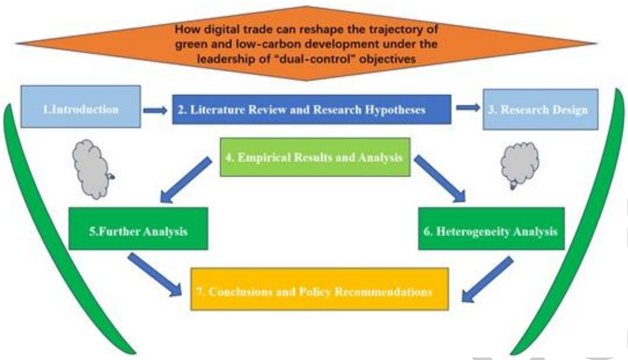
Global NEST Journal, Vol 27, No X, pp 1-16

How digital trade can reshape the trajectory of green and low-carbon development under the leadership of “dual-control” objectives

Yunxia Wu[1,2], Xinyue Wang[1], Henglang Xie[3] and Shenglin Ma[1]*
[1]School of Economics and Management, North University of China, Taiyuan, China
[2]School of Economics, Nankai University, Tianjin, China
[3]School of Business and Economics, University Putra Malaysia
Received: 24/04/2025, Accepted: 10/07/2025, Available online: 25/07/2025
*to whom all correspondence should be addressed: e-mail: sz202209002@st.nuc.edu.cn
https://doi.org/10.30955/gnj.07580

Graphical abstract



Abstract

In the context of the dual - control targets, this study focuses on the impact of digital trade on the level of green and low-carbon development.Provide comprehensive and reliable theoretical support and practical guidance for China's economic green transformation and sustainable development, thereby enabling digital trade to better contribute to green and low-carbon development. Using panel data from 30 Chinese provinces over the period 2011-2022, an empirical test was conducted. The results indicate that digital trade has a significant positive effect on green and low -carbon development, effectively reducing carbon emission intensity. This conclusion remains robust after a robustness test. Digital trade can reduce carbon emission intensity by improving resource - use efficiency and leveraging economies of scale. Industrial structure transformation has a positive moderating effect on the carbon-reducing impact of digital trade. Heterogeneity analysis shows that digital trade has a better carbon - reducing effect in the central and western regions, areas with less developed digital infrastructure, and non-pilot groups. Based on these findings, policy recommendations are proposed from multiple levels, including national, regional, and digital trade development. These recommendations include strengthening infrastructure construction, establishing uniform standards, promoting regional-differentiated development, and optimising pilot policies, to facilitate the role of digital trade in green and low - carbon development under the dual - control targets.

Keywords: digital trade, carbon emission intensity, economies of scale, industrial structure transformation

1. Introduction

In the global context of actively combating climate change, green and low - carbon development has become an inevitable trend in world economic development. As a responsible major country, China explicitly proposed in the *Decision of the Central Committee of the Communist Party of China on Further Comprehensively Deepening Reform and Promoting Chinese-Style Modernisation* to improve the green and low - carbon development mechanism (Zeng 2024; Zhang *et al.* 2025a; Tong *et al.* 2025). The General Office of the State Council issued the *Action Plan for Accelerating the Construction of a Carbon Emission Dual - Control System*, which implements a carbon emission dual - control system mainly based on intensity control and supplemented by total - quantity control (Abedin *et al.* 2024; Zeng *et al.* 2025a; Ma & Appolloni 2025). This demonstrates China's firm determination on the path of green and low - carbon development. Meanwhile, with the rapid development of digital technology, digital trade, as a new type of trade model in the digital economy era, is reshaping the global trade pattern at an unprecedented speed. According to the *Global Digital Economy White Paper* (*2024*) by the China Academy of Information and Communications Technology, the digital economy accounted for 60% of the global gross domestic product (GDP) in 2023, with digital trade playing a key role. With its digital, intelligent and efficient characteristics, digital trade not only promotes economic growth but also brings new opportunities and possibilities for green and low - carbon development (Zeng *et al.* 2023; Zeng *et al.* 2024a; Ma *et al.* 2024; Wu *et al.* 2025b).

Under the "double control" target, carbon emission reduction of digital trade is not only to control the total amount of carbon emissions, but also to focus on controlling the intensity of carbon emissions. However, in the process of promoting green and low - carbon development, digital trade still faces many challenges. On the one hand, the rapid development of the digital economy also brings new environmental problems, such as high energy consumption and high carbon emissions in the production and use of digital equipment, and the continuous expansion of the scale of digital waste (Lu *et al.* 2023; Zeng *et al.* 2024b). According to the *2024 Digital Economy Report* by the United Nations Conference on Trade and Development, the carbon dioxide emissions in the information and communication technology (ICT) field are estimated to be between 600 million and 1.6 billion tonnes, accounting for 1.5% - 3.2% of global greenhouse gas emissions, and this figure is expected to rise with the growth of the digital economy (Lu & Zeng 2023; Zeng *et al.* 2025c; Wu *et al.* 2025a). On the other hand, there are significant differences in the level of digital trade development and the foundation of green and low - carbon development in different regions (Zeng & Ahmed 2023). How to play the role of digital trade in promoting green and low - carbon development according to local conditions is an urgent issue for in - depth research. Against this backdrop, it is of great theoretical and practical significance for China to achieve green transformation and sustainable development under the dual - control targets to explore the impact of digital trade on the level of green and low - carbon development, its mechanism of action and regional heterogeneity.

