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Strategic Digital Transformation and Firm Sustainability under Industry 5.0: Evidence from Manufacturing Sector in China

Bifeng Ren[1], Sutana Boonlua[2*], Sumittra Jirawuttinunt[3]
[1]*Ph.D candidate, Mahasarakham Business School, Mahasarakham University, Thailand*
[2,3]*Lecturer, Mahasarakham Business School, Mahasarakham University, Thailand*
*Corresponding Author: Sutana Boonlua

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ABSTRACT

This research uses empirical data from 360 Chinese manufacturing firms listed on the Shanghai and Shenzhen stock markets to investigate the effects of strategic digital transformation on firm sustainability in the context of Industry 5.0. The research objective is to determine how strategic digital transformation (four dimensions: business transformation and operational strategy, digital intelligence and analytics, strategic digital leadership, and culture and organization development) affect ESG performance. Additionally, the research looks into the moderating influence of eco-incentive finance and the mediating role of green innovation (greenovation). Results indicate that organizational culture and strategic digital leadership significantly improve ESG outcomes, and greenovation has a beneficial impact on firm sustainability. While eco-incentive finance does not significantly alter the relationship between strategic digital transformation and firm sustainability, and neither business transformation and operational strategy nor digital intelligence and analytics demonstrate any distinct effects. These findings demonstrate how significant organizational culture and leadership are to promoting sustainable manufacturing practices. The research also emphasizes that to reach China's "dual-carbon" targets for 2030 and 2060, eco-finance laws must be implemented more strictly and digital initiatives must be in line with ESG objectives. Under the Industry 5.0 paradigm, it provides actionable advice for manufacturers and regulators on how to promote high-quality, low-carbon development through integrated digital and sustainability initiatives.

Keywords: Strategic Digital Transformation, Greenovation, ESG, Industry 5.0, China's Manufacturing Sector

INTRODUCTION

China was the world's top manufacturing country in 2022 (World Bank, 2023). The manufacturing sector's value added accounted for 27.7% of GDP in 2022, with the total value contributed of all industries surpassing 40 trillion renminbi (Yuan or RMB), or 33.2% of GDP (China National Bureau of Statistics, 2023). Regardless of the overall volume or growth rate, China's position as a significant manufacturing nation is unquestionable. The main reason why few people consider China to be a manufacturing powerhouse, despite the fact that it is the world's most recognised manufacturing nation, is that its manufacturing sector lacks the capacity to develop essential technology. The manufacturing sector, which drives the country's economic growth, performs poorly in terms of energy consumption and carbon emissions. Almost 90% of China's industrial energy usage is attributed to the manufacturing sector. China, the nation with the highest carbon emissions, is dealing with a number of issues, including low productivity, excessive resource consumption, and environmental pollution, despite its impressive manufacturing output (Li & Tang, 2019).

Major management consultancies (Deloitte & GeSI, 2019) and numerous governments (United Nations, 2020) have made the acceleration of digital and sustainability transformation a top goal. Businesses today need to think about their environmental, social, and governance (ESG) responsibilities in addition to pursuing sustainable development that goes beyond economic efficiency. ESG is a vital indicator of corporate sustainability and is an expansion and

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enhancement of the idea of socially responsible investing (SRI) (Nekhili, Boukadhaba, Nagati, & Chtioui, 2021). Businesses are integrating corporate governance, social performance, and environmental stewardship into their development processes as a result of the increasing popularity of ESG investment strategies (McKinsey, 2021). ESG assists businesses in methodically managing their governance frameworks, social obligations, and environmental effects to make sure that their growth is in line with the SDG objectives. One of the biggest consumers of resources and contributors to carbon emissions in China is the industrial sector. Against the backdrop of increasingly strict international standards for sustainable development, manufacturing companies can meet national policy and global market compliance requirements as well as lower operational risks, increase efficiency, boost brand value, and attract foreign investment by improving their ESG performance (McKinsey, 2021; Matos, 2020). As a result, studying and encouraging the use of ESG in the manufacturing sector can assist businesses in adjusting to the global trend of sustainable development and advance the high-quality, environmentally friendly growth of China's economy. As a result, ESG rating has emerged as a major motivator for businesses looking to boost their reputation, increase operational effectiveness, and obtain a competitive and sustainable advantage (Zhang, Zhang, & Managi, 2019).

