM

Note: i.*p < 0.1, ** p < 0.05, *** p < 0.01.
ii. FEM is the fixed effects model.

As shown in Table 5, the F-statistic for model 3 is 27.36 (p < 0.001), suggesting that the variables (OO, TD, SL, HMC, GI, and LCCP) are collectively significant in predicting ESG. For ESG, the results of Model 3 show similar results to Model 1, with OO negatively impacting ESG (β = -0.0037, p < 0.01), and both SL and HRC having positive effects (β = 0.0030, p < 0.01; β = 0.0025, p < 0.01, respectively). GI is also shown to positively influence ESG (β = 0.0034, p < 0.01).

The study findings reveal the differential impact of different dimensions of digital transformation (DT) on corporate ESG performance, which has both theoretical and practical implications as follows:

1. Among the four dimensions of DT, digital business strategy and leadership (SL) and human resource capabilities and culture (HRC) show positive and statistically significant impacts on ESG rankings, indicating that companies with visionary leadership and skilled and adaptive human capital are more likely to align their operations with ESG principles. These

results reinforce the importance of strategic intent and employee competencies in driving sustainability performance in the Industry 5.0 era.

However, transformative organization and operation (OO) shows a significant negative relationship with ESG rankings, which may reflect a potential misalignment between operational restructuring and ESG objectives. This could be due to short-term cost reductions, process automation, or efficiency-focused changes that impact social or environmental responsibility. Digital technology and data analysis (TD) does not show a significant direct impact on ESG rating, indicating that the adoption of digital tools alone, without alignment with human strategy or integration, may not lead to better ESG outcomes.

2. Green innovation (GI), measured by green patent filings, has a positive and significant impact on ESG performance. A mediation analysis using Baron & Kenny (1986) supports the partial mediation of the relationship between DT and ESG, by GI. These findings highlight the mechanistic role of GI in transforming digital strategies, particularly those driven by leadership vision, into measurable sustainability outcomes. Digital transformation alone is not enough; it must be driven by innovation and aligned with sustainability to have a positive impact on ESG rating.

Therefore, this study found that two dimensions of digital transformation, namely, digital business strategy and leadership (SL) and human resource capabilities and culture (HRC), have a positive and significant impact on ESG performance, while organizational operations (OO) has a significant negative impact, and digital technology and data analysis (TD) has no significant impact. Furthermore, green innovation (GI) significantly improves ESG rating, partially mediating the relationship between DT and ESG rating, especially SL and OO. These findings highlight the important role of leadership-driven and innovation-driven strategies in enhancing corporate sustainability under Industry 5.0.

4.3 DISCUSSION

4.3.1 Relationship between Digital Transformation and ESG Performance during 2010-2022

The findings shown in Table 5 indicate that two dimensions of DT (SL and HRC) have positive relationships with corporate ESG rating (H1c and H1d). In contrast, OO is shown to have a negative impact on corporate ESG rating (H1a), while TD has no relationship with ESG rating. Niu et al. (2022) concluded that the synergy between digital leadership and ESG management is crucial in fostering organizational innovation and sustainability by integrating digital strategies with ESG practices, thereby enhancing corporate adaptability to changing environments and stakeholder expectations. Kong et al. (2024) and Jorgji et al. (2024) both stressed the importance of strategic employee initiatives in enhancing corporate ESG performance. Meanwhile, Kong et al. (2024) suggested that tailored employee incentives can boost ecological engagement, and Jorgji et al. (2024) emphasized that prioritizing sustainable human capital management practices such as training, diversity, and benefits, leads to stronger ESG outcomes. Our findings showed that SL and HRC contribute to increasing corporate ESG rating, which is consistent with the existing literature.

The study by Perez Baez & Remond (2022) emphasizes that ESG integration has been a significant driver of organizational change, necessitating adaptations in organizational structures and strategies to address emerging ESG requirements. However, the findings of this study reveal that transformative organizational practices and operations have a significant negative impact on corporate ESG rating (H1a). This discovery contradicts Friede et al. (2015), who proposed that fostering an innovative culture with appropriate organizational adjustments enhances ESG management.

To address this discrepancy, the study conducted by Yang & Han (2024) offers valuable insights. They found that DT has an inverted U-shaped effect on ESG performance, where moderate levels of transformation improve ESG outcomes, but excessive transformation can introduce conflicts and increase costs, ultimately harming ESG performance. This suggests that in manufacturing, where DT is complex and resource-intensive, excessive changes in organizational structure may lead to inefficiencies and conflicts that counteract the potential benefits for ESG performance.