Regarding the relationship between economic trade and low - carbon development, there are three theoretical divergences in academia. The trade - harmful theory (Tian *et al.* 2022; Zeng *et al.* 2024c) argues that international trade exacerbates environmental problems. Wang *et al.* (2022) verified that developed countries, in order to avoid high pollution, transfer high - pollution industries to developing countries with relatively lower production costs. In contrast, supporters of the trade - beneficial theory emphasise the positive effects of trade (Rodrik 2018). For example, Obobisa (2024) found that trade openness promotes the absorption of clean technology. Scholars of the trade - neutral theory propose a more complex explanatory framework (Zeng & Lu 2022; Wang *et al.* 2023). Grossman and Lee *et al.* (2023), combining the environmental Kuznets curve theory, pointed out that the environmental impact of trade has dynamic and compound characteristics.

With the deep penetration of digital technology into the economic field, research on digital trade has become an emerging hotspot. At the basic theoretical level, scholars have conducted research and analysis on multiple aspects of digital trade, such as the concept of digital trade (Hu & Xu 2018; Zeng *et al.* 2025d), the comprehensive measurement model of digital trade, digital trade efficiency (Suh & Roh 2023), digital trade infrastructure (Ismail 2021), and digital trade rules (Shamel Azmeh *et al.* 2020; Chen *et al.* 2022). In terms of driving mechanisms, Seyoum & Ramirez (2019) supplemented regulatory factors such as government intervention and foreign direct investment. Research on the economic effects of digital trade presents multidimensional characteristics. At the micro - level, Wang *et al.* (2025) confirmed the accelerated green transformation of the manufacturing industry. At the meso - level, Li *et al.* (2022), using data from China from 2010 to 2019, concluded that factors such as internet development, population income, industrial structure, payment convenience, fixed - asset investment, online transaction scale and economic development all have positive impacts on China's digital trade development level. At the macro - level, Shi *et al.* (2025), starting from the global industrial chain perspective, explored the impact of digital trade on the improvement of global value chain status; Nham & Bao (2023), using cross - country panel data, revealed the positive correlation between digitalisation and service import and export activities.

Research on the association mechanism between digital trade and low - carbon development presents multi - scale characteristics. At the industry level, Wen and Zhu (2024) found through research on the transportation industry that the mediating effect of industrial scale significantly promotes carbon emissions, while the mediating effects of technological innovation and industrial structure upgrading significantly inhibit carbon emissions. At the urban scale level, Ni *et al.* (2024) confirmed through policy experiments the carbon - efficiency - enhancing effect; Li *et al.* (2024) indirectly promoted urban carbon emission efficiency by affecting green technological innovation, industrial clusters and energy structure optimisation. At the regional level, Dai *et al.* (2025) further found the positive regulatory effects of trade openness and foreign direct investment; Wang *et al.* (2023) believed that industrial agglomeration and carbon emission trading mechanisms also play regulatory roles in carbon - reduction effects. Cross - country comparisons show that the energy - structure - optimisation path proposed by Li *et al.* (2023) and the industrial - agglomeration mechanism of Shen & Peng (2021) form complementary explanations.

In summary, the existing literature mainly focuses on the relationship between trade and environment, theoretical research on digital trade and other related studies on low-carbon development (Wang *et al.* 2025). Through the analysis of the existing literature, this paper may have the following marginal contributions. First, innovation in research perspective: under the dual - control perspective, this paper deeply analyses the impact of digital trade on the level of green and low - carbon development from the dimensions of the regulatory mechanism of industrial structure transformation and the mediating effects of resource - use efficiency and economies of scale. It breaks the limitations of previous single - perspective studies and constructs a more comprehensive and in - depth theoretical analysis framework, providing a new way of understanding the role of digital trade in green and low - carbon development(Wang & Ma 2024). Second, improvement in empirical research methods: using panel data from 30 Chinese provinces from 2011 to 2022 for testing, and integrating a more comprehensive digital trade development index system, compared with previous studies, the sample size is larger and the time span is longer, which enhances the credibility and universality of the research conclusions. At the same time, through rigorous robustness tests, the reliability of the research conclusions is ensured, providing high - quality data references and methodological references for subsequent research. Third, supplementation and expansion of research conclusions: not only is the promoting effect of digital trade on green and low - carbon development confirmed, but also the specific paths and regulatory mechanisms for reducing carbon emission intensity are further clarified (Zou *et al.* 2024). Especially in the heterogeneity analysis, the differences and reasons for the inhibitory effects of digital trade on carbon emission intensity in different regions and development stages, as well as the carbon emission - trading - pilot - policy, provide theoretical basis for regional - differentiated policy - making and enrich the research results in the field of digital trade and green and low - carbon development(Zhang G *et al.* 2025).

