

The Sustainable Development Effects of Collaborative Green Transformation in Enterprises

-- A Dual Pathway based on Policy Empowerment and Resource Reconstruction

Yan Chen¹, Dongfeng Zhang²

¹ Institute of Finance and Public Management, Anhui University of Finance & Economics, Bengbu, Anhui 233030, China

² Institute of Statistics and Applied Mathematics, Anhui University of Finance & Economics, Bengbu, Anhui 233030, China

Abstract

Against the backdrop of the “dual carbon” goals and global sustainable development, the synergistic transformation of digitalization and greenification has become a key factor for enterprises to break through development bottlenecks. This paper, based on strategic synergy theory, uses 1,659 Chinese A-share listed companies from 2011 to 2021 as a sample. It employs the entropy method and the coupling coordination degree model to measure the level of synergy in enterprises' digital and green transformation. Through a two-way fixed effects model, it empirically tests the influence mechanism and the moderating effect of local low-carbon policies. The findings reveal: (1) The essence of corporate digital-green transformation synergy lies in the dynamic adaptation and resource complementarity between digitalization capabilities and green capabilities, forming a mutually reinforcing strategic synergy relationship; (2) Corporate digital-green transformation synergy significantly enhances economic performance and environmental and social responsibility performance, with optimized resource allocation efficiency serving as the key pathway; (3) There is a positive relationship between the intensity of local low-carbon policies and the promotion of sustainable development through enterprise digital-green transformation coordination. This study enriches the theoretical framework of enterprise “dual transformation” coordination and provides references for government policy formulation and enterprise sustainable development.

Keywords

Digital Green Transformation Synergy; Sustainable Development Performance; Strategic Synergy Theory; Local Low-Carbon Policies.

1. Introduction

Since the 21st century, the global climate imbalance and the decline in resource carrying capacity have formed a dual crisis. The sixth assessment report of the IPCC warns that “net zero emissions” must be achieved through deep institutional and technological changes. The EU's “dual transformation” strategy positions green collaboration as the core solution. This concept has become a global consensus. As the largest carbon emitter, China has successively proposed the “dual carbon” goals and incorporated them into the top-level planning. Through a series of policies, it has clearly defined the guidance for the integration of green and digital development. Digitalization and greenization are two major trends in industrial transformation. The synergy between digitalization and greenization (digital-green transformation synergy) is the core

strategy for enterprises to break through resource constraints and reshape competitive advantages. Its essence is to deeply integrate and configure the two types of resources, using digitalization to empower green, and green to drive digital innovation, achieving a triple benefit increase. However, in practice, enterprises face dual pressures. The high energy consumption of digital infrastructure and the high costs of green transformation coexist. Therefore, exploring the path of digital-green synergy and leveraging its sustainable development effect is urgent.

Digitalization and green development are the two major trends of the new round of technological revolution and industrial transformation. On the one hand, digital empowerment can effectively promote the green transformation of enterprises. On the other hand, low-carbon green development will accelerate the digitalization process of enterprises, while green technological innovation provides a strong guarantee for the digital transformation of enterprises. The synergistic transformation of digitalization and green development (hereinafter referred to as “digital-green transformation synergy”) will become the core strategy for enterprises to break through resource constraints and reshape their competitive advantages. Enterprise digital-green transformation synergy refers to the strategic synergy formed by enterprises deeply integrating and efficiently allocating digital resources and green production factors while simultaneously implementing the two major strategic transformations of digitalization and green development. Its core lies in leveraging digital technology to empower green development while using green development goals to drive digital innovation, ultimately achieving a threefold leap in economic, environmental, and social benefits and realizing sustainable development. Despite clear policy guidance, enterprises still face the “dual squeeze” of digital and green transformation in practice. On one hand, digital transformation relies on high-energy-consuming digital infrastructure, which may exacerbate carbon footprints. On the other hand, green transformation requires substantial capital investment and technological breakthroughs, leaving small and medium-sized enterprises (SMEs) facing the dilemma of “high costs and long payback periods for green innovation.” Therefore, it is imperative to explore synergistic pathways between digitalization and green transformation and leverage the sustainable development effects of enterprise digital-green transformation synergy.