Innovations in man-machine integration technologies propelled Industry 5.0, which was first presented as the chronological successor to Industry 4.0 (Longo, Padovano, & Umbrello, 2020). But according to more recent viewpoints, Industry 5.0 is a transformational trend that complements Industry 4.0 and emphasises sustainable growth (Xu, Lu, Vogel-Heuser, & Wang, 2021). The European Commission stated in a recent policy brief that Industry 4.0 by itself was no longer a sufficient foundation for resolving current socio-environmental challenges or for sustainable economic change. Scholars (Ghobakhloo, Iranmanesh, Morales, Nilashi, & Amran, 2023) have created a strategic roadmap that describes how Industry 5.0 enablers should be controlled and utilised to meet the industry's feasible goals to further the forward-looking agenda of Industry 5.0.

By making environmental preservation, human-centered methods, and resilience its primary goals, Industry 5.0 enhances and expands the advantages of Industry 4.0 (Breque, Nul, & Petridis, 2021). Extending its 2021 conceptualisation, the European Commission clarified that Industry 5.0 should encompass more than only the technological expansion of existing production and consumption economic models. Rather, Industry 5.0 ought to direct industrial transformation in the direction of sustainable development while promoting societal progress and well-being.

According to this research, Industry 5.0 is a paradigm shift in the way digital industrial transformation is managed with the goal of attaining sustainable socio-environmental and economic development. The sustainable development objective of the UN is closely matched with the present Industry 5.0 framework (European Commission, 2022). It seeks human-centered methods, environmental preservation, social progress, economic resilience, and a more just distribution of income. In fact, Industry 5.0 calls for a significant overhaul of business models, value systems, consumption patterns, and public participation in order to achieve its lofty sustainability goals (Sindhwani, Afridi, Kumar, Banaitis, Luthra, & Singh, 2022).

The necessity for corporations to engage in sustainable development and include social responsibility into their growth processes—especially in creative activities—has been underlined more and more by the global industry. Although China's economic expansion has been remarkably successful, certain enterprises' pursuit of development at the expense of these issues has had detrimental effects on the environment and society. China formally unveiled the "dual-carbon" policy in 2020, establishing the targets of reaching "carbon peak" by 2030 and "carbon neutrality" by 2060. According to the carbon peak target, China's carbon dioxide emissions are expected to peak by 2030 and then start to fall. By 2060, the carbon neutrality target seeks to achieve a net-zero carbon footprint by offsetting carbon emissions through a variety of strategies. Business attention must be directed towards both technological and responsible innovation to implement the "dual-carbon" approach. The establishment of the Bureau of Science and Technology Innovation and the Bureau of Social Responsibility by the State-owned Assets Supervision and Administration Commission of the State Council (SASAC) in 2022 served as a signal to corporations that they should incorporate social responsibility and technological innovation into their operations. Scientific and technological innovation must come before high-quality development that prioritises ecological balance and green, low-carbon growth to meet the "dual-carbon" goals (Boonlua et al., 2024).

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China's environmental performance has improved dramatically over the last 20 years as a result of the extensive usage of ICTs (Jin, Wen, & He, 2022). One may argue that China has offered invaluable real-world experience in fostering ecological innovation in the field of digital technology. Thus, Chinese manufacturing firms registered on the Shanghai and Shenzhen stock exchanges are the focus of this research. According to the China Association of Listed Companies' Industry Classification Results of Listed Companies in the First Half of 2023, the 3,452 Chinese manufacturing firms are listed on the Shanghai and Shenzhen stock exchanges. As a result, all 3,452 of these firms were chosen as the research population in 2022 from the China Stock Exchange Market and Accounting Research Database.

OBJECTIVES

The research question is "what is the impact of strategic digital transformation and firm sustainability in the context of Industry 5.0?" The following are the objectives of this research:

1. To examine on the relationship between strategic digital transformation and firm sustainability (ESG);

2. To investigate on the mediating effect of eco-incentive finance in the relationship between strategic digital transformation and firm sustainability;

3. To examine on the moderating effect of eco-incentive finance in the relationship between strategic digital transformation and greenovation;

4. To provide suggestions for manufacturing firms and government who aim to enhance sustainable practices in the context of Industry 5.0.