2. Literature Review and Research Hypotheses

2.1. Digital Trade Promotes Green and Low - Carbon Development and Reduces Carbon Emission Intensity

China has been committed to the dual - carbon strategy, promoting the integration of the digital economy and green development. The *14th Five - Year Plan for Digital Economic Development* explicitly stated that by leveraging digital trade platforms, the cross - border circulation of green products and services could be facilitated, and the international competitiveness of green industries could be enhanced. This provided a solid policy foundation for digital trade to assist low - carbon development (Wen *et al.* 2025a; Wen *et al.* 2024b; Wu *et al.* 2024). Various industries accelerated their digital transformation (Liu *et al.* 2025; Li *et al.* 2024; Zeng *et al.* 2025e). Digital trade optimised supply - chain management by using big data to accurately forecast demand, thereby avoiding over - production and reducing energy consumption (Wen *et al.* 2025b). Meanwhile, it gave rise to emerging green industries such as digital finance and digital logistics, injecting new momentum into reducing carbon emissions (Zeng *et al.* 2024d; Wen *et al.* 2025c; Ma *et al.* 2025a). In regions with relatively mature digital trade development, resources were integrated to promote the green transformation of industries (Wen *et al.* 2024a). In areas with a concentration of producer services and collaborative concentration of manufacturing and producer services, the carbon - reducing effect of digital trade was strengthened (Liu *et al.* 2022; Li *et al.* 2025), forming industrial clusters, such as the green and low - carbon industrial clusters in Shanghai. In economically underdeveloped regions with heavy - industry - oriented structures, such as the central and western regions, although digital trade was lagging, it could still be used to optimise traditional industrial processes and promote industrial structure upgrading (Salman *et al.* 2022), reducing dependence on high - energy - consuming industries and lowering carbon emission intensity (Ma *et al.* 2025b). Under the "double control" target, will the development of digital trade promote the level of green and low-carbon development? Based on this, the following hypothesis was proposed in this paper:

H1: Digital trade promotes the level of green and low - carbon development and reduces carbon emission intensity.

2.2. Digital Trade Reduces Carbon Emission Intensity through Resource - Use Efficiency and Economies of Scale

The country encouraged enterprises to use digital technology to reduce energy consumption and emissions. Enterprises that promoted the efficient use of resources in digital trade were given support such as tax preferences. The *Opinions on Promoting the Implementation of the National Cultural Digitalisation Strategy* reflected the emphasis on the resource - use efficiency of cultural digital trade and helped reduce carbon emissions (Wang *et al.* 2024). Digital trade broke geographical barriers, enabling enterprises to obtain environmentally friendly raw materials through platforms and improve resource - use efficiency. E-commerce platforms integrated merchants and consumers, centralised delivery and warehousing, and reduced logistics energy consumption. In addition, digital trade accelerated the dissemination of technology and knowledge. Enterprises used this to improve production efficiency and further reduce carbon emissions (Tong *et al.* 2024). In resource - rich but economically underdeveloped regions, digital trade could be used to transform resource advantages into economic advantages. By introducing digital mining techniques, energy productivity could be improved (Ni *et al.* 2024; Zeng *et al.* 2025f), reducing emissions. In economically developed regions, such as Beijing and Shenzhen, digital trade enterprises used big data and cloud computing to manage supply chains in a refined manner. Under the scale - effect, the carbon emission intensity per unit of output was reduced. Meanwhile, digital finance increased carbon total - factor productivity and the proportion of clean energy consumption in total energy consumption, having a significant positive impact on the low - carbon energy transition (Zhang K *et al.* 2025). This positive effect was attributed to the environmental benefits brought about by capital - biased technological progress. Technological progress strengthened the scale and price effects of capital, replacing production factors such as energy, especially non -clean energy, thereby promoting energy - use efficiency and the development of clean energy (Li *et al.* 2023). To sum up, most studies start from the micro level and believe that digital trade can reduce carbon emissions by improving resource utilization efficiency and scale effect respectively. On the macro level, can digital trade achieve the "double control" goal and reduce carbon emission intensity through resource utilization efficiency and scale effect? Based on this, the following hypothesis was proposed in this paper:

H2: Digital trade reduces carbon emission intensity through resource - use efficiency and economies of scale.

2.3. Industrial Structure Transformation Positively Moderates the Carbon - Reducing Effect of Digital Trade

The nation placed significant emphasis on optimising industrial structures, encouraging traditional industries to undergo green and intelligent transformations, and nurturing emerging low - carbon industries (Wang *et al.* 2024; Zeng *et al.* 2024e). Industrial policies guided the flow of funds towards emerging and green industries, promoting the application of digital trade within these sectors. The *Guiding Opinions on Accelerating the Establishment of a Green, Low - Carbon, and Circular Economic System* reinforced this positive moderating effect. Driven by industry competition and consumer demand for green products, enterprises accelerated the adjustment of their industrial structures. Tan *et al.* (2024) and Duan et al (2025) argued that low - carbon sustainable development is regarded as a fundamental strategy for achieving economic growth and environmental protection, necessitating a fundamental shift in industrial structure. This includes the development of clean technologies, improvement of energy efficiency, and adoption of sustainable production and consumption patterns (Xia *et al.* 2024; Zeng *et al.* 2025b). Digital trade provided a technological platform for the transformation of traditional manufacturing industries and propelled the development of emerging low - carbon industries such as new - energy vehicles. Industrial upgrading increased the complexity of the industry's demand for digital trade, thereby enhancing its carbon - reducing effect. For example, the new - energy vehicle industry used digital trade platforms to reduce energy consumption in operations and promotion (Zeng *et al.* 2024). In regions dominated by traditional manufacturing, such as the old industrial base in the Northeast, promoting industrial structure transformation and developing digital trade could achieve green upgrades and drive the development of the service industry. In regions primarily focused on high - tech and service industries, such as the Yangtze River Delta and the Pearl River Delta, industrial structure transformation was rapid, and digital trade was deeply integrated with emerging industries. For instance, the Yangtze River Delta used intelligent resource allocation to significantly reduce carbon emission intensity. Moreover, industrial structure transformation could promote inter - regional industrial collaboration, achieving complementary advantages through digital trade and jointly promoting green and low - carbon development. To sum up, under the "double control" target, what role does industrial structure transformation play in reducing carbon emissions of digital trade? Based on this, the following hypothesis was proposed in this paper:

H3: Industrial structure transformation positively moderates the carbon - reducing effect of digital trade.