In recent years, the academic community has begun to conduct research on “digital-green transformation synergy.” For example, *Technology in Society* dedicated a special column in 2022 to exploring the synergistic relationship between digitalization and greenification; Li Yixuan et al. (2025)⁰ utilized the theoretical perspective of synergy theory to construct the theoretical logic of dual-transformation synergy development; however, current research remains focused on the national and industry levels, such as lv et al. (2023)^[2] used national e-commerce pilot city policies as a quasi-natural experiment for regional digital transformation, expanding existing understanding of green development in the digital economy; Huang Beila et al. (2023)^[3] based their research on existing industrial realities, advocating for the promotion of synergistic development between industrial digitalization and greenization. However, research at the enterprise level remains relatively scarce, such as Tian Haifeng et al. (2024)^[4] exploring the mutual interaction between enterprise digital transformation and green innovation.

And the vast majority of current domestic and international studies look at the relationship between digitalization and greening in a fragmented way, focusing only on exploring the impact of a single transformation on corporate sustainability. For example, Wang Bo et al. (2023)^[5] revealed the impact of digital transformation on corporate sustainability performance and its transmission mechanism; Wu Zongfa et al. (2024)^[6] found that enterprises can improve corporate sustainability performance by promoting green technology innovation. However, with the development of society, some scholars have begun to gradually consider the synergistic relationship between the two in their studies, e.g., Shan Xiyan (2025)^[7] considered

the mediating effect of greening in the process of examining the impact of digital transformation on corporate sustainability. Ye et al. (2024) [8] explored the integration of greening and digitalization to achieve sustainable development.

Overall, while most scholars have recognized the critical role of corporate digital-green transformation synergy in sustainable development, existing literature has not interpreted the essence of such synergy from a strategic synergy theory perspective, lacks measurement at the corporate level, and has not yet uncovered the mechanisms underlying how corporate digital-green transformation synergy influences sustainable development performance, thereby lacking a holistic perspective. Especially in the context of China's policy-driven push for digital-green transformation co-creation coexistence with corporate practice challenges, unraveling the dual pathways of "how policies empower" and "how resources dynamically reconfigure" has become the key to explaining the synergistic effects of corporate digital-green transformation co-creation.

2. Theoretical Analysis and Research Hypotheses

2.1. The Impact of Synergy in Digital and Green Transformation on Sustainable Development Performance

The theory of strategic synergy emphasizes that enterprises adapt to environmental changes through a diversified strategic portfolio. Based on this theory, this paper examines from the perspective of resource synergy the impact mechanism of enterprise digital-green transformation synergy on sustainable development performance, focusing on digitalization and green transformation.

Sustainable development performance comprehensively reflects an enterprise's balance of economic, environmental, and social values. Digital-green transformation synergy can establish a digitally empowered green manufacturing system, resolving the traditional "economic-environment" paradox of transformation. However, in the context of incomplete domestic industrialization and uneven informatization levels, enterprises face the dilemma of high investment and low returns, requiring the integration of all key resources to overcome this challenge.

Digital technologies can optimize resource use and control carbon footprints, while green objectives drive the green upgrading of digital infrastructure. Together, they form a synergistic effect of "1+1>2," shifting economic, environmental, and social goals from conflict to compatibility. Based on dynamic capabilities theory, digital-green transformation synergy allows enterprises to orchestrate and integrate digital and green resources, forming unique composite capabilities and thereby enhancing sustainable development performance. Accordingly, the following research hypotheses are proposed:

H1: Collaborative green transformation among enterprises can help improve their sustainable development performance.

Economic performance, as the material foundation of a sustainable development system, depends on the dual drivers of efficiency innovation and innovation premiums. In terms of efficiency, digitization effectively reduces the energy and material consumption costs per unit of output by precisely matching resource supply and demand. Meanwhile, the circular economy model advocated by green transformation further reduces raw material procurement costs through resource recycling. In terms of innovation, the deep integration of green demand and digital technology capabilities has spawned new products and market models, creating a competitive advantage through differentiation. The synergistic effects of the two can release significant synergistic rents.