In China's manufacturing sector, the relationship between transformative organizational shifts and ESG performance is complex. Industry, a cornerstone of the economy, is environmentally sensitive, and faces challenges in balancing innovation, operational stability, and sustainability, amidst digital transformation (DT). Initiatives such as "Made in China 2025" and global calls for decarbonization drive modernization, but research warns of the potential negative impacts of excessive transformation on ESG performance. Yang & Han's (2024) theory of an inverted U-shaped curve is particularly pertinent here. In China's intricate manufacturing landscape, this could undermine the intended benefits of DT. Rapid DT can exacerbate these challenges, increasing management costs, control issues, and principal-agent problems, ultimately undermining ESG progress. Therefore, manufacturers need to adopt a cautious approach, carefully managing change, ensuring organizational preparedness, and prioritizing long-term sustainability.

The findings of this study reveal that whether companies adopt new digital technologies or not, does not influence ESG performance. This finding contradicts Feroz, Zo, & Chiravuri (2021) and Wang et al.'s (2023) suggestion that integrating digital technologies into ESG initiatives enhances transparency, accountability, and environmental stewardship in business operations. Targeting the Chinese manufacturing sector, this result may be due to the following reasons. First, technology and data analytics' may have a lagging impact on ESG, requiring time to translate into improvements. Second, varying levels of technology adoption maturity across companies obscure the overall trend. Third, not all digital technologies are equally effective, and some may require other management practices to achieve the desired impact. For instance, IoT helps reduce waste in manufacturing but may be less effective in standardized beverage production where supply chain and water management are key. Lastly, external factors such as the macroeconomy, policy changes, and societal focus on ESG can also obscure the impact of digital technologies.

In conclusion, DT is essential for China's manufacturing sector, but it must be pursued carefully. The negative correlation between excessive change and ESG factors highlights the importance of finding a balance. Emphasizing sustainable, gradual improvements over radical transformations is key. This strategy allows for both modernization and sustainability, ultimately safeguarding long-term competitiveness.

4.3.2 The Mediating Effect of Green Innovation on the Relationship of Digital Transformation and ESG Performance

This study supports the mediating effect of green innovation on the relationship between DT and ESG performance (H3). The findings suggest that DT can significantly drive green innovation within a business, leading to improved ESG outcomes (H3). These results are consistent with earlier studies, such as those by Wu & Hua (2021), which emphasize that green innovation focuses on enhancing the utilization of natural resources and reducing environmental pollution through technological advancements, product upgrades, and process innovations. Additionally, Weng et al. (2015) found that such innovations in green products and processes can enhance corporate financial, environmental, and social performance by reducing waste and costs.

Specifically, the results in Table 5 indicate that green innovation partially mediates OO and SL by 7.5% and 23.1% respectively. The finding about SL is consistent with several existing studies. Le & Lei (2018) and Han et al. (2016) found that digital business strategy and leadership motivate employees to acquire and integrate new knowledge into environmentally friendly processes and product innovation. Another dimension OO, may have a negative impact on GI, particularly when the focus is on rapid structural change or efficiency-driven transformations that prioritize short-term financial performance over long-term sustainability. In China's manufacturing industry, OO's negative impact on GI can be significant. Companies often prioritize rapid modernization, automation, or expansion, sometimes neglecting environmental concerns. This can lead to higher energy use, waste, and reduced investment in sustainable tech. Supply chain changes might also disrupt green practices, causing firms to select less eco-friendly suppliers. While transformation drives efficiency, it may hinder green innovation if environmental goals are deprioritized. Balance between transformation and sustainability is crucial for long-term ESG success.

For the dimension of human resource capabilities and culture (HRC), the findings show that green innovation has no mediating effect on the relation of HRC to ESG rating. That means the HRC can enhance the manufacturing sectors' ESG rating, but not through green innovation. This finding contradicts with earlier studies suggesting that strategic human resource management positively impacts product innovation in organizations with a developmental culture and flat organizational structures (Wei et al., 2011). HRC in China's manufacturing struggles to promote green innovation due to lack of environmental training, resistance to change, misaligned incentives, and focus on short-term gains. Alignment with sustainability objectives is needed to encourage green innovation.