3. Research Design

3.1. Variable Explanation

3.1.1. Dependent Variable: Level of Green and Low - Carbon Development

Referring to the approach of Dong *et al.* (2022), this paper used the carbon emission intensity of each province to represent the level of green and low - carbon development under the dual - control targets. It also referred to the methods of Li *et al.* (2022) and Dong *et al.* (2022) for carbon emissions and drew on the calculation methods of Cheng *et al.* (2021) and Zeng *et al.* (2023) for carbon emission intensity. The specific calculation process is as follows.

Carbon Emissions: In accordance with the reference approach in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, this paper selected eight types of energy, including raw coal, coke, and crude oil, to calculate carbon dioxide emissions. The calculation formula is as follows:

$$C_{ijt} = \sum_{i=1}^{8} E_{ijt} \times NCV_i \times CEF_i \times COF_i \times \frac{44}{12} \tag{1}$$

Where i stands for each type of energy, j stands for each province, and t stands for time. Carbon intensity: expressed as carbon emissions/real GDP

3.1.2. Independent Variable: Level of Digital Trade Development

While there is no unified standard for measuring the level of digital trade development in academia, a core concept has been established.The level of digital trade development is a comprehensive reflection of its maturity and sophistication in economic activities. Its foundation is rooted in the dual support of digital network infrastructure and trade potential. The core driving force behind digital trade development is the advancement of digital technology. Digital industrialization and the digital transformation of industries are concrete manifestations of this development. These three aspects are interdependent and work together to form a complete picture of the development level of digital trade. Drawing on and extending the index system constructed by Wang *et al.* (2023), this paper developed an index system for the level of digital trade development from five dimensions: digital network infrastructure construction, digital - based industrial trade, digital - enabled industrial trade, digital technology level, and trade potential. Finally, the entropy value method is used to measure the development level index of digital trade. The specific index system is presented in **Table 1** below.

Table 1. Index System for the Level of Digital Trade Development

Primary Indicators	Secondary Indicators	Indicator Symbols	Units	Indicator Attributes
Digital network infrastructure	Domain names	X_1	Ten thousand units	+
	Number of websites	X_2	Ten thousand units	+
	Internet broadband access ports	X_3	Ten thousand units	+
	Length of long-distance fiber-optic lines	X_4	Kilometers	+
Digital industrialization trade	Total telecommunications business	X_5	Billions of yuan	+
	Software business revenue	X_6	Ten thousand yuan	+
	Fixed Asset Investment in Information Transmission, Computer Services and Software	X_7	Billions of yuan	+
	Information Technology Service Revenue	X_8	Ten thousand yuan	+
Digitized trade in industry	E-commerce purchases	X_9	Billions of yuan	+
	E-commerce sales	X_{10}	Billions of yuan	+
	Number of enterprises with e-commerce trading activities	X_{11}	Unit	+
Level of digital technology	Employed persons in urban units of the information transmission, software and information technology services industry	X_{12}	Ten thousand people	+
	R&D expenditure of industrial enterprises above designated size	X_{13}	Ten thousand yuan	+
	Number of authorized patent applications	X_{14}	Piece	+
Trade potential	Trade openness	X_{15}	%	+
	GDP per capita	X_{16}	Yuan	+
	Consumption expenditure per capita	X_{17}	Yuan	+
	Total retail sales of consumer goods	X_{18}	Billions of yuan	+

3.1.3. Mediating Variables

Resource - use efficiency (RUE): The energy - use efficiency was proxied by the electricity consumption per unit of gross domestic product (GDP) (Jiang & Yu 2025), with this indicator being a reverse indicator. Economies of scale (ln EOS): Measured by the natural logarithm of regional gross domestic product (GDP) (Shi, X. & Liu, Y. al. 2024).

3.1.4. Moderating Variable

Structural effect: Industrial structure transformation (ISU) was measured by the ratio of the value - added of the tertiary industry to that of the secondary industry (Oteng - Abayie *et al.* 2023).

3.1.5. Control Variables

Referring to the approach of Feng & Ge (2024), this paper controlled for other economic, political, and social factors that might influence the level of green and low - carbon development in each province. Economic factors included financial development level (finance), measured by the ratio of the year - end financial institutions' deposits and loans balance to year - end GDP (Salman *et al.* 2022); and industrial development level (industry), measured by the ratio of industrial value - added to GDP (Dong *et al.* 2023). Political factors included government intervention (regulation), measured by the ratio of public fiscal expenditure to GDP in each province (Combes *et al.* 2019). Social factors included urbanisation level (urban), measured by the ratio of urban population to total population (Chang *et al.* 2023); and human capital level (human), measured by the ratio of the number of college students in each province to the year - end resident population (Diamantouros *et al.* 2015).