Environmental and social responsibility performance is a binding requirement for sustainable development, primarily encompassing two dimensions: compliance-based emissions reduction and proactive contributions. On the compliance front, digital technology enhances the transparency and verifiability of carbon emissions data, providing technical support for enterprises to respond to “dual carbon” policy requirements and helping mitigate regulatory penalty risks. On the proactive contribution level, the synergistic transformation of digitalization and greenization has redefined corporate social responsibility paradigms. AI-driven pollution prediction models have enhanced the precision and efficiency of ecological protection, while green digital services have provided enabling pathways for community sustainable development. Based on this, the following research hypotheses are proposed:

H1a: The synergistic transformation of digitalization and greenization can enhance corporate economic performance;

H1b: The synergistic transformation of digitalization and greenization can enhance corporate environmental and social responsibility performance.

2.2. The Regulatory Effects of Local “Low-Carbon” Policy Intensity

The local low-carbon policies have been strengthened, using institutional pressure and resource empowerment as the paths to amplify the synergy effect of digital green transformation on sustainable development performance. Based on the theory of institutions, high-intensity policies form mandatory isomorphic pressure, compelling enterprises to integrate digital and green resources, combine green finance and digital infrastructure subsidies to reduce transformation costs, promote the deep integration of digital carbon reduction and green-induced digital innovation, and help achieve a threefold performance improvement.

The policies empower economic performance by reconfiguring the cost-benefit structure. They not only reduce costs through stepped carbon pricing and intelligent manufacturing subsidies, but also expand markets and increase profits through green procurement and consumption subsidies. Jia Zhijie et al. (2022) ^[9] also confirmed that the synergy of carbon trading policies and renewable energy standards can increase the green innovation return rate of enterprises by 0.057% - 0.132%, confirming that the policies can alleviate financing constraints, reduce technical uncertainty, and release the complementary value of digital green assets. At the same time, the policies strengthen environmental social responsibility performance through a dual-track mechanism of mandatory carbon monitoring disclosure and reputation incentives for green certification, promoting digitalization to become an environmental governance platform. Based on this, the following research hypotheses are proposed::

H2: As policy intensity increases, the synergistic effect of corporate digital green transformation on sustainable development performance significantly increases.

H2a: As policy intensity increases, the synergistic effect of corporate digital green transformation on economic performance significantly increases.

H2b: As policy intensity increases, the synergistic effect of corporate digital green transformation on environmental and social responsibility performance significantly increases.

3. Research Design

3.1. Model Setting

This study constructs a two-way fixed-effects model with economic performance (EP) and environmental and social responsibility performance (ESRP) representing sustainable development performance (SDP) as the dependent variables, and corporate digital-green transition synergy (DG) as the core explanatory variable, as shown below:

$$EP_{it} = \alpha_0 + \alpha_1 DG_{it} + \alpha_j X_{it} + \varphi_t + \mu_i + \varepsilon_{it}$$

$$ESRP_{it} = \beta_0 + \beta_1 DG_{it} + \beta_j X_{it} + \varphi_t + \mu_i + \varepsilon_{it}$$

Among them, the explanatory variables EP_{it} and $ESRP_{it}$ represent the economic performance and environmental and social responsibility performance of enterprise i in year t , respectively; the core explanatory variable DG_{it} represents the level of green transformation synergy of enterprise i in year t ; X_{it} is the set of all control variables in this study, φ_t and μ_i represent the time fixed effect and individual fixed effect, respectively; ε_{it} is the residual.

3.2. Variable Description

3.2.1. Sustainable Development Performance

This study follows the research of Yu Feifei et al. and divides corporate sustainable development performance into economic performance and environmental and social responsibility performance. Economic performance is measured using return on net assets, while environmental and social responsibility performance is measured using the total score from the environmental and social responsibility ratings published by the Hexun Network database.

3.2.2. Corporate Digital-Green Transformation Synergy Level

In this study, the core explanatory variable is the corporate digital-green transformation synergy level (DG). Digital-green transformation synergy emphasizes the interaction and coordinated development between digitalization and green transformation. The coupling coordination model can both measure the correlation between the two and depict the intensity of their interaction. Therefore, this study adopts this model to measure the corporate digital-green synergy level.