In the context of China's manufacturing industry, these findings have significant implications. As the backbone of China's economy, the manufacturing sector faces immense pressure to innovate while also meeting stringent environmental standards. The integration of digital transformation and green innovation can serve as a crucial pathway for manufacturing firms to enhance their ESG performance. By cultivating strong leadership, Chinese manufacturers can significantly reduce their environmental impact and improve operational efficiency. Reducing radical and short-term corporate structural reforms, and aiming for long-term sustainable corporate development and gradual reforms may be more suitable for China's manufacturing enterprises to improve their green innovation and ESG ratings. Therefore, the findings of this study underscore the importance of strategically managing digital transformation to maximize its positive impact on green innovation and, consequently, on ESG performance across China's manufacturing landscape.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study examined the relationship between DT and ESG rating, and investigated the mediating effect of GI in the relationship between DT and ESG rating, using 360 Chinese manufacturing firms listed on the Shanghai Stock Exchange and Shenzhen Stock Exchange from 2010 to 2022. The independent variables were the four dimensions of DT, including transformative organization and operation (OO), digital technology and data analysis (DT), digital business strategy and leadership (STR), and human resource capability and culture (HRC). ESG was the dependent variable, and green innovation was a mediator, while the low-carbon city pilot policy was used as a control variable. The main findings of this study, with specific implications for China's manufacturing industry, are as follows: three dimensions of

DT were found to be significantly related to corporate ESG rating. Specifically, SL and HRC were shown to have positive relationships with ESG rating, suggesting that Chinese manufacturing companies can enhance their sustainability performance through strategic investments in these areas. However, OO was shown to have a negative relationship with ESG rating, indicating that extensive organizational changes might introduce complexities that could hinder ESG performance, particularly in an industry as intricate as manufacturing. Meanwhile, the mediating effect of GI was confirmed, meaning that green innovation significantly mediates the relationship between DT and ESG rating. For China's manufacturing sector, fostering GI through DT is crucial for achieving both economic and environmental objectives, positioning firms to meet both domestic and international sustainability standards.

This study contributes to existing knowledge by providing empirical evidence on how specific dimensions of digital transformation (DT) influence environmental, social, and governance (ESG) performance in the context of Industry 5.0. Dividing DT into four dimensions: organizational performance, technology adoption, strategic leadership, and human capital capability, provides a deeper understanding of how digital capabilities impact sustainability outcomes. This study highlights the role of green innovation (GI) as an important mechanism through which DT, particularly leadership and organizational change, lead to better ESG assessments. The study also agrees that green innovation (GI) plays a mediating role, particularly in the link between SL and ESG, underscoring the importance of innovation-driven strategies in achieving sustainability goals. By highlighting the crucial role of leadership, human capital, and innovation pathways, in leveraging digital transformation for ESG advancement, this study extends beyond traditional frameworks of digital transformation. This study demonstrates that not all digital efforts are equally conducive to ESG success. The study contributes to both theoretical and practical understanding of how a digital strategy aligned with innovation and sustainability can drive responsible business performance in the emerging Industry 5.0 model.

The results of this study offer both theoretical and managerial implications. Firstly, concerning the theoretical aspects, we introduce a new digital transformation framework that is grounded in resource-based and knowledge management theories. This framework bridges gaps in the existing literature on the concepts of GI, DT, and ESG (Esposito & Ricci, 2021). This study also answers Guandalini's (2022) call for more in-depth sustainability research through DT, with a specific focus on management practices. This research makes a significant theoretical contribution by utilizing keyword frequency analysis (KFA) to examine the annual reports of listed manufacturing companies in China. From a managerial perspective, this study presents a holistic view of ESG performance, providing guidance to manufacturers on leveraging DT for sustainable practices and enhancing ESG rating. It also offers practical advice on GI, helping to align with national environmental objectives. The policy implications highlight the necessity for government support to incentivize sustainable DT strategies, thereby promoting environmental stewardship and enhancing global competitiveness within China's manufacturing sector.