3.2. Model Construction

To investigate the impact of digital trade on the level of green and low - carbon development under the "dual - control" targets, the regression model shown in Equation (2) was constructed in this paper:

$$CI_{i,t+1} = \beta_0 + \beta_1 DT_{i,t} + \sum \beta_2 X_{i,t} + \mu_i + \gamma_t + \varepsilon_{i,t} \quad (2)$$

Where $CI_{i,t+1}$ denotes the carbon emission intensity of province i in year t+1. $DT_{i,t}$ denotes the level of digital trade development in province i in year t. $X_{i,t}$ denotes the control variables. μ_i denotes province fixed effects. γ_t denotes time fixed effects; and $\varepsilon_{i,t}$ denotes a random disturbance term.

3.3. Data Sources

This paper takes the panel data of 30 Chinese provinces (excluding Tibet, Hong Kong, Macao and Taiwan) from 2011-2022 as the research sample. The data are obtained from the official website of the National Bureau of Statistics (NBS), statistical yearbooks of each province, China Energy Statistical Yearbook, and China Statistical Yearbook. In addition, in the sample, interpolation is used to supplement for a small number of missing values.

3.4. Descriptive Statistics

The descriptive statistical information of the variables is shown in **Table 2** below. The mean value of digital trade development level and carbon emission intensity are 0.1798 and 11.7415, respectively, the maximum value is 0.6213 and 50.18, the minimum value is 0.0368 and 1.8, and the standard error is 0.1189 and 9.9991, indicating that there are large differences in digital trade and green and low-carbon development among different provinces.

Table 2. Descriptive statistics of main variables

Variable	Sample size	Mean	Standard deviation	Min	Max
dt	360	0.1798	0.1189	0.0368	0.6213
ci	360	11.7415	9.9991	1.8000	50.1800
finance	360	1.5100	0.4400	0.7379	2.5772
industry	360	0.3205	0.0805	0.1129	0.4827
regulation	360	0.2473	0.1011	0.1181	0.6121
urban	360	0.6013	0.1203	0.3700	0.8900
human	360	0.0210	0.0057	0.0092	0.0389

4. Empirical Results and Analysis

4.1. Benchmark Regression Results

Table 3 reports the regression results of digital trade on carbon emission intensity. In the process of gradually adding control variables, adj R^2 shows an increasing trend, indicating that the control variables included in the model can capture more information affecting the explained variable, so that the model can better fit the data and describe the impact of digital trade development level on green and low-carbon development more accurately. The results indicate that digital trade has an inhibitory effect on carbon emission intensity, thereby achieving the effect of green and low - carbon development. This fully demonstrates that digital trade promotes green and low - carbon development, thus verifying Hypothesis H1. Digital trade can significantly inhibit carbon emissions. On the one hand, with the rapid development of digital technology, its integration with traditional industries has been accelerating. Digital technology, through its empowering approaches of digitalisation, intelligence and networking, has driven the transformation of traditional industries and given rise to new industries and business forms. This process has greatly strengthened the industrial structure effect of digital trade in promoting low - carbon development. On the other hand, as a new type of trade model and business form, digital trade has exerted a strong demonstration effect. From the demand side, it has greatly expanded the demand for low - carbon and clean products. Under the influence of market forces, manufacturing enterprises, in order to meet market demand, have proactively transformed and upgraded towards green and low - carbon directions. The transformation of numerous enterprises has collectively driven the establishment of a clean, efficient and low - carbon green production network, achieving energy - saving and emission - reduction goals at the source of production, and ultimately exerting a significant inhibitory effect on carbon emissions.

Table 3. Benchmark Model Regression Results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	ci	ci	ci	ci	ci	ci
dt	-29.3854***	-31.2925***	-33.4712***	-19.4411***	-26.4409***	-29.1175***
	(-7.0593)	(-7.4216)	(-7.8443)	(-3.6124)	(-4.7851)	(-4.8958)
finance		2.6670**	4.5265***	1.6432	-4.4289**	-3.7841*
		(2.3398)	(3.3790)	(1.1067)	(-2.1500)	(-1.7797)
industry			18.6489**	21.7561***	23.9278***	23.1389***
			(2.5893)	(3.0706)	(3.4438)	(3.3179)
regulation				27.8252***	47.1993***	42.5315***
				(4.1296)	(5.8475)	(4.7579)
urban					31.3394***	33.9462***
					(4.1551)	(4.3308)
human						-1.4e+02
						(-1.2116)
_cons	17.0251***	13.3408***	4.9473	-1.0997	-15.0037***	-12.7316**
	(18.9793)	(7.3727)	(1.3351)	(-0.2813)	(-2.9532)	(-2.3524)
Individual fixed	yes	yes	yes	yes	yes	yes
Time fixed	yes	yes	yes	yes	yes	yes
N	360	360	360	360	360	360
adj. R^2	0.120	0.131	0.144	0.181	0.217	0.218

*Note: *, ** and *** denote significance of the estimated coefficients at the 10%, 5% and 1% levels, respectively. The t - values are in parentheses. The same applies to the following tables.*

4.2. Addressing Endogeneity Issues

In this paper, the two-stage least squares method and system GMM method are used to deal with endogeneity problems. After processing, the impact of digital trade on green and low-carbon development level is still significant.

