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The Impact of Digital Transformation on Enterprise Internationalization under the Dual-Carbon Strategy

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Abstract. Taking China's A-share listed companies from 1990 to 2024 as the research sample, this paper analyzes the impact of corporate energy conservation and emission reduction on enterprise internationalization under the "dual-carbon" strategy and explores the underlying mechanisms. The study finds that energy conservation and emission reduction facilitate the internationalization process of enterprises. The mechanism lies in digital transformation: the implementation of energy-saving and emission-reduction policies acts as a driving force that compels enterprises to increase R&D investment, thereby fostering green technological innovation and accelerating digital transformation. This in turn provides new momentum for internationalization. This study provides empirical evidence for carbon reduction practices and international strategies and offers theoretical and practical insights into promoting enterprise internationalization through digital transformation under the dual-carbon goals.

Keywords: Dual-carbon strategy, Carbon emissions, Internationalization, Digital transformation, Green technological innovation

1. Introduction

Achieving "carbon peaking and carbon neutrality" is an inherent requirement for implementing the new development philosophy, fostering a new development paradigm, and promoting high-quality economic development. In January 2018, the Environmental Protection Law of the People's Republic of China officially came into effect, marking a significant step forward in the legalization of environmental governance in China. On the international stage, by 2024, more than 130 countries have pledged to achieve carbon neutrality. As major contributors to carbon emissions, enterprises are subject to increasing pressure. The European Union's Carbon Border Adjustment Mechanism (CBAM), piloted in 2023 and set for full implementation in 2026, will impose taxes on high-carbon imports, thereby compelling the global supply chain toward decarbonization [1]. This underscores the urgency for enterprises to manage carbon emissions and reduce costs amid current economic pressures, which is also of vital importance to their internationalization.

With the gradual establishment of the "1+N" dual-carbon policy system, comprehensive carbon emission management has shifted from a voluntary corporate initiative to an internal compliance requirement, becoming a key manifestation of corporate social responsibility. In recent years, the emphasis on carbon emissions has spurred the rise of digital technologies such as artificial

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intelligence and big data, along with green and low-carbon industries, profoundly transforming corporate production models and management processes. From a theoretical standpoint, the introduction of dual-carbon goals creates a reverse pressure mechanism that encourages enterprises to pursue green and low-carbon technological innovation. This, in turn, contributes to improved production efficiency and enhanced carbon emission management capabilities, ultimately leading to substantial reductions in emissions. However, it is worth noting that in the early stages of carbon emission management, firms often face additional management costs. These added costs may temporarily offset the efficiency gains brought by digital technologies and could even delay the process of internationalization in the short term. Against this backdrop, exploring the intrinsic relationship and underlying mechanisms between corporate carbon emissions and internationalization holds significant theoretical and practical relevance for guiding enterprises in achieving green transformation and upgrading.

Drawing upon the existing body of literature, this paper investigates the impact of energy conservation and emission reduction on enterprise internationalization under the dual-carbon framework and explores the corresponding mechanisms. This study contributes to the field in three primary ways: (1) It enriches the literature by addressing the relationship between carbon emissions and internationalization. While prior studies have explored carbon emission policies in relation to internationalization, foreign direct investment, environmental pollution, and regional differences, few have directly examined how energy conservation and emission reduction affect the internationalization process. This paper fills that gap through both theoretical and empirical analysis. (2) It introduces digitalization as a mediating mechanism, offering a new perspective on how emission reduction influences internationalization, and thereby improves the theoretical framework connecting corporate environmental responsibility and globalization. (3) It considers both the breadth and depth of internationalization, providing a comprehensive analysis of the impact of emission reduction on international expansion, which helps deepen the understanding of this relationship. Overall, the findings suggest that carbon management, by promoting digital transformation and reducing costs, enables enterprises to proactively respond to global markets and trade barriers, making this study of high practical significance.

The remainder of this paper is structured as follows: Section 2 introduces the basic theoretical framework; Section 3 presents the research design; Section 4 reports empirical results and analysis; Section 5 tests the underlying mechanisms; and Section 6 concludes with policy implications.