(1) Indicator Selection

The measurement method for digital transformation (D) is based on annual report text analysis. First, a digital transformation vocabulary database is constructed, referencing the research of Wu Fei et al., which categorizes digital terminology into two types: underlying technology application and technological practice application. Second, annual reports of listed companies are collected, and the "Management Discussion and Analysis" (MD&A) section is extracted and text segmentation is performed using Python. Finally, the degree of a company's digital transformation is calculated by dividing the frequency of occurrence of various digital technology terms by the total number of words in the MD&A text.

The measurement of green transformation (G) covers three dimensions: environmental protection investment, green patents, and pollutant emissions. First, referencing the research of Zhang Qi et al. (2019) ^[10], environmental protection investment is measured by the ratio of environmental protection-related investments under the "construction in progress" account in the company's annual report to total assets. Second, following the method proposed by Han Feng et al. (2024) ^[11], chemical oxygen demand, ammonia nitrogen, sulfur dioxide, nitrogen oxides, and particulate matter emissions are selected as indicators of pollutant emission intensity. Finally, the annual number of green patent applications filed by the company is selected as a positive output indicator of the progress of green transformation.

Table 1. Green Synergy Indicator System

Primary Indicators	Secondary Indicators	Indicator Description	Nature
Digital Transformation	Artificial Intelligence Technology	Proportion of AI-related keyword frequency	+
	Big Data Technology	Proportion of big data, data mining, and other related keyword frequency	+
	Cloud Computing Technology	Proportion of cloud computing and other related keyword frequency	+
	Blockchain Technology	Proportion of blockchain, digital currency, and other related keyword frequency	+
	Digital Technology Application	Proportion of internet, mobile data, and other related keyword frequency	+
Green Transformation	Environmental Protection Investment	Proportion of expenditures directly related to environmental protection in the “construction in progress” detailed items relative to total assets	+
	Pollutant Emission Intensity	Comprehensive pollutant emission intensity calculated based on chemical oxygen demand, ammonia nitrogen, sulfur dioxide, nitrogen oxides, and particulate matter emissions	-
	Green Patents	Number of green patent applications filed by listed companies	+

(2)Weight Assignment

This study employs the entropy weight method to determine the weights of various indicators for corporate digital transformation and green transformation, while conducting robustness tests using multiple methods to ensure the reliability of the measurements.

(3)Synergy Measurement

Since the synergy between digital and green transformation is a strategic relationship that influences and promotes each other, the coupling coordination model can comprehensively reflect the overall effectiveness and synergy of multiple subsystems. Therefore, this paper uses this model to calculate the synergy of digital and green transformation, defining the two-dimensional coupling degree calculation formula as:

$$C = 2 \times \left[\frac{U_1 U_2}{(U_1 + U_2)^2} \right]^{\frac{1}{2}}$$

Among them, U_1 represents the degree of enterprise digital transformation, and U_2 represents the degree of enterprise green transformation. Furthermore, the coupling coordination degree model is introduced, and the calculation formula is as follows:

$$D = \sqrt{C \times T}$$

$$T = aU_1 + bU_2$$

Since digital transformation and green transformation are equally important for enterprises, default weight coefficients $a=b=\frac{1}{2}$ are assigned, and the final calculation yields the degree of synergy between digital and green transformation (DG) as the core explanatory variable of this paper.

3.3. Moderating Variables

This study uses the intensity of local “low-carbon” policies (LC) as a moderating variable to explore the extent of sustainable development effects from corporate green transformation collaboration under different policy intensity levels across regions. To this end, this study used keywords such as “low-carbon,” “carbon reduction,” and “carbon emission reduction” to collect and organize relevant low-carbon policies issued by provinces across China from 2011 to 2021 from the Peking University Law Database, totaling 2,987 valid policies. The formula for calculating the policy intensity of major provinces in each year is as follows:

$$PS_i = \sum_{j=1}^N p_{ij}$$

In this formula, i represents the region, j represents the policy, N represents the number of policies in that region, and p_{ij} represents the score for the intensity of the j th policy in region i .