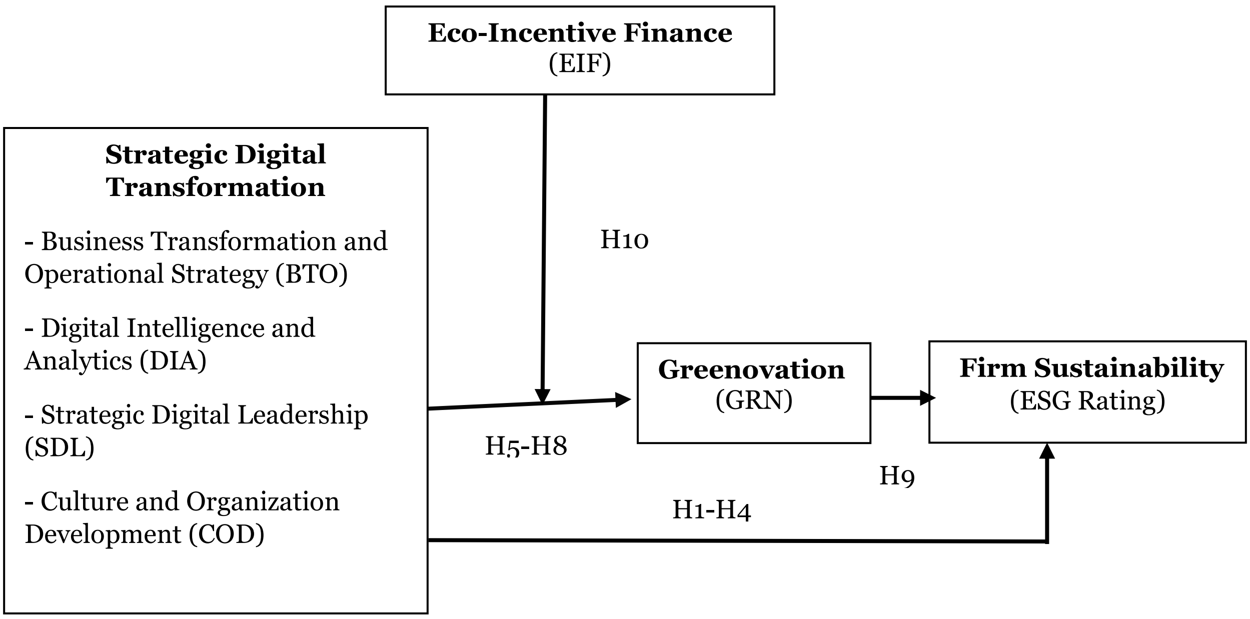

Figure 1. The Conceptual Framework

Therefore, the hypotheses of thus research could be:

H_1: Business transformation and operational strategy has a positive relationship with firm sustainability,

H_2: Digital intelligence and analytics has a positive relationship with firm sustainability,

H_3: Strategic digital leadership has a positive relationship with firm sustainability,

H_4: Culture and organization development has a positive relationship with firm sustainability,

H_5: Business transformation and operational strategy has a positive relationship greenovation,

H_6: Digital intelligence and analytics has a positive relationship with greenovation,

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H_7: Strategic digital leadership has a positive relationship with greenovation,

H_8: Culture and organization development has a positive relationship with greenovation,

H_9: Greenovation has a positive relationship with firm sustainability,

H_{10}: Eco-incentive finance moderates the relationship between strategic digital transformation and firm sustainability.

METHODS

According to the China Association of Listed Firms' Industry Classification Results of Listed Firms in the First Half of 2023, 3,452 Chinese manufacturing firms are listed on the Shanghai and Shenzhen stock exchanges. Thus, all 3,452 of these listed firms in 2022 are chosen as the research population for this research (Wang, Yang, He, & Liao, 2023). Using Yamane's (1973) sampling formula, the sample size for this research is 360 listed firms, with e=0.05.

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

The China Stock Exchange Market and Accounting Research Database (CSMAR) is the source of the data. Based on relevant research (Zhou, Sun, Qi, Li, & Gao, 2023), the research samples are handled as follows in this research: A-shares (listed in China and traded in yuan) and B-shares (listed in China and traded in foreign currency) are excluded, as are samples with missing pertinent data, special treatment samples, and samples of specific transfer firms. Additionally, samples with gearing ratios greater than one are excluded. Additionally, this research reduces the upper and lower 1% of all continuous variables in the model to lessen the influence of extreme values on the findings.