2. Theoretical hypotheses

Over the past half-century, the global economy has grown by nearly 50%, yet environmental degradation has worsened in tandem. According to a report by the United Nations Environment Programme, despite a temporary decline in greenhouse gas emissions due to the COVID-19 pandemic, global warming may still reach up to 3 degrees Celsius—posing a major challenge for humanity. Against this backdrop, carbon emission policies (such as carbon taxes and cap-and-trade mechanisms) and environmental standards (such as the EU's Carbon Border Adjustment Mechanism, or CBAM) significantly influence enterprise internationalization by imposing cost constraints, reshaping competitive dynamics, and shaping corporate brand images [2]. Existing research reflects two contrasting perspectives: on one hand, multinational corporations promote low-carbon transitions across global supply chains through green technology transfer [3], and outbound foreign direct investment (FDI) from countries with medium-to-high carbon emissions has been shown to reduce global emissions. On the other hand, stricter environmental standards in developed countries may lead to the relocation of polluting industries to developing nations, where

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environmental regulations may be sacrificed in favor of economic growth. In the Chinese context, studies show that while carbon trading policies can facilitate energy conservation and emission reduction, they may also affect firms' competitiveness by altering investment structures [4]. Overall, there is a bidirectional relationship between corporate emission reduction and internationalization, influenced by cross-country differences in carbon emission levels. Based on the institutional context of China's dual-carbon policy framework, this paper proposes the following hypothesis:

H1: By reducing carbon emissions, enterprises can enhance their international competitiveness, thereby accelerating the process of internationalization.

Under the dual-carbon strategy, enterprises must overcome international green trade barriers and reduce costs through technological innovation and managerial transformation. This process is centrally manifested as digital transformation. As a core element of corporate strategic restructuring, digital transformation encompasses not only the adoption of frontier technologies such as artificial intelligence, blockchain, cloud computing, and big data (collectively referred to as "ABCD" technologies), but also systematic changes in strategic positioning and organizational structure. By integrating technologies, processes, and knowledge, digital transformation empowers green innovation and fosters a virtuous cycle in which emission pressures drive increased R&D investment [5], thereby enhancing global competitiveness. However, academic views diverge on the cost implications of digital transformation. Some studies suggest that initial increases in management costs may undermine its positive effect on firm performance [6]. Nonetheless, under the stringent environmental regulations and high entry barriers of Western markets, Chinese firms can only break through international trade barriers by enhancing their carbon management capabilities through digital transformation. While existing literature generally recognizes digital transformation as a key pathway linking emission reduction to internationalization, the direction and magnitude of this influence require further empirical validation within the dual-carbon context. Accordingly, this paper proposes the second hypothesis:

H2: Digital transformation plays a moderating role in the relationship between corporate emission reduction and internationalization—that is, emission reduction positively influences internationalization by prompting firms to advance digital transformation.

3. Model specification and data sources

3.1. Model specification

This study investigates the impact of digital transformation on the internationalization of Chinese listed companies under the dual-carbon strategy by constructing the following two-way fixed effects model:

$$Inter = a_0 + a_1 PCER_{it} + a_2\, controls + \mu_i + \delta_t + \varepsilon_{it} \quad (1)$$

Where: i and t represent the firm and year respectively; Inter denotes the degree of internationalization, measured from both the breadth and depth of overseas operations (i.e., interbread and interdepth); $PCER_{it}$ refers to the natural logarithm of per capita carbon emissions, used as the core explanatory variable to measure emission reduction efforts; Controls includes control variables such as firm size (log of total assets) and Tobin's Q (market value to total asset ratio); μ_i and δ_t capture firm-specific and time fixed effects; ε_{it} is the error term.

The core explanatory variable in this study is the per capita carbon emission level (PCER). Drawing on the measurement methods of Wang Hao et al [7]. and Wiedmann & Minx [8], this paper

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systematically collects carbon emissions data disclosed in listed companies' corporate social responsibility reports, sustainability reports, and environmental reports to construct an indicator of corporate per capita carbon emissions [7]. Specifically, the per capita carbon emission indicator (log_PCER) is calculated as the natural logarithm of the ratio of a firm's total carbon emissions to its total number of employees [8].