3.4. Control Variables

Considering that different enterprises vary in size and demonstrate different capabilities in responding to different resource allocation strategies and policy environments, this paper selects enterprise size, enterprise age, debt-paying ability, economic level, development potential, and R&D intensity as control variables to better reflect enterprise economic performance and environmental and social responsibility performance.

Table 2. Variable measures

Variable type	Variable name	Symbol	Definition
Explanatory variable	Degree of coordination between digital and green transformation	DG	For details, see Section 3.2.2.
	Digital transformation	D	
	Green transformation	G	
Dependent variable	Corporate sustainability performance	EP	Economic performance: Return on net assets
		ESRP	Environmental and social responsibility performance: Corporate social responsibility score
Moderator variable	Strength of local “low-carbon” policies	LC	Annual “low-carbon” policy levels in each province
Control variable	Age of enterprise	lnage	Logarithm of the number of years since the company was established
	Scale of enterprise	lnsize	Logarithm of total assets
	Debt-paying ability	solve	Total liabilities/total assets
	Economic level	economic	Net cash flow/total assets
	Development potential	potential	Increase in operating income/total operating income for the previous year
	R&D intensity	investment	R&D investment/operating income

3.5. Data Sources

The corporate data used in this study primarily comes from CSMAR, Wind databases, and relevant corporate annual reports. National-level data is sourced from the statistical yearbooks of various cities over the years. Within the empirical analysis framework, the study sample was defined as A-share listed companies on the Shanghai and Shenzhen stock exchanges from 2011 to 2021. After data processing following the methodologies of Wu Fei et al. (2021) ^[12] and Ni Kejin et al. (2021) ^[13], a total of 1,659 listed companies were ultimately included in the study, yielding 10,382 observations. The sample selection process was as follows: first, financial companies, ST companies, and companies that were delisted during the study period were excluded to ensure the industry representativeness of the sample; second, samples that did not comply with international accounting standards or had missing key variable data were excluded to ensure data integrity and accuracy; third, to reduce the potential interference of outliers on the regression analysis, continuous variables were trimmed at the 1% level.

3.6. Descriptive Statistic

This paper conducts descriptive statistical analysis on the main variables in the model, with results shown in Table 3. It was found that the mean value of the digital transformation synergy (DG) of enterprises was 0.6191, with a standard deviation of 0.9823, indicating that the overall synergy level among enterprises was relatively low and highly differentiated. Some enterprises exhibited higher synergy, but most lagged significantly. The descriptive statistics results for other variables in this study are also reasonable, and the VIF values for all variables are less than 4.50, ruling out multicollinearity issues in the model and enabling further empirical analysis.

Table 3. Descriptive statistics of variables

Variable	Definition	Observed value	Mean	Standard deviation	Minimum value	Maximum value
DG	Degree of coordination between digital and green transformation	10382	0.6191	0.9823	0	4.1435
EP	Economic performance	10382	0.1102	0.0808	-0.4792	0.5823
ESRP	Environmental and social responsibility performance	10382	0.4158	0.1049	0.1015	0.8352
LC	Strength of local "low-carbon" policies	2987	1.1655	1.3717	1	5
lnage	Length of time in business	10382	0.686	1.3856	0.2508	4.4187
lnsize	Company size	10382	5.9723	1.7589	2.9669	8.6195
solve	Debt-paying ability	10382	0.0215	0.1871	-0.0131	0.3257
economic	Economic level	10382	0.2135	0.4197	0.1227	0.6482
potential	Development potential	10382	1.0786	1.0281	-0.2342	2.2451
investment	R&D intensity	10382	0.4583	0.0493	0.2873	1.0829

4. Empirical Analysis

4.1. Benchmark Regression Analysis

Based on the regression results of the two-way fixed-effects model in Table 4 (Columns (1)–(2)), the synergistic effects of digital-green transformation on both economic performance and environmental and social responsibility performance are significantly positive at the 1% level, indicating that such synergistic effects can significantly enhance both economic performance and environmental and social responsibility performance. This validates Hypothesis H1, which posits that the synergistic effects of digital-green transformation significantly improve sustainable development performance. This is because enterprises, through digital-green transformation synergy practices, generate a composite synergistic effect between digital technology and green innovation, effectively resolving the resource misallocation dilemma under a single transformation model, and significantly reducing the operational uncertainty risks derived from technological iteration. As a result, the strategic focus of enterprises shifts toward long-term value creation, ultimately driving the systematic realization of a sustainable development paradigm. This conclusion is consistent with the research findings of Rehman et al. (2023) [14].