The CSMAR database provides the firm financial and corporate governance data, the CSI ESG rating system provides the ESG performance data (firm sustainability), and the keywords frequency statistics of the annual reports of listed firms provide the strategic digital transformation data. The relevant annual reports of listed firms are sourced from the official websites of the Shanghai Stock Exchange (SSE) and Shenzhen Stock Exchange (SZSE). The China National Intellectual Property Administration (CNIPA) provides the sample data for green patents that were used to gauge green innovation (greenovation). The China Industrial Statistics Yearbook is the source of the eco-incentive finance statistics.

The corporate ESG performance (ESG) serves as the explanatory variable. The ESG rating of the CSI index is used in this research to gauge the ESG performance of businesses, with reference to the data sources of Wang et al. (2023) and Xie, Zhu, & Wang (2019). Other ESG rating methods suffer from limited coverage and infrequent updates when compared to the CSI ESG rating. Based on the fundamental ESG concepts, the CSI ESG evaluation system includes more indicators that are appropriate for the nation's current stage of development than other systems used by foreign markets. These indicators include information disclosure, poverty alleviation, penalties imposed by the Securities and Futures Commission, and the number of government-recognized firms. The ESG rating of all A-share listed companies over the previous ten years is systematically measured by adding up the underlying indicators using the industry weighting matrix (total score = 100) and assigning nine ratings of "AAA-C" in accordance with this method, which combines dynamic tracking and quarterly evaluation (Yang & Han, 2024). The ratings in this research are as follows: AAA is assigned as 9, AA is assigned as 8, A is assigned as 7, BBB is assigned as 6, BB is assigned as 5, B is assigned as 4, CCC is assigned as 3, CC is assigned as 2, and C is assigned as 1. The better the corporations fulfil their ESG responsibilities, the higher the value.

The relationship between strategic digital transformation and firm sustainability (ESG rating) is mediated by eco-incentive finance (EIF). Prior researche indicate that green patents are frequently used to measure green innovation (greenovation) and can be used as indicators of green innovation development trends and accomplishments (Zhu & Tan, 2022). As a result, the number of green patent applications filed by businesses is frequently used to quantify green innovation. This research screens patent application data from sample companies on the China National Intellectual Property Administration's (CNIPA) website to find green patents using the "IPC Green List" created by the World Intellectual Property Organisation. CNIPA grants patents for exterior designs, utility models, and inventions.

The moderator in the conceptual model is eco-incentive finance (EIF). Because the majority of listed firms do not reveal environmental information, it is challenging to get green credit information from every firm. The degree of eco-incentive finance or green credit in the province where the firm is based is therefore used in this research to represent the firm's green credit. There are two types of eco-incentive finance indicators: positive and negative. Three methods could be used to quantify the positive indicators: the percentage of bank loans for pollution-controlled investments, the percentage of loans given by financial institutions for environmental protection projects, or the percentage of loans given by financial institutions overall. This research focusses on corporate or provincial data. Additionally, this research used the negative indicator of green credit while taking data continuity and accessibility into account. Lastly, a higher eco-incentive finance score indicates that financial institutions lend more money to businesses that pollute more, while they lend less to businesses that don't pollute as much. Stated differently, a lower eco-incentive finance indicator indicates that the province is more willing to finance businesses that don't produce a lot of pollution.

The control variable is reported in the Low-Carbon City Pilot Policy (LCCP) in this research. Pilot projects for low-carbon provinces, regions, and cities were started in 2010 when the Notice on the Pilot Work of Low-Carbon Cities was issued and approved by the National Development and Reform Commission (NDRC). 2012 and 2017, respectively, saw the identification of the second and third batches of low-carbon pilot sites. By encouraging eco-friendly technology and boosting innovation ability, the LCCP dramatically lowers corporate pollution, according to Yang, Jahanger, & Hossain (2023). As an LCC variable in this research, the Low-Carbon City Pilot Policy is crucial in determining how China's industrial sector develops. The strategy has significantly improved the environmental performance of the manufacturing sector by incentivising areas to embrace and promote eco-friendly technologies. Due to regulatory pressures and policy incentives, manufacturing firms based in these pilot cities are more likely to invest in sustainable practices and technology. As a result, pollution has significantly decreased, and the sector's total potential for innovation has increased.