To address potential endogeneity arising from omitted variable bias, this study includes a range of control variables that may influence a firm's carbon emissions management. At the firm level, the control variables include: Firm size (size), measured by the natural logarithm of total assets at the end of the period; Firm value (TBQ), measured as the ratio of the firm's market value to total assets.

3.2. Data sources

This study selects A-share listed companies in China as the research sample. The data are obtained from the CSMAR (China Stock Market & Accounting Research) database, as well as the official websites of the Shanghai Stock Exchange and the Shenzhen Stock Exchange. The sample period spans from 1990 to 2024. Following established practices in the literature [9], the dataset of Chinese industrial enterprises is processed and cleaned accordingly. The data cleaning procedures are as follows: (1) Firms designated as ST or *ST are excluded; (2) Delisted firms are removed from the sample; (3) Firms with missing values in any of the required variables are excluded; (4) Continuous variables are winsorized at the 1st and 99th percentiles to reduce the influence of outliers.

4. Regression analysis

4.1. Baseline regression

Table 1. Baseline regression results

VARIABLES	(1) interbread	(2) interdepth	(3) interbread	(4) interdepth	(5) interbread	(6) interdepth
log_PCER	-0.655***	-1.276***	-0.442***	-0.815***	-0.452***	-0.837***
	(-10.50)	(-10.66)	(-5.62)	(-5.41)	(-5.66)	(-5.47)
Size			0.427***	0.924***	0.421***	0.928***
			(4.42)	(5.00)	(4.16)	(4.80)
TBQ					0.006	0.065
					(0.07)	(0.35)
Constant	-1.691***	-4.429***	-9.530***	-21.391***	-9.448***	-21.635***
	(-2.75)	(-3.75)	(-5.08)	(-5.95)	(-4.70)	(-5.62)
Observations	2,174	2,174	2,174	2,174	2,164	2,164
R-squared	0.086	0.088	0.095	0.099	0.095	0.099
Time Fixed Effects	YES	YES	YES	YES	YES	YES

To examine the effect of corporate energy conservation and emission reduction on internationalization, a series of baseline regressions were conducted. The detailed results are presented in Table 1. In columns (1) and (2), only the log-transformed per capita carbon emissions (log_PCER) and time fixed effects are included. The regression coefficients of log_PCER on internationalization breadth and depth are -0.655 and -1.276, respectively, both significant at the 1%

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level. These results indicate a significantly negative relationship between per capita carbon emissions and the level of internationalization: the higher the per capita emissions, the slower the internationalization process. Therefore, when firms engage in energy-saving and emission-reduction practices that lower per capita carbon emissions, their internationalization level improves. In columns (3) and (4), firm size is added as a control variable. The coefficients of log_PCER remain significant at the 1% level, with values of -0.442 and -0.815, respectively. This suggests that the relationship remains robust after controlling for firm scale. In columns (5) and (6), Tobin's Q is further included to represent firms' long-term performance. After controlling for these additional firm-level factors that may influence internationalization, the coefficients of log_PCER remain significantly negative at -0.452 and -0.837, respectively, again at the 1% significance level.

Across all six specifications in Table 1, the coefficient of per capita carbon emissions is consistently negative and statistically significant for both internationalization breadth and depth. These findings confirm that corporate efforts to reduce carbon emissions help advance internationalization, and the direction of the effect remains stable with the inclusion of control variables. This demonstrates a high degree of robustness and provides empirical support for Hypothesis 1.