Table 4. Benchmark Regression Results

Variables	(1) EP	(2) ESRP
DG	0.377*** (0.099)	0.022*** (0.009)
lnage	0.176 (0.114)	-0.014 (0.009)
lnsize	0.496 (2.074)	0.371** (0.172)
solve	-0.607*** (0.067)	-0.132*** (0.005)
economic	0.512*** (0.144)	0.159*** (0.012)
potential	0.009* (0.005)	0.003*** (0.001)
investment	-0.004 (0.008)	0.001* (0.001)
Constant	-0.191 (0.279)	0.272*** (0.023)
Time effect	YES	YES
Individual effect	YES	YES
Observed value	10382	10382
R ²	0.015	0.119

Note: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively, with standard errors in parentheses.

Compared to European and American corporate practices, digital transformation collaboration significantly increases the probability of a company becoming an industry innovation leader and drives scale expansion and long-term competitiveness. At its core, the digital transformation penetration rate in developed countries exceeds 70%, with most companies having entered the mid-to-late stages of transformation. At this stage, the overuse of digital technology paradoxically leads to the “digital pollution paradox.” Empirical evidence validates the inverted U-shaped relationship between “digital maturity” and “green synergy intensity,”

providing a critical pathway to address the sustainability growth bottleneck in highly digitalized stages.

4.2. Moderating Effect Analysis

The moderating effect test in Table 5 indicates that the intensity of local low-carbon policies significantly strengthens the promotional effect of digital-green synergy on sustainable development performance: under policy regulation, the positive effects of digital-green synergy on economic performance and environmental and social responsibility performance are significant at the 1% level, and the interaction term coefficient is significantly positive, verifying hypothesis H2. The underlying mechanism lies in local governments using incentive measures such as carbon quota trading and green subsidies to reduce the costs of technological upgrades, while constraints and regulations such as emission limits and environmental disclosure drive technological restructuring. This expands the explanatory boundaries of environmental regulation theory regarding corporate sustainable transformation from a policy coordination perspective.

Table 5. Moderating Effects of Local Low-Carbon Policies

Variable	(1) EP	(2) ESRP
DG	0.377*** (0.099)	0.022*** (0.009)
LC	0.004* (0.002)	0.001*** (0.001)
DG*LC	0.061*** (0.012)	0.002* (0.001)
Control variables	YES	YES
Constant	-0.228 (0.281)	0.257*** (0.022)
Time effect	YES	YES
Individual effect	YES	YES
Observed value	10382	10382
R ²	0.019	0.121

Note: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively, with standard errors in parentheses.

4.3. Mechanism Testing

To further validate the mechanism through which corporate digital transformation synergy influences sustainable development performance, this study adopts a resource synergy perspective, drawing on the methodology of Shi et al. (2018) ^[15], and uses total factor productivity (TFP) to measure corporate resource allocation efficiency, conducting a mediation effect mechanism test.^[16]

Table 6 shows the results of the mechanism test. Specifically, column (1) shows that the coefficient (0.157) of corporate digital-green transformation synergy (DG) is significantly positive at the 1% level, confirming the core role of digital-green transformation synergy in optimizing resource allocation efficiency.^[17] Columns (2) and (3) further validate that TFP significantly enhances the growth of corporate economic performance and environmental and social responsibility performance. This result indicates that corporate digital-green transformation synergy can promote the integration and synergy between digital and green resources, forming resource synergy effects, which helps enterprises improve their sustainable development performance.^[18]

Table 6. Mechanism Testing

Variable	(1) TFP	(2) EP	(3) ESRP
DG	0.157*** (0.047)	0.384*** (0.106)	0.017** (0.008)
TFP		0.105*** (0.025)	0.042*** (0.002)
Control variables	YES	YES	YES
Constant	3.419*** (0.151)	-0.684* (0.354)	0.157*** (0.028)
Time effect	YES	YES	YES
Individual effect	YES	YES	YES
Observed value	10382	10382	10382
R ²	0.163	0.017	0.173

Note: ***, **, and * represent significance levels of 1%, 5%, and 10%, respectively, with standard errors in parentheses.