Validity and Reliability

The precision of the measurement that demonstrates the idea of taking into account to confirm the validity and accuracy of the research instrument is shown in validity. According to Hair, Black, Babin, & Anderson (2014), construct validity is the ability of a group of measured items to accurately reflect the theoretical latent construct that they are intended to measure. Convergent validity and discriminant validity should be established if the scale accurately reflects and signals its designated construct. Furthermore, the factor loading size needs to be statistically significant and larger than the 0.40 cut-off to guarantee construct validity (Nunnally & Berstein, 1994). Convergent validity serves as an example of construct validity in this research. Thus, in a particular construct, the high factor loading values were taken into account. According to the findings, every variable item is loaded into a single factor, with factor loadings ranging from 0.418 to 0.638. These values show acceptable construct validity because they are higher than the cut-off score of 0.4 dependability. According to Hair et al. (2014), reliability is the extent to which the measurement is accurate and dependable. This research may conclude that the entire scale in this research is internally consistent.

Statistical Techniques

All of the raw data was examined, encoded, and stored in a data file prior to hypothesis testing. Regression analysis's underlying assumptions, including those regarding outliers, missing data, normality, linearity, and multicollinearity, were then examined.

Variance inflation factor (VIF)

This research used a variance inflation factor (VIF) as indicators to show a high level of multicollinearity among the independent variables to address the multicollinearity issue. According to Hair et al. (2014), multicollinearity is not an issue when the VIF is less than 10. There is no multicollinearity issue in this research, according to a collinearity statistical analysis, which shows that the VIF values vary from 1.010 to 1.389. Correlation analysis was shown to evaluate the correlation among all variables, and a correlation matrix was produced to highlight the intercorrelations among all variables for the initial analysis. Multicollinearity may arise if there is a significant correlation between the variables and the correlation coefficient is more than 0.8 (Homberg, Artz, & Wieseke, 2012). High-correlated variables were grouped together in this research using factor analysis, and factor scores for each variable were created to prevent the multicollinearity issue. As a result, the independent variable associations are appropriate for multiple regression analysis and do not present any issues. All hypotheses are tested using the Ordinary Least Squares (OLS) regression methodology. OLS is a suitable technique for investigating the proposed correlations because the dependent and independent variables in this research are both categorical and interval data (Hair et al., 2014). The equations for this research could be:

Equation 1: $ESG = \alpha_1 + \beta_1 BTO + \beta_2 DIA + \beta_3 SDL + \beta_4 COD + \varepsilon$

Equation 2: $ESG = \alpha_2 + \beta_5 BTO + \beta_6 DIA + \beta_7 SDL + \beta_8 COD + \beta_9 LCC + \varepsilon$

Equation 3: $GRN = \alpha_3 + \beta_{10} BTO + \beta_{11} DIA + \beta_{12} SDL + \beta_{13} COD + \varepsilon$

Equation 4: $GRN = \alpha_4 + \beta_{14} BTO + \beta_{15} DIA + \beta_{16} SDL + \beta_{17} COD + \beta_{18} LCC + \varepsilon$

Equation 5: $ESG = \alpha_5 + \beta_{19} GRN + \varepsilon$

Equation 6: $ESG = \alpha_6 + \beta_{20} BTO + \beta_{21} DIA + \beta_{22} SDL + \beta_{23} COD + \beta_{24} BTO*EIF + \beta_{25} DIA*EIF + \beta_{26} SDL*EIF + \beta_{27} COD*EIF + \varepsilon$

Equation 7: $ESG = \alpha_7 + \beta_{28} BTO + \beta_{29} DIA + \beta_{30} SDL + \beta_{31} COD + \beta_{32} BTO*EIF + \beta_{33} DIA*EIF + \beta_{34} SDL*EIF + \beta_{35} COD*EIF + \beta_{36} LCC + \varepsilon$

Where:

BTO = Business Transformation and Operational Strategy; DIA = Digital Intelligence and Analytics; SDL = Strategic Digital Leadership; COD = Culture and Organization Development; EIF = Eco-Incentive Finance; GRN = Greenovation; and LCC = Low-carbon city.

RESULTS

The random selected sample firms are Chinese listed firms in the manufacturing sector on the Shanghai Stock Exchange and Shenzhen Stock Exchange. 31 provinces are located of the 360 sample firms. While Hainan, Ningxia, Qinghai, and Xizang provinces each have one sample firm, Guangdong and Zhejiang provinces have the most, with 48 sample firms each.

Descriptive Analysis Results

A number of low-carbon provinces, regions, and cities were created as a result of the Low-Carbon City Pilot Policy, which went into effect in 2010. Tianjin, Chongqing, Shenzhen, Xiamen, and Hangzhou are the first group of pilot cities that were authorised in 2010. The second batch, which includes 28 cities such as Beijing, Shanghai, Guangzhou, Chengdu, and others, was announced in 2012. Forty-five cities were part of the third batch, which was revealed in 2017. As a result, China currently has 78 low-carbon pilot cities in total. In 2010, 109 of the 360 sample enterprises were located in the low-carbon pilot cities. In 2022, nevertheless, this number would have increased to 212 firms.