4.2. Robustness checks

Table 2. Robustness test results

	(1)	(2)	(3)	(4)	(5)	(6)
	Change of Time Range		Change of Core Variable		Additional Control Variables	
VARIABLES	interbread	interdepth	interbread	interdepth	interbread	interdepth
log_PCER	-0.452***	-0.837***			-0.453***	-0.837***
	(-5.53)	(-5.22)			(-5.59)	(-5.23)
log_CE			0.215***	0.410***		
			(3.44)	(3.41)		
Size	0.421***	0.928***	0.591***	1.133***	0.418***	0.933***
	(3.34)	(3.74)	(8.41)	(8.23)	(3.15)	(3.62)
TBQ_int	0.006	0.065	0.104	0.171	-0.008	0.068
	(0.07)	(0.37)	(1.52)	(1.32)	(-0.08)	(0.37)
roa					0.898	0.172
					(0.26)	(0.03)
roe					-0.156	-0.294
					(-0.07)	(-0.06)
Constant	-9.448***	-21.635***	-10.018***	-20.100***	-9.411***	-21.723***
	(-3.82)	(-4.44)	(-6.38)	(-6.59)	(-3.65)	(-4.34)
Observations	2,164	2,164	3,327	3,327	2,164	2,164
R-squared	0.095	0.099	0.099	0.098	0.095	0.099
Time Fixed Effects	YES	YES	YES	YES	YES	YES

(1) Changing the Time Frame

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To account for the impact of major public health events, particularly the COVID-19 pandemic, all observations from 2020 onward are excluded. The sample is re-examined using data from 1990–2019. The regression results in columns (1) and (2) show that the coefficients of per capita carbon emissions (log_PCER) on internationalization breadth and depth are -0.452 and -0.837, respectively, both significant at the 1% level. This suggests that even after accounting for time-related external shocks, the positive effect of carbon management on internationalization remains significant—demonstrating the robustness of the findings.

(2) Changing the Core Explanatory Variable

To further ensure robustness, the study adopts an alternative method to measure energy conservation and emission reduction. According to Zhang Yang et al [10]. and Porter & van der Linde [11], enterprises are the primary agents of emission reduction policies, and improvements in carbon efficiency (i.e., emission reduction per unit of output) are a core objective of carbon management [10,11]. Since unobserved variables may still influence per capita carbon emissions, the study introduces a new variable: carbon efficiency (CE)—calculated as the natural logarithm of the ratio of total carbon emissions to operating profit. In columns (3) and (4), the coefficients of log_CE on internationalization breadth and depth are 0.215 and 0.410, respectively, both significant at the 1% level. These results are consistent with the baseline findings, further validating the robustness of the conclusion.

(3) Adding Supplementary Control Variables

Following Wooldridge [12], additional control variables that may serve as proxies for omitted variables are introduced to mitigate endogeneity [12]. Specifically, the return on assets (ROA) and return on equity (ROE) are added to the model to capture aspects of firm profitability. As shown in columns (5) and (6), after including these additional controls, the coefficients of log_PCER remain significantly negative at -0.453 and -0.837, respectively. This confirms that the positive effect of energy conservation and emission reduction on internationalization remains statistically robust, even under more stringent model specifications.

5. Mechanism analysis

Based on the results of the benchmark regression discussed above, it is evident that corporate energy conservation and emission reduction (ECER) efforts help promote the internationalization of enterprises. This raises the question: what is the underlying mechanism through which this effect occurs? According to Bhatia & Meena [13], digital technologies (such as AI, IoT, and blockchain) contribute to achieving carbon neutrality goals through mechanisms including policy enforcement, economic efficiency, and technological empowerment [13]. Drawing on the empirical model design proposed by Yao Lijie et al [14]., this study constructs the following mediation model to test the pathway through which ECER influences enterprise internationalization [14]:

$$MV = \beta_0 + \beta_1 PCER_{it} + \beta_2 \, controls + \mu_i + \delta_t + \varepsilon_{it} \tag{2}$$

$$Inter = \gamma_0 + \gamma_1 PCER_{it} + \gamma_2 MV_{it} + \gamma_2 \, controls + \mu_i + \delta_t + \varepsilon_{it} \tag{3}$$

In this model, MV represents the mediating variable, namely the level of digitalization (Digital_Level). Since coefficient a_1 in the benchmark model is statistically significant, we only need to examine the significance of coefficients β_1 and γ_2 in the mediation model. If both β_1 and γ_2 are significant, it indicates that MV has a mediating effect—i.e., corporate carbon emissions promote internationalization through digital transformation.