4.2.1. Two - Stage Least Squares (2SLS) Method

The two - stage least squares (2SLS) method was employed in this paper. Drawing on the approach of Yilanci & Kilci (2024), the number of telephone users at the end of 1984 and the information technology service revenue of the previous year for each province were selected. The interaction term obtained by multiplying these two variables was used as a historical instrumental variable for digital trade development. The results in column (1) show that the KP rk Wald F - statistic value is 53.176, which exceeds the Stock - Yogo critical value of 16.38 (at the 10% level). The null hypothesis of weak instrumental variables is rejected, indicating that the instrumental variables used in this paper are valid. The results of column (1) in **Table 4** show that the impact coefficient of digital trade on carbon emission intensity is still significantly negative

4.2.2. System Generalised Method of Moments (GMM)

The level of green and low - carbon development is a dynamic process, meaning that the current level may be influenced by its historical level. To capture this dynamic feature, following the approach of Zhu (2024), the first - order lag of the dependent variable was introduced into the benchmark regression model, transforming it into a dynamic panel model. The system generalised method of moments (GMM) was then used to estimate the parameters. The first - order lag of the dependent variable and the current - period independent variables were treated as endogenous variables, and the second - order lags of the independent variables were used as instrumental variables for the two - step system GMM estimation. The results in column (2) of **Table 4** show that the coefficient of digital trade on carbon emission intensity remains significantly negative.

Table 4. Results of Endogeneity Tests

	(1)		**(2)**
	2SLS		**System GMM**
	first	second	
	dt	ci	
Dig	3.49e-06***		
	(3.65)		
dt		-27.818*	-1.373**
		(-1.71)	(-2.08)
Individual time double-fixed	yes	yes	yes
Control	yes	yes	yes
F statistic	53.176		
AR (1) test		P value=0.013	
AR (2) test		P value=0.879	
Hansen test		0.547	
N	360	360	360
R^2	0.622	0.231	

4.3. Robustness Tests

In the study of the relationship between digital trade and green and low - carbon development, a series of rigorous regression analyses were conducted to further verify the stability and reliability of the impact of digital trade on reducing carbon emission intensity, with the results presented in **Table 5**.

4.3.1. Lagged Independent Variable

The first - order lag of digital trade was introduced as a new independent variable into the regression model. This was done to account for the persistent and dynamic nature of the impact of digital trade. The regression analysis in column (1) revealed highly significant results: the first - order lag of digital trade had a strong negative effect on carbon emission intensity. This finding indicates that the development of digital trade in previous periods not only affects carbon emission intensity in the current period but also continues to have a stable and lasting impact in subsequent periods. For example, an expansion in the scale of digital trade in a previous period may prompt enterprises to make long - term adjustments in supply - chain management and production - technology innovation, thereby continuously driving down carbon emission intensity in subsequent periods (Shen *et al.* 2025; Zhang e al.,2025b). This mechanism is highlighted by the significant negative effect of the lagged variable.

4.3.2. Alternative Dependent Variable

To avoid potential biases in the estimation results caused by the specific measurement of the dependent variable, the strategy of replacing the dependent variable was employed. Given the possible limitations of the original measurement of carbon emission intensity, the approach of Shahzad *et al.* (2023) was followed, and per - capita carbon dioxide emissions (cp) were used as an alternative measure of carbon emission intensity. The regression model was then re - constructed and analysed. The results in column (2) show that the coefficient of digital trade on the level of low - carbon development remains significantly negative. This finding confirms that the positive impact of digital trade on reducing carbon emission intensity is not dependent on a specific measurement of the dependent variable. Whether the original measure of carbon emission intensity or the alternative measure of per - capita carbon dioxide emissions is used, digital trade consistently plays a key negative role in promoting low - carbon development. That is, as digital trade develops, the level of low - carbon development increases and carbon emission intensity decreases, indicating highly robust results.

4.3.3. Winsorisation

To mitigate the influence of extreme values, the main variables were subjected to 1% - 99% winsorisation. The results are shown in column (3) of **Table 5**. The findings indicate that the positive effect of digital trade on the level of low - carbon development remains significant.

4.3.4. Alternative Sample

Considering the potential impact of the "COVID - 19 pandemic" on economic activities, data from 2020 onwards were excluded, and the period 2011 - 2019 was used as the sample for re - estimation. The results are presented in column (4) of **Table 5**. It was found that, after excluding the possible effects of external shocks, the positive impact of digital trade on the level of low - carbon development remains significant.

Table 5. Results of Robustness Tests

	Core explanatory variables 1 period lagged	**Replacement of explanatory variables**	**Tailoring**	**Replacement of estimation sample**
	ci	**cp**	**ci**	**ci**
L.dt	-30.3397***			
	(-4.5280)			
dt		-29.4525***	-29.1175***	-38.8836***
		(-5.3087)	(-4.8958)	(-4.7928)
finance	-3.8950*	-3.1801	-3.7841*	-3.0002
	(-1.7386)	(-1.6033)	(-1.7797)	(-1.1961)
industry	28.3490***	30.3486***	23.1389***	7.4563
	(3.8037)	(4.6650)	(3.3179)	(0.9656)
regulation	45.6953***	29.6298***	42.5315***	29.0383***
	(4.7683)	(3.5533)	(4.7579)	(2.8180)
urban	34.6794***	51.6625***	33.9462***	31.9994***
	(4.1882)	(7.0655)	(4.3308)	(3.3136)
human	-1.2e+02	-1.9e+02*	-1.4e+02	-3.4e+02**
	(-1.0259)	(-1.7765)	(-1.2116)	(-2.2791)
_cons	-15.6986***	-22.5335***	-12.7316**	0.2473
	(-2.7119)	(-4.4632)	(-2.3524)	(0.0402)
Individual fixed	yes	yes	yes	yes
Time fixed	yes	yes	yes	yes
N	330	360	360	270
adj. R^2	0.228	0.192	0.218	0.192

5. Further Analysis

5.1. Mediating Effect Analysis

In delving into the underlying mechanisms through which digital trade reduces carbon emission intensity, it becomes evident that resource - use efficiency and economies of scale play crucial mediating roles. To precisely dissect the mediating effects of these two factors, this paper drew on the Sobel - Goodman method, as used by Wang *et al.* (2024), for in - depth analysis.