The descriptive statistical analysis of this research, the sample's ESG rating is relatively discontinuous, with a mean of 4.247 and a standard deviation (SD) of 0.809. No firm in the sample has the AAA level, which receives a score of 9 in this research, according to the ESG rating's minimum and maximum values. Business transformation and operational strategy had the lowest mean score (14.528) among the four strategic digital transformation dimensions, with a standard deviation (SD) of 9.999. This suggests that the scores are less distinct and more concentrated. With a mean of 15.806 and a large standard deviation (SD) of 39.987, digital intelligence and analytics exhibit comparable conditions. The data widths from 0 to 409, illustrating the diverse range of business outcomes in this dimension. The moderately discrete mean for strategic digital leadership is 32.436, with a standard deviation (SD) of 31.328. The standard deviation (SD) is 60.330 and the mean value is 100.969 for the culture and organization development. The data ranges for the four dimensions are broad, but the means for operational strategy and business transformation (lowest) and culture and organization development (highest) differ. This suggests that most of the sample firms do not explicitly engage in transformative activities in strategic business operation, but they are very passionate about human resources capabilities, culture, and organization development.

Correlation Analysis Results

For two reasons, this research uses a bivariate correlation analysis of Pearson's correlation on all variables. Investigating the connections between the variables is the primary goal. Another purpose is to verify the multicollinearity problem. Multicollinearity when the intercorrelation between independent variables is more than 0.80, there is a concern (Hair et al., 2014). This research uses a two-tailed test of statistical significance at two levels: $p < 0.01$ and a $p < 0.05$ for the bivariate correlation technique. Table 1 presents the findings of the correlation analysis of every variable used in this research.

Table 1. Correlation Analysis Results of All Variables

	ESG	GRN	EIF	BTO	DIA	SDL	COD	LCC	VIF
Mean	4.247	9.506	0.448	14.528	15.806	32.436	100.969	0.589	
SD	0.809	31.074	0.131	9.999	39.987	31.328	60.330	0.493	
GRN	0.197**								
EIF	-0.173**	-0.054							
BTO	0.034	-0.010	0.031						1.010
DIA	0.182**	0.126*	-0.148**	-0.019					1.346
SDL	0.249**	0.241**	-0.185**	0.070	0.504**				1.389
COD	0.304**	0.059	-0.039	-0.022	0.102	-0.185**			1.039
LCC	0.060	0.138**	-0.143**	0.056	0.169**	0.161**	0.093		1.045

**$p < 0.01$ and * $p < 0.05$

Table 1 shows that the three of four dimensions of strategic digital transformation have significant positive relationships with firm sustainability (ESG rating) ($r = 0.182 – 0.304$, $p < 0.01$) with the exception of the business transformation and operation strategy ($r = 0.034$) has not significant at either $p < 0.01$ or $p < 0.05$. However, there is a substantial inverse relationship between firm sustainability and eco-incentive finance ($r = -0.173$, $p < 0.01$). The ratio of energy-intensive sectors' interest costs to those of all industries is the negative indicator. In turn, financial institutions give less financial support to non-heavy polluting enterprises and more loans to heavy polluting companies when the green credit indicator is higher. Stated differently, a lower green credit indicator indicates that the province is more willing to finance firms that don't produce a lot of pollution. All of the variables in the conceptual model have correlations that are less than 0.8 (Hair et al., 2014). Therefore, the findings of this research show no issues with multicollinearity.

Hypothesis Testing and Multiple Regression Analysis Results

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Model 1 evaluates how strategic digital transformation affects firm sustainability (as measured by ESG rating) in all four dimensions. With the addition of the control variable, Model 2 is comparable to Model 1. While Model 4 includes the control variable (LCC), Model 3 evaluates the effects of strategic digital transformation (again, across the four dimensions) on greenovation without it. The ninth hypothesis is tested by Model 5. The moderating impact of eco-incentive finance on the relationship between firm sustainability and strategic digital transformation is examined in Models 6 and 7, the control variable is included in Model 7.