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As shown in Table 3, the corporate carbon emission level (log_PCER) is positively and significantly correlated with the level of digitalization (Digital_Level) at the 1% significance level. This suggests that the higher the per capita carbon emissions, the greater the impetus for enterprises to deepen digital transformation. Columns (2) and (3) test the mediating role of digitalization in the subsamples of internationalization breadth and depth, respectively. The results show that the coefficients of digitalization on internationalization breadth and depth are -0.501 and -0.940, respectively—both significantly negative at the 1% level. This confirms the existence of a mediating effect and demonstrates that digital transformation plays a regulatory role in the relationship between ECER and enterprise internationalization. In other words, corporate ECER efforts can promote substantive digital transformation through a transmission chain of "policy pressure → cost restructuring → market opportunities." In turn, digital transformation shows a positive correlation with the process of enterprise internationalization. Thus, Hypothesis 2 (H2) is supported.

Table 3. Results of mechanism testing

VARIABLES	(1) Digital_Level	(2) interbread	(3) interdepth
log_PCER	0.082***	-0.501***	-0.940***
	(3.04)	(-5.42)	(-5.26)
Digital_Level		0.343***	0.636***
		(4.17)	(3.99)
age	0.293***	0.518***	1.158***
	(8.86)	(4.49)	(5.19)
TBQ_int	0.382***	0.010	0.082
	(13.96)	(0.10)	(0.43)
Constant	-0.856	-13.010***	-29.298***
	(-1.30)	(-5.81)	(-6.76)
Observations	1,724	1,724	1,724
R-squared	0.114	0.083	0.089

6. Conclusion and policy implications

Corporate energy conservation and emission reduction (ECER) efforts can promote enterprise internationalization. Fundamentally, this reflects an adaptive strategy under the global transition to a low-carbon economy. More importantly, it represents a critical opportunity for firms to restructure global value chains through green innovation. In this context, carbon capabilities may emerge as a core internationalization asset—on par with core technologies and brand equity—holding significant implications for enterprises' future global expansion. This paper first establishes a theoretical framework to examine the impact and underlying mechanisms of ECER on enterprise internationalization. The theoretical model demonstrates a closely intertwined relationship between ECER and the internationalization process, suggesting that ECER not only encourages continuous innovation but also helps enterprises overcome trade barriers and reduce costs in their internationalization journey. Subsequently, using A-share listed firms in the Chinese market as the research sample, we construct a benchmark regression model to empirically investigate the impact of ECER on enterprise internationalization. The findings indicate that a reduction in corporate

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carbon emissions accelerates the internationalization process, and this conclusion remains robust across various testing approaches. Furthermore, the study finds that carbon emissions management under the "Dual Carbon" policy context (carbon peaking and carbon neutrality) facilitates firms' digital transformation, and that the level of digitalization, in turn, plays a mediating role in promoting internationalization.

This research confirms that carbon emissions management under the Dual Carbon strategy not only aligns enterprises with international market standards—thus helping to avoid trade barriers—but also enhances their technological advantage in global markets, supports the formation of green supply chains, improves the efficiency of global resource allocation, and strengthens their positions in international industrial chains. These outcomes play a crucial role in advancing enterprise internationalization. The findings have important implications for academia, industry, and policymakers: ①Enterprises should accelerate digital transformation to build green industrial chains and facilitate international expansion. First, firms should increase investment in digital technologies and enhance digital infrastructure, including cloud computing platforms, big data centers, and IoT systems, to provide stronger technical support for carbon emissions management. Second, enterprises should deeply integrate digital technologies into all aspects of production and management. Through intelligent operations, they can improve productivity and enhance carbon management efficiency. ②Strengthening talent development is essential. Under the Dual Carbon strategy, enterprises should establish specialized roles and recruit professionals for carbon management, such as sustainability or ESG-related positions. They should also develop comprehensive carbon emissions management systems to enable accurate monitoring and intelligent adjustment of different energy sources, thus maximizing the use of clean energy at minimal cost and effectively supporting ECER. ③ While carbon emissions reductions indeed promote internationalization, short-term ECER investments may increase corporate burdens. Future research should explore how the timing and scale of ECER investments affect internationalization processes over the long term.

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