5.2 Limitations

The limitations of the study are related to the need for refinement of the framework and the limited sample size, which limits the diversity of industries studied. Despite its great usefulness, this study suffers from several limitations. First, the analysis is limited to listed manufacturing companies in China, which may limit the generalizability of the findings to other industries or international contexts with different regulatory environments, ESG frameworks, or levels of digital maturity. Second, the use of secondary data sources, such as ESG rating and green patent filings, may not fully capture the depth and nuances of an organization's

sustainability practices or innovation outcomes. Third, while panel regression methodology (FEM/REM) effectively controls for firm-specific effects over time, it does not take into account latent variables or the complex relationships between constructs, which may be better measured using methods such as structural equation modeling (SEM). Finally, this study focuses only on the quantitative measure of green innovation (via the number of patents), which may overlook the qualitative dimensions of green practices, such as organizational learning, stakeholder engagement, or eco design strategies.

5.3 Recommendations for Future Research

Future research should aim to enhance the framework by incorporating additional dimensions and perspectives, as well as expanding the scope by conducting comparative studies across manufacturing industries in other countries, such as Thailand and Vietnam; or conducting comparative analyses in other industries, such as finance, healthcare, and retail.

Although this study used panel regression modeling (FEM/REM) to examine the causal relationship between digital transformation (DT), green innovation (GI), and ESG performance over time, future research could benefit from the application of structural equation modeling (SEM) or path analysis to further explore theoretical validity and structural insights. SEM is ideal for analyzing complex causal models, as it can simultaneously assess direct and indirect effects, test mediation paths, and analyze measurement error by incorporating latent variables. Applying SEM to future studies would allow for a more holistic examination of how different dimensions of DT influence ESG outcomes via GI, while also capturing unobservable factors such as organizational culture, innovation capability, or stakeholder engagement that are difficult to directly measure. SEM also allows for model fit assessment and hypothesis testing in both cross-sectional and multi-level studies, making it an appropriate approach for developing conceptual models that go beyond the scope of traditional regression techniques.

ACKNOWLEDGEMENTS

This study project was financially supported by Mahasarakham University, Thailand. Further¬more, GuangZhou Polytechnic University Social Science Project, China (2025SK02); Guangdong Province General Higher Characteristic Innovation Project, China (2021WTSCX206); and Guangzhou Philosophy and Social Science Planning Project, China (2022GZYB12).

REFERENCES

Andriopoulos, C., & Lewis, M. W. (2010). Managing innovation paradoxes: Ambidexterity lessons from leading product design companies. *Long Range Planning, 43*(1), 104–122. https://doi.org/10.1016/j.lrp.2009.08.003

Ardito, L., Raby, S., Albino, V., & Bertoldi, B. (2021). The duality of digital and environmental orientations in the context of SMEs: Implications for innovation performance. *Journal of Business Research, 123*, 44-56. https://doi.org/10.1016/j.jbusres.2020.09.022

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology, 51*(6), 1173–1182. https://doi.org/10.1037/0022-3514.51.6.1173

Burki, U., Ersoy, P., & Dahlstrom, R. (2018). Achieving triple bottom line performance in

manufacturer–customer supply chains: Evidence from an emerging economy. *Journal of Cleaner Production, 197*, 1307–1316. https://doi.org/10.1016/j.jclepro.2018.06.236

Chen, J., Gao, M., Mangla, S. K., Song, M., & Wen, J. (2020). Effects of technological changes on China's carbon emissions. *Technological Forecasting and Social Change, 153*, 119938. https://doi.org/10.1016/j.techfore.2020.119938

Costa, V., & Monteiro, S. (2016). Key knowledge management processes for innovation: A systematic literature review. *VINE Journal of Information and Knowledge Management Systems, 46*(3), 386–410. https://doi.org/10.1108/VJIKMS-02-2015-0017

de Burgos-Jiménez, J., Vázquez-Brust, D., Plaza-Úbeda, J. A., & Dijkshoorn, J. (2013). Environmental protection and financial performance: An empirical analysis in Wales. *International Journal of Operations & Production Management, 33*(8), 981–1018. https://doi.org/10.1108/IJOPM-11-2010-0374

Deloitte, (2018). Digital Maturity Model. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Technology-Media-Telecommunications/deloitte-digital-maturity-model.pdf

Dranev, Y., Izosimova, A., & Meissner, D. (2020). Organizational ambidexterity and performance: Assessment approaches and empirical evidence. *Journal of the Knowledge Economy, 11*(5), 1713–1728. https://doi.org/10.1007/s13132-018-0560-y