Table 2. Results of the Effects of Strategic Digital Transformation on Firm Sustainability

	Model 1	**Model 2**
Dependent Variable	**ESG**	**ESG**
Equation	**1**	**2**
Hypothesis	**H1-H4**	**H1-H4**
Business Transformation and Operational Strategy (BTO)	0.002 (0.004)	0.002 (0.004)
Digital Intelligence and Analytics (DIA)	0.002 (0.001)	0.002 (0.001)
Strategic Digital Leadership (SDL)	**0.004**** (0.002)	**0.004**** (0.002)
Culture and Organization Development (COD)	**0.004**** (0.001)	**0.004**** (0.001)
Low-Carbon City (LCC)		-0.008 (0.083)
Constant term	**3.694**** (0.101)	**3.698**** (0.107)
No. of observations	360	360
Durbin-Watson Test	2.119	2.119
F-Statistics	13.843**	11.045**
Adj. R^2	0.125	0.123

$^{**}p < 0.01$ and $^{*}p < 0.05$, Beta coefficients with standard errors in parenthesis

Table 2 presents the results of OLS regression analysis of the effects of strategic digital transformation on firm sustainability. The strategic digital leadership (SDL) and culture and organization development (COD) (Hypotheses 3-4) are significantly and positively related to the firm sustainability (ESG rating): strategic digital leadership (β_3 = 0.004, p < 0.01; β_7 = 0.004, p < 0.01), and culture and organization development (β_4 = 0.004, p < 0.01; β_8 = 0.004, p < 0.01). The robust model in which these variables collectively help predict firm sustainability outcomes is indicated by the strong F-statistics. The results of Models 2 and 3 reveal strategic digital leadership and culture and organization development impact firm sustainability, while business transformation and operational strategy and digital intelligence and analytics have no significant impact on firm sustainability. **Therefore, hypotheses 3 and 4 are supported.**

Table 3. Results of the Effects of Strategic Digital Transformation on Greenovation

	Model 3	**Model 4**
Dependent Variable	**GRN**	**GRN**
Equation	**3**	**4**
Hypothesis	**H5-H8**	**H5-H8**

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Business Transformation and Operational Strategy (BTO)	0.001 (0.001)	-0.100 (0.160)
Digital Intelligence and Analytics (DIA)	0.001 (0.001)	-0.007 (0.046)
Strategic Digital Leadership (SDL)	**-0.010**** (0.001)	**0.228**** (0.060)
Culture and Organization Development (COD)	0.001 (0.001)	0.003 (0.027)
Low-Carbon City (LCC)		**6.565*** (3.305)
Constant term	**0.465**** (0.017)	-0.507 (4.275)
No. of observations	360	360
Durbin-Watson Test	2.390	1.926
F-Statistics	3.694**	5.288**
Adj. R^2	0.029	0.056

**$p < 0.01$ and * $p < 0.05$, Beta coefficients with standard errors in parenthesis

The findings of an OLS regression analysis on how strategic digital transformation affects greenovation are shown in Table 3. The only variable that has a significant relationship with greenovation is strategic digital leadership (SDL) (Hypotheses 3-4) ($\beta 12 = -0.010$, $p < 0.01$; $\beta 16 = 0.228$, $p < 0.01$). On the other hand, the greenovation in Model 3 is significantly impacted negatively by the strategic digital leadership. The results of the analysis of the control variable in Model 4 indicate a significant positive sign of strategic digital leadership on greenovation. **Therefore, Hypothesis 7 is supported.**

Table 4. Results of the Moderating Effects of Eco-Incentive Finance on the Relationship between Strategic Digital Transformation and Firm Sustainability

	Model 5	**Model 6**	**Model 7**
Dependent Variable	**ESG**	**ESG**	**ESG**
Equation	**5**	**6**	**7**
Hypothesis	**H9**	**H10**	**H10**
Business Transformation and Operational Strategy (BTO)		-0.006 (0.013)	-0.006 (0.013)
Digital Intelligence and Analytics (DIA)		-0.006 (0.005)	-0.006 (0.005)
Strategic Digital Leadership (SDL)		0.003 (0.006)	0.003 (0.006)
Culture and Organization Development (COD)		**0.005*** (0.003)	**0.005*** (0.003)
Greenovation (GRN)	**0.005**** (0.001)		
Eco-Incentive Finance (EIF)		-0.983 (0.707)	-0.997 (0.709)
BTO*EIF		0.018 (0.024)	0.018 (0.025)