5. Conclusion and Recommendations

5.1. Research Conclusion

Under the background of "dual carbon", the coordinated transformation of digitalization and greenization of enterprises is the core path to achieving sustainable development. Based on the theory of strategic synergy, this study constructs a theoretical framework of "synergy of digital and green transformation → resource allocation efficiency → sustainable development performance", measures the level of synergy of digital and green transformation by using the entropy method and the coupling coordination degree model, and empirically examines its influence mechanism and the moderating effect of local low-carbon policies through the two-way fixed effect model. The research conclusions are as follows:

(1) This study breaks through the limitation of analyzing digital and green transformation separately, reconstructs the connotation of "synergy of digital and green transformation" based on the theory of strategic synergy, points out that its essence is the dynamic adaptation and resource complementarity of digital and green capabilities, and refines three major characteristics of technology, resource, and institutional synergy, providing a unified theoretical framework for the research on dual transformation and filling the application gap of the theory of strategic synergy in the field of sustainable development.

(2) The synergy of digital and green transformation of enterprises has a significant positive driving effect on economic performance and environmental social responsibility performance, and can enhance the sustainable development performance of enterprises. Compared with most studies focusing on the impact of a single transformation, this paper quantitatively measures the degree of synergy and explains the mechanism of action in combination with the theory of strategic synergy, enriching the research on the antecedent factors of enterprise sustainable development.

(3) Optimizing resource allocation efficiency is the key path for the synergy of digital and green transformation to empower sustainable development. Enterprises break the barriers to resource flow in each link through data sharing, guide technology, capital, human resources and other elements to gather in high value-added and low energy consumption fields, and inject impetus into performance improvement.

(4) Local low-carbon policies significantly strengthen the positive correlation between the synergy of digital and green transformation and sustainable development performance, playing a catalytic role. Policies reduce the transformation costs of enterprises through financial

support and tax reduction, and at the same time, use regulatory pressure to force enterprises to accelerate transformation, helping them achieve dual improvement in economic and environmental performance.

5.2. Policy Recommendations

To promote enterprise digital-green transformation synergy and enhance sustainable development performance, governments and enterprises must collaborate to create a synergistic and coordinated framework.

At the government level, it is essential to strengthen top-level design, incorporate digital-green transformation synergy into the overall planning of regional socio-economic development, and clarify the objectives, tasks, and implementation pathways for each phase. Tailored policies should be developed based on the characteristics of different industries and cities. Fiscal subsidies can be used to reduce the costs of digital infrastructure construction and green technology adoption, while tax incentives can encourage enterprises to increase investments in digital-green transformation synergy. Concurrently, strict environmental enforcement should be enforced, with severe penalties imposed on enterprises violating environmental regulations to compel them to accelerate their transformation.

At the corporate level, companies should firmly establish a strategic awareness of digital-green synergy and integrate it into the core components of their long-term development strategies. They should precisely plan transformation pathways based on the characteristics of their industries and cities, actively collaborate with research institutions and upstream/downstream enterprises, proactively align with government policy resources and industry-leading resources, and dynamically optimize transformation strategies based on external environmental changes and their own development circumstances to ensure the practical effectiveness of digital-green synergy transformation.

Acknowledgments

This work is supported by Anhui University of Finance & Economics 2025 Undergraduate Research innovation fund project fund, Project number: XSKY25203.