Esposito, P., & Ricci, P. (2021). Cultural organizations, digital corporate social responsibility and stakeholder engagement in virtual museums: A multiple case study. How digitization is influencing the attitude toward CSR. *Corporate Social Responsibility and Environmental Management, 28*(2), 953–964. https://doi.org/10.1002/csr.2074

Feroz, A. K., Zo, H., & Chiravuri, A. (2021). Digital transformation and environmental sustainability: A review and research agenda. *Sustainability, 13*(3), 1530. https://doi.org/10.3390/su13031530

Ferraris, A., Santoro, G., & Dezi, L. (2017). How MNCs' subsidiaries may improve their innovative performance? The role of external sources and knowledge management capabilities. *Journal of Knowledge Management, 21*(3), 540–552. https://doi.org/10.1108/JKM-09-2016-0411

Friede, G., Busch, T., & Bassen, A. (2015). ESG and financial performance: Aggregated evidence from more than 2000 empirical studies. *Journal of Sustainable Finance & Investment, 5*(4), 210–233. https://doi.org/10.1080/20430795.2015.1118917

Guandalini, I. (2022). Sustainability through digital transformation: A systematic literature review for research guidance. *Journal of Business Research, 148*, 456–471. https://doi.org/10.1016/j.jbusres.2022.05.003

Han, S. H., Seo, G., Li, J., & Yoon, S. W. (2016). The mediating effect of organizational commitment and employee empowerment: How transformational leadership impacts employee knowledge sharing intention. *Human Resource Development International, 19*(2), 98–115. https://doi.org/10.1080/13678868.2015.1099357

Hao, X., Li, Y., Ren, S., Wu, H., & Hao, Y. (2023). The role of digitalization on green economic growth: Does industrial structure optimization and green innovation matter? *Journal of Environmental Management, 325*, 116504.

https://doi.org/10.1016/j.jenvman.2022.116504

Hu, S., Zhang, C., Ji, Y., & Zhang, C. (2023). Does environmental information disclosure tone affect corporate green innovation in China? Based on the institutional perspective. *Environment, Development and Sustainability, 26*(5), 1–44. https://doi.org/10.1007/s10668-023-03782-0

Ivanov, D. (2023). The Industry 5.0 framework: Viability-based integration of the resilience, sustainability, and human-centricity perspectives. *International Journal of Production Research, 61*(9), 1–13. https://doi.org/10.1080/00207543.2022.2118892

Jabbour, C. J. C., de Sousa Jabbour, A. B. L., Sarkis, J., & Godinho Filho, M. (2017). Unlocking the circular economy through new business models based on large-scale data: An integrative framework and research agenda. *Technological Forecasting and Social Change, 144*(2), 546–552. https://doi.org/10.1016/j.techfore.2017.09.010

Jin, X., & Wu, Y. (2024). How does digital transformation affect the ESG performance of Chinese manufacturing state-owned enterprises? —Based on the mediating mechanism of dynamic capabilities and the moderating mechanism of the institutional environment. *PLOS ONE, 19*(5), e0301864. https://doi.org/10.1371/journal.pone.0301864

Jorgji, S., Teta, J., Mousa, S., Ponkratov, V., Elyakova, I., Vatutina, L., Pozdnyaev, A., Chernysheva, T., Romanenko, E., & Kosov, M. (2024). Sustainable human capital management, ESG, and firm performance: Moderating role of ESG disclosure. *Humanities and Education, 5*(2), 101–120. https://doi.org/10.28991/HEF-2024-05-02-08

Junaid, M., Zhang, Q., & Syed, M. W. (2022). Effects of sustainable supply chain integration on green innovation and firm performance. *Sustainable Production and Consumption, 30*(4), 145–157. https://doi.org/10.1016/j.spc.2021.11.031

Kagermann, H. (2017). Chancen von Industrie 4.0 nutzen. In T. Bauernhansl, M. ten Hompel, & B. Vogel-Heuser (Eds.), *Industrie 4.0 in Produktion, Automatisierung und Logistik: Anwendung · Technologien · Migration* (pp. 23–35). Springer Vieweg. https://doi.org/10.1007/978-3-662-53254-6_12

Kammerer, D. (2009). The effects of customer benefit and regulation on environmental product innovation: Empirical evidence from appliance manufacturers in Germany. *Ecological Economics, 68*(8-9), 2285–2295. https://doi.org/10.1016/j.ecolecon.2009.02.016