The analysis results are presented in columns (1) and (2) of **Table 6**. The data in column (1) clearly show that resource - use efficiency has a mediating effect in the process by which digital trade influences the level of low - carbon development. This means that digital trade does not directly affect the level of low - carbon development but partially exerts a positive influence on it through the intermediate link of improving resource - use efficiency. For example, digital trade, leveraging advanced digital technologies, prompts enterprises to optimise resource allocation in various stages such as production, transportation and sales, thereby enhancing resource - use efficiency and indirectly promoting the improvement of the low - carbon development level.

Turning to column (2), it is evident that economies of scale have a mediating effect on the inhibitory effect of digital trade on carbon emission intensity. As the scale of the digital trade market continues to expand, enterprises can reduce the production costs and energy consumption per unit of product through large - scale purchasing, production and sales activities. Meanwhile, large - scale business operations enable enterprises to invest more resources in technology research and development and management optimisation, further improving resource - use efficiency and reducing carbon emission intensity. For example, e - commerce platforms, by integrating a vast number of merchants and consumers, achieve centralised delivery and warehousing management, effectively reducing the empty - running mileage in the logistics and transportation process and significantly lowering energy consumption and carbon emission intensity.

In summary, the analysis using the Sobel - Goodman method in this paper strongly verifies Hypothesis H2, that is, resource - use efficiency and economies of scale indeed play important mediating roles in the process of digital trade reducing carbon emission intensity.

Table 6. Further Analysis

	Mediating effects	**Moderating effects**			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
	ci	**ci**	**ci**	**ci**	**ci**
rue	136.9666***				
	(18.3206)				
lneos		-4.9258***			
		(-3.5502)			
isu				0.6707	2.5961**
				(0.8808)	(2.1985)
dtisu					-15.4415**
					(-2.1259)
dt	-12.1729***	-3.0819	-29.1175***	-28.7532***	-13.9333
	(-2.7916)	(-0.3285)	(-4.8958)	(-4.8214)	(-1.5220)
finance	-7.6694***	-5.1208**	-3.7841*	-4.3227*	-4.9607**
	(-4.9861)	(-2.4089)	(-1.7797)	(-1.9532)	(-2.2320)
industry	-4.9533	27.4102***	23.1389***	22.1131***	20.4446***
	(-0.9477)	(3.9344)	(3.3179)	(3.1265)	(2.8871)
regulation	-8.3087	26.1240***	42.5315***	43.1314***	43.0458***
	(-1.1904)	(2.6292)	(4.7579)	(4.8096)	(4.8239)
urban	19.4848***	25.9265***	33.9462***	35.0633***	39.7432***
	(3.4357)	(3.2260)	(4.3308)	(4.4145)	(4.8442)
human	485.5222***	-25.1778	-1.4e+02	-1.3e+02	-1.6e+02
	(5.4386)	(-0.2138)	(-1.2116)	(-1.1518)	(-1.3896)
_cons	-6.9437*	38.3060**	-12.7316**	-13.3686**	-15.9259***
	(-1.7847)	(2.4986)	(-2.3524)	(-2.4475)	(-2.8610)
Individual fixed	yes	yes	yes	yes	yes
Time fixed	yes	yes	yes	yes	yes
N	360	360	360	360	360
adj. R^2	0.599	0.243	0.218	0.218	0.225

5.2. Moderating Effect Analysis

To further investigate whether industrial structure transformation has an impact on the process of digital trade in reducing carbon emission intensity, this study constructed a moderating effect model for analysis. Against the global backdrop of advocating green development and actively combating climate change, clarifying the synergistic relationship between digital trade and industrial structure transformation is of vital significance for achieving a reduction in carbon emission intensity and promoting low - carbon economic development.

The results of the model calculations and data processing are shown in column (5) of **Table 6**. The results in column (5) clearly show that industrial structure transformation has a positive moderating effect on the role of digital trade in reducing carbon emission intensity. This means that industrial structure transformation is not just a bystander in the relationship between digital trade and carbon emission intensity, but an active participant and promoter. As the industrial structure gradually transforms towards digitalisation, the inhibitory effect of digital trade on carbon emission intensity is significantly enhanced, thereby effectively promoting the improvement of the low - carbon development level.

Specifically, as the digital elements in the industrial structure increase, traditional industries optimise production processes, innovate management models, and improve resource allocation efficiency through digital technologies. For example, in traditional manufacturing, digital transformation enables enterprises to achieve precise control of the production process through intelligent manufacturing technologies, reducing energy waste and carbon emissions. Meanwhile, digital trade provides these transformed industries with broader market expansion opportunities and more efficient trading platforms. Enterprises can use digital trade platforms to promote green and low - carbon products and services to the global market, further expand the scale of the industry, achieve economies of scale, and thereby reduce the carbon emission intensity per unit of product to a greater extent.