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DIA*EIF		0.020 (0.013)	0.019 (0.013)
SDL*EIF		0.001 (0.014)	0.001 (0.014)
COD*EIF		-0.003 (0.005)	-0.003 (0.005)
Low-Carbon City (LCC)			-0.032 (0.083)
Constant term	**4.199**** (0.044)	**4.157**** (0.342)	**4.177**** (0.346)
No. of observations	360	360	360
Durbin-Watson Test	2.080	2.144	2.144
F-Statistics	14.403**	7.363**	6.625**
Adj. R^2	0.036	0.138	0.135

$p < 0.01$ and * $p < 0.05$,** Beta coefficients with standard errors in parenthesis

Table 4, Model 5, F-statistic is 14.403 ($p < 0.001$), demonstrating that the independent variable (Greenovation: GRN) significantly explain the variation in firm sustainability (ESG rating). This suggests that greenovation (Green innovation), is collectively significant in predicting the firm sustainability via ESG rating. Greenovation positively influences firm sustainability ($\beta 19 = 0.005$, $p < 0.01$). **Therefore, Hypothesis 9 is supported.**

Table 4 presents the moderating effect of eco-incentive finance on the relationships between the four dimensions of strategic digital transformation and firm sustainability. It is evident that the relationship between strategic digital transformation and its outcomes—greenovation and firm sustainability—is not significantly moderated by eco-incentive financing. The only dimension of strategic digital transformation that is positively significant at $p < 0.05$ is culture and organization development. This shows that the Chinese manufacturing sector is not at all satisfied with green innovative concepts and ESG ratings when eco-incentive finance is not volatilely pushed to build strategic digital transformation.

Nevertheless, the results of hypotheses 1, 2, 5, 6, 8, and 10 contradict the research's expectations. The regression results in Tables 2-4 demonstrate that the relationships between greenovation and company sustainability are unaffected by business transformation and operational strategy, digital intelligence and analytics, and eco-incentive finance. Consequently, there is no evidence to support Hypotheses 1, 2, 5, 6, 8, and 10.

DISCUSSION

It has been empirically shown that strategic digital leadership improve firm ESG scores (H_3). This result is consistent with research by Niu, Park, & Jung (2022), which examined how organisational innovation and sustainability are impacted by digital leadership and ESG management. By combining digital strategies with ESG management, they came to the conclusion that digital leadership is essential to creating an atmosphere that supports firm sustainability. In addition to fostering organisational innovation, the collaboration of digital leadership with ESG management improves a firm's capacity to adjust to shifting stakeholder expectations and environmental changes.

According to the research results, a firm's ESG rating can be considerably raised by its culture, human resource capabilities, and organization development (H4). This is consistent with Kong, Liu, Wang, & Zhu (2024) findings that the adoption of particular employee incentive programs can enhance businesses' ecological engagement, especially with regard to environmental protection spending, the caliber of environmental information disclosure, and overall ESG ratings. In a similarity with Jorgji et al.'s research from 2024 emphasises that firms that prioritise sustainable culture and human capital management practices—like funding staff training, encouraging diversity and inclusion, and improving employee benefits—are more likely to see improvements in the ESG performance.

In conclusion, Chinese manufacturing sector that want to obtain excellent ESG ratings must integrate strategic digital leadership with ESG management. For these firms to succeed and remain competitive over the long run, strategic digital leaders must be able to lead them through the challenges of sustainability and digital transformation. This research emphasises how significant digital leadership is to advancing sustainability and innovation in the manufacturing sector, both of which are essential for improving ESG performance. Chinese manufacturing firms confront additional difficulties because of their significant environmental impact, which makes incorporating effective culture, human resource and organizational methods especially important. Manufacturing firms may better address the environmental and social challenges they face by fostering a culture of sustainability in the workplace and providing workers with the skills and information they need. This strategy not only raises a firm's ESG scores but also makes it more resilient and progressive. Manufacturing firms that invest in their employees and give ESG principles top priority are better positioned to lead and innovate in a market that is becoming more and more focused on sustainability, guaranteeing long-term success and competitiveness.

The research results highlight the importance of leadership and organizational culture in advancing sustainable manufacturing practices. The research also suggests the need for more stringent eco-finance regulations and digital projects that align with ESG goals to approach China's "dual-carbon" ambitions for 2030 and 2060. It offers manufacturers and regulators practical guidance on how to encourage high-quality, low-carbon development through integrated digital and sustainability activities within the Industry 5.0 paradigm.

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