Kratzer, J., Meissner, D., & Roud, V. (2017). Open innovation and company culture: Internal openness makes the difference. *Technological Forecasting & Social Change, 119*, 128–138. https://doi.org/10.1016/j.techfore.2017.03.022

Kong, D., Liu, J., Wang, Y., & Zhu, L. (2024). Employee stock ownership plans and corporate environmental engagement. *Journal of Business Ethics, 189*(1), 177–199. https://doi.org/10.1007/s10551-023-05334-y

Le, P. B., & Lei, H. (2018). The mediating role of trust in stimulating the relationship between transformational leadership and knowledge sharing processes. *Journal of Knowledge Management, 22*(3), 521–537. https://doi.org/10.1108/JKM-10-2016-0463

Lee, O. K. D., Choi, B., & Lee, H. (2020). How do knowledge management resources and capabilities pay off in short term and long term? *Information & Management, 57*(2),

103166. https://doi.org/10.1016/j.im.2019.05.001

Li, W. L., Pan, W. D., & Yuan, K. B. (2022). Enterprise digital transformation and the development of China's real economy [in Chinese]. *Journal of Quantitative & Technical Economics, 39*(9), 5–25. https://doi.org/10.13653/j.cnki.jqte.2022.09.001

Lin, R. J., Tan, K. H., & Geng, Y. (2013). Market demand, green product innovation, and firm performance: Evidence from Vietnam motorcycle industry. *Journal of Cleaner Production, 40*, 101–107. https://doi.org/10.1016/j.jclepro.2012.01.001

Liu, X., Liu, F., & Ren, X. (2023). Firms' digitalization in manufacturing and the structure and direction of green innovation. *Journal of Environmental Management, 335*, 117525. https://doi.org/10.1016/j.jenvman.2023.117525

Longo, F., Padovano, A., & Umbrello, S. (2020). Value-oriented and ethical technology engineering in Industry 5.0: A human-centric perspective for the design of the factory of the future. *Applied Sciences, 10*(12), 4182. https://doi.org/10.3390/app10124182

Ma, S., & Li, C. (2020). Paradox Management in the Digital Transformation of Time-honored Enterprises: a Case of Zhanggong [in Chinese]. *China Soft Science*, (4), 184-192.

Martinez-Conesa, I., Soto-Acosta, P., & Carayannis, E. G. (2017). On the path towards open innovation: Assessing the role of knowledge management capability and environmental dynamism in SMEs. *Journal of Knowledge Management, 21*(3), 553–570. https://doi.org/10.1108/JKM-09-2016-0403

Matt, C., Hess, T., & Benlian, A. (2015). Digital transformation strategies. *Business & Information Systems Engineering, 57*(5), 339–343. https://doi.org/10.1007/s12599-015-0401-5

McKinsey. (2021). *The financial performance of ESG investing* [Report]. McKinsey & Company. Retrieved from https://www.mckinsey.com/spContent/bespoke/esg-pdf/pdfs/in/McKinsey_2021_ESG_Report_VF.pdf

Mittal, S., & Dhar, R. L. (2016). Effect of green transformational leadership on green creativity: A study of tourist hotels. *Tourism Management, 57*, 118–127. https://doi.org/10.1016/j.tourman.2016.05.007

Nahavandi, S. (2019). *Industry 5.0—A human-centric solution*. Sustainability, 11(16), 4371. https://doi.org/10.3390/su11164371

Nekhili, M., Boukadhaba, A., Nagati, H., & Chtioui, T. (2021). ESG performance and market value: The moderating role of employee board representation. *The International Journal of Human Resource Management, 32*(14), 3061–3087. https://doi.org/10.1080/09585192.2019.1629989

Ning, J., Jiang, X., & Luo, J. (2023). Relationship between enterprise digitalization and green innovation: A mediated moderation model. *Journal of Innovation & Knowledge, 8*(1), 100326. https://doi.org/10.1016/j.jik.2023.100326

Niu, S., Park, B. I., & Jung, J. S. (2022). The Effects of Digital Leadership and ESG Management on Organizational Innovation and Sustainability. *Sustainability, 14*(23), 15639. https://doi.org/10.3390/su142315639

Perez Baez, C. A., & Remond, M. A. (2022). *Environmental, social and governance (ESG) integration and organizational change: A multi-case study of investment companies*