References

- [1] Li Yixuan, Zhai Yun. Toward a Synergistic Transition Toward Digitalization and Green Development: Theoretical Logic, Practical Mechanisms, and the Role of Government [J]. *E-Government*, 2025, (07): 2-15.
- [2] Lijuan L, Yan C. The Collision of Digital and Green: Digital Transformation and Green Economic Efficiency [J]. *Journal of Environmental Management*, 2023, 351119906-119906.
- [3] Huang Beila, Huang Xue, Luo Yetao. Promoting the Synergistic Development of Industrial Digitalization and Green Development with the Orientation of Cultivating New Productive Forces [J]. *Zhejiang Economy*, 2024, (03): 38-40.
- [4] Tian Haifeng, Liu Huajun. Research on the "Dual Synergy" Mechanism of Enterprise Digital Transformation and Green Innovation [J]. *Industrial Economics Research*, 2023, (06): 29-41+72.
- [5] Wang Bo, Kang Qi. Digital Transformation and Corporate Sustainable Development Performance [J]. *Economic Management*, 2023, 45(06): 161-176.
- [6] Wu Zongfa, Zhai Yiwén, Zeng Yufei. The Impact of Low-Carbon City Pilot Policies on Corporate Sustainable Development Performance [J]. *Shanghai Economic Research*, 2024, (11): 53-64+91.
- [7] Shan Xiyan. A Study on the Impact of Digital Transformation on Corporate Sustainability: The Mediating Effects of Green Technological Innovation and Green Management Innovation [J/OL]. *Science and Technology Progress and Policies*, 1-10 [2025-08-01].

- [8] Ye F, Zheng J, Li Y, et al. Exploring the Fusion of Greening and Digitalization for Sustainability [J]. *Journal of Cleaner Production*, 2024, 442141085-.
- [9] Jia Zhijie, Wen Shiyan, Zhu Runqing. Carbon Emission Trading and Total Factor Carbon Efficiency: Evidence from China's Carbon Trading Pilot Programs [J]. *Journal of Xiamen University (Philosophy and Social Sciences Edition)*, 2022, 72(02): 21-34.
- [10] Zhang Qi, Zheng Yao, Kong Dongmin. Regional Environmental Governance Pressure, Executive Experience, and Corporate Environmental Investment: A Quasi-Natural Experiment Based on the "Environmental Air Quality Standards (2012)" [J]. *Economic Research Journal*, 2019(6): 183-198.
- [11] Han Feng, Huang Min, Jiang Zhuqing. Corporate Digitalization, Network Position, and Pollution Reduction [J]. *World Economy*, 2024(2): 204-232.
- [12] Wu Fei, Hu Huiyi, Lin Huiyan, et al. Corporate Digital Transformation and Capital Market Performance: Empirical Evidence from Stock Liquidity [J]. *Management World*, 2021, 37(07): 130-144+10.
- [13] Ni Kejin, Liu Xiuyan. Digital Transformation and Corporate Growth: Theoretical Logic and Chinese Practice [J]. *Economic Management*, 2021, 43(12): 79-97.
- [14] Ur S R, Daniele G, Qingyu Z, et al. Twin Transitions & Industry 4.0: Unpacking the Relationship Between Digital and Green Factors to Determine Green Competitive Advantage [J]. *Technology in Society*, 2023, 73.
- [15] Shi Daqian, Ding Hai, Wei Ping, et al. Can Smart City Construction Reduce Environmental Pollution? [J]. *China Industrial Economics*, 2018, (06): 117-135.
- [16] Yu Feifei, Mao Jiayi, Jiang Qing. The Impact and Mechanism of Enterprise Digital-Green Transformation Synergy on Sustainable Development Performance: An Analysis of the Moderating Effect of Local Low-Carbon Policies [J]. *Science and Technology Management*, 2024, 45(11): 89-98.
- [17] Wang Shuangjin, Tian Yuan, Dang Lili. Industrial Enterprises' ESG Responsibility Implementation, Competitive Strategy, and Financial Performance [J]. *Accounting Research*, 2022, (03): 77-92.
- [18] Huang Jingcheng, Zhu Guangshun. China's Model of Green Development: Government Procurement and Corporate Green Innovation [J]. *World Economy*, 2023, 46(11): 54-78.