(Master's thesis, Malmö University, Faculty of Culture and Society, Department of Urban Studies). Malmö University. https://urn.kb.se/resolve?urn=urn:nbn:se:mau:diva-52103

Polzin, F., & Sanders, M. (2020). How to finance the transition to low-carbon energy in Europe? *Energy Policy, 147*, Article 111863. https://doi.org/10.1016/j.enpol.2020.111863

Qi, G., Zeng, S., Li, X., & Tam, C. (2012). Role of internalization process in defining the relationship between ISO 14001 certification and corporate environmental performance. *Corporate Social Responsibility and Environmental Management, 19*(3), 129–140. https://doi.org/10.1002/csr.258

Santoro, G., Vrontis, D., Thrassou, A., & Dezi, L. (2018). The Internet of Things: Building a knowledge management system for open innovation and knowledge management capacity. *Technological Forecasting & Social Change, 136*, 347–354. https://doi.org/10.1016/j.techfore.2017.02.034

Sassen, R., Hinze, A. K., & Hardeck, I. (2016). Impact of ESG factors on firm risk in Europe. *Journal of Business Economics, 86*(8), 867–904. https://doi.org/10.1007/s11573-016-0819-3

Seeck, H., & Diehl, M. R. (2017). A literature review on HRM and innovation – taking stock and future directions. *The International Journal of Human Resource Management, 28*(6), 913–944. https://doi.org/10.1080/09585192.2016.1143862

Shujahat, M., Sousa, M. J., Hussain, S., Nawaz, F., Wang, M., & Umer, M. (2019). Translating the impact of knowledge management processes into knowledge-based innovation: The neglected and mediating role of knowledge-worker productivity. *Journal of Business Research, 94*, 442–450. https://doi.org/10.1016/j.jbusres.2017.11.001

Sindhwani, R., Afridi, S., Kumar, A., Banaitis, A., Luthra, S., & Singh, P. L. (2022). Can industry 5.0 revolutionize the wave of resilience and social value creation? A multi-criteria framework to analyze enablers. *Technology in Society, 68*, 101887. https://doi.org/10.1016/j.techsoc.2022.101887

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal, 18*(7), 509–533. http://www.jstor.org/stable/3088148

Verburg, R. M., Den Hartog, D. N., & Koopman, P. L. (2007). Configurations of human resource management practices: A model and test of internal fit. *The International Journal of Human Resource Management, 18*(2), 184–208. https://doi.org/10.1080/09585190601102349

Wang, J., Hong, Z., & Long, H. (2023). Digital transformation empowers ESG performance in the manufacturing industry: From ESG to DESG. *SAGE Open, 13*(4). https://doi.org/10.1177/21582440231204158

Wang, J., Song, Z., & Xue, L. (2023). Digital technology for good: Path and influence—Based on the study of ESG performance of listed companies in China. *Applied Sciences, 13*(5), 2862. https://doi.org/10.3390/app13052862

Wang, Y., Yang, R., He, K., & Liao, Y. (2023). Can digital transformation improve enterprise ESG performance? —— Research based on legitimacy theory and information asymmetry theory [in Chinese]. *Securities Market Herald*, (7), 14-25.

Weng, H.-H., Chen, J.-S., & Chen, P.-C. (2015). Effects of green innovation on environmental and corporate performance: A stakeholder perspective. *Sustainability, 7*(5), 4997–5026. https://doi.org/10.3390/su7054997

Westerman, G., Bonnet, D., & McAfee, A. (2014). Leading digital: *Turning technology into business transformation*. Harvard Business Press.

Wu, H., Hu, S., & Hu, S. (2023). *RETRACTED ARTICLE: How digitalization works in promoting corporate sustainable development performance? The mediating role of green technology innovation.* Environmental Science and Pollution Research, 30(8), 22013–22023. https://doi.org/10.1007/s11356-022-23762-7

Wu, J., & Hua, X. (2021). Top management team attention and firm green innovation strategy: Empirical evidence from listed Chinese manufacturing companies [in Chinese]. *First Science, Science and Management of S. & Trans, 42*, 122–142.

Xie, C., Ye, L., Zhong, N., & Wan, W. (2024). *Impact of digital finance on corporate green innovation: Exploring role of land resource misallocation in China*. Resources Policy, 91, 104920. https://doi.org/10.1016/j.resourpol.2024.104920

Xu, X., Lu, Y., Vogel-Heuser, B., & Wang, L. (2021). Industry 4.0 and Industry 5.0—Inception, conception, and perception. *Journal of Manufacturing Systems, 61*, 530–535. https://doi.org/10.1016/j.jmsy.2021.10.006 sciencedirect.com+2portal.fis.tum.de+2

Yamane, T. (1973). *Statistics: An introductory analysis* (3rd ed.). New York, NY: Harper & Row.

Yang, X., & Han, Q. (2024). Nonlinear effects of enterprise digital transformation on environmental, social and governance (ESG) performance: Evidence from China. *Sustainability Accounting, Management and Policy Journal, 15*(2), 355–381. https://doi.org/10.1108/SAMPJ-08-2023-0553

Yoo, Y. (2010). Computing in everyday life: A call for research on experiential computing. *MIS Quarterly, 34*(2), 213–231. https://doi.org/10.2307/20721425

Zhao, X., & Qian, Y. (2024). Does digital technology promote green innovation performance? *Journal of the Knowledge Economy, 15*(2), 7,568–7,587. https://doi.org/10.1007/s13132-023-01410-w

Zhou, G., Liu, L., & Luo, S. (2022). Sustainable development, ESG performance and company market value: Mediating effect of financial performance. *Business Strategy and the Environment, 31*(7), 3371–3387. https://doi.org/10.1002/bse.3089

Appendix A

Summary of Digital Transformation Metrics

Primary Metrics	Secondary Metrics	Tertiary Metrics-Keywords
Digital Transformation	Transformative organization and operation (OO)	Structure, Restructure, Business processes, Business Process Digitalization, Business Processes Vertical Integration, Business Processes Horizontal Integration, Data-Driven Decision Management, Quantitative Performance Management, Self-Optimized Decision Management, Business Process Integration toward Life-cycle, Quantitative Process Improvement, Organizational Structure Management, Freedom to experiment, Strong commitment, Partnerships, Eco-systems, Organization agility, Cross-functional collaboration, Corporate venturing, Innovation labs, Digital factories
	Digital technology and data analysis (TD)	Information Technology, Artificial Intelligence, Big Data, Blockchain, Internet of Things (IoT), Internet of Wisdom, Cloud Computing, 5G, Cloud Platform, Virtual Reality (VR), Augmented Reality (AR), Mixed Reality, Business Intelligence, Intelligent Data Analytics, Image Understanding, Investment Decision Aids, Intelligent Robotics, Machine Learning, Deep Learning, Semantic Search, Biometrics, Face Recognition, Voice Recognition, Identity Verification, Autonomous Driving, Natural Language Processing, Digital Currency, Distributed Computing, Differential Privacy Technology, Intelligent Financial Contracts, Stream Computing, Graph Computing, In-Memory Computing, Multi-Party Secure Computing, Brain-Like Computing, Green Computing, Cognitive Computing, Converged Architecture, Billion-Level Concurrency, Exabyte-Level Storage, Information Physical Systems, Data Mining, Text Mining, Data Visualization, Heterogeneous Data, Information Security Management

Primary Metrics	Secondary Metrics	Tertiary Metrics-Keywords
	Digital business strategy and leadership (SL)	Digitization, Digitalization, Digital Transformation, Informatization, Intelligent, Intelligent Manufacturing, Internet+, Network, Industrial Internet, Industry 4.0, Industry 5.0, Green Manufacturing, Mobile Internet, Internet Healthcare, E-commerce, Mobile Payment, Third-party Payment, NFC Payment, Intelligent Energy, Business to Business (B2B), Business to Consumer (B2C), Consumer to Business (C2B), Consumer to Consumer (C2C), Online To Offline (O2O), Intelligent Wearable, Intelligent Transportation, Intelligent Medical, Intelligent Customer Service, Intelligent Home, Intelligent Investment, Intelligent Culture and Tourism, Intelligent Environmental Protection, Intelligent Grid, Intelligent Marketing, Digital Marketing, Unmanned Retailing, Internet Finance, Net link, Fintech, Digital Finance, Quantitative Finance, Open Banking
	Human resource capabilities and culture (HRC)	Awareness of changes, Engagement, Motivation, Participation, HR Skill Development, Organizational Change Management, Sustainable Learning Management, Skill Training, Knowledge, Education, Flexible work arrangements