Overall, the greater the degree of digital transformation of the industrial structure, the more prominent the effect of digital trade in reducing carbon emissions. This research result strongly verifies Hypothesis H3, providing solid empirical evidence for our in - depth understanding of the synergistic mechanism of digital trade and industrial structure transformation in green and low - carbon development, and also providing valuable references for government policy - making and corporate strategic adjustments.

6. Heterogeneity Analysis

Considering the significant differences in resource endowments across regions and the distinct geographical characteristics of digital trade development, the benefits that different regions derive from digital trade vary. To explore the regional and developmental heterogeneity of the digital economy in carbon emission reduction, this paper grouped the samples based on geographical location, the development of digital trade, and carbon emission trading policies. Drawing on past research and following the approaches of Han *et al.* (2023) and Wang *et al.* (2023), the 30 provinces (cities) were divided into eastern, central, and western regions according to geographical location. Referring to Hong *et al.* (2023), the level of digital infrastructure was measured by the number of Broadband China strategic demonstration cities within the province, with the average number of pilot cities serving as the dividing line. The 30 provinces (cities) were thus categorised into provinces with well - developed and relatively less - developed digital infrastructure. Following Pan *et al.* (2024), the 30 provinces (cities) were divided into pilot and non - pilot groups based on whether they had implemented a “ carbon emission trading pilot policy” .

6.1. Regional Heterogeneity

The regression results in column (1) of **Table 7** show that in the eastern region, the impact of digital trade on the level of low - carbon development is not significant. However, in the central and western regions, digital trade has a significant impact on the level of low - carbon development. The eastern region, being the most economically developed area in China, has a solid industrial base and a thriving service sector. Its development model is mature, with high energy - use efficiency, production efficiency, and carbon emission efficiency. Most of the easily achievable energy - saving and emission - reduction results have already been realised, indicating limited room for further carbon emission reduction through digital trade. The central region, currently in a period of rapid industrialisation and urbanisation, is experiencing a sharp increase in energy demand. The rapid development of the digital economy has added new momentum to its growth through advanced information technologies and management models, helping to improve traditional energy efficiency, optimise industrial processes, and reduce resource waste, thus achieving carbon emission reduction targets to some extent. The western region, although relatively underdeveloped, has vast territory, abundant natural resources, and great potential for clean energy. The rapid progress of the digital economy has promoted the effective development and rational use of clean energy, reducing dependence on high - carbon - emission energy sources and strongly advancing the process of carbon emission reduction.

6.2. Digital Infrastructure Heterogeneity

The regression results in column (2) of **Table 7** show that in provinces with relatively well - developed digital infrastructure, the impact of digital trade on the level of low - carbon development is less significant than in provinces with relatively less - developed digital infrastructure. In provinces with relatively well - developed digital infrastructure, digital trade is more advanced, and the industrial structure is more sophisticated, with the service sector, especially digital - related services, dominating. The service sector itself has low energy consumption and low carbon emission intensity. The role of digital trade in resource allocation and efficiency improvement has limited marginal space for enhancing the overall level of low - carbon development. In contrast, provinces with relatively less - developed digital infrastructure are dominated by traditional manufacturing and resource - based industries, which have high carbon emission intensity. Digital trade can introduce advanced technologies and management experience to digitally transform traditional industries, significantly reducing energy consumption and carbon emissions and substantially improving the level of low - carbon development. Being in the early stages of digital trade development, these provinces can draw on the mature digital trade technologies and models of developed provinces and quickly apply them to low - carbon fields. Meanwhile, strong policy support for the integration of digital trade and low - carbon technologies encourages enterprises to adopt new technologies, driving digital trade to have a significant impact on the level of low - carbon development.

6.3. Pilot Policy Heterogeneity

The regression results in column (3) of **Table 7** show that in the heterogeneity analysis of carbon emission trading pilot policies, digital trade has a significant promoting effect on the level of green and low - carbon development in both pilot and non - pilot groups. However, compared with the non - pilot group, the promoting effect of digital trade development level on low - carbon development level is weaker in the pilot group. In regions with carbon emission trading pilot policies, enterprises, influenced by policies over the long term, have shifted their low - carbon awareness and behaviour and have adapted to the requirements of low - carbon development. Industrial structure adjustment is basically complete, and dependence on traditional high - carbon projects has significantly decreased. In contrast, in non - pilot regions, enterprises are still in the process of transitioning to low - carbon operations and lack mature low - carbon transformation paths. At this time, the rise of digital trade provides enterprises with new ideas, enabling them to quickly update production technologies, optimise business processes, and shift to green and low - carbon operating models. These factors make the impact of digital trade on low - carbon development level in pilot provinces less significant than in non - pilot provinces.

Table 7. Results of Heterogeneity Analysis

	By geographic location			By state of digital infrastructure		By pilot policy	
	(1)			(2)		(3)	
	East	Central	West	Perfective	Non-perfective	Pilot group	Non-pilot group
	ci	ci	ci	ci	ci	ci	ci
dt	-1.6089	-34.7483***	-1.0e+02***	-14.2971**	-94.4936***	-3.2207**	-46.4634***
	(-0.7359)	(-3.2816)	(-5.9231)	(-2.1782)	(-8.1300)	(-2.1748)	(-6.0778)
finance	0.9580	23.3682***	-4.0057	-19.5101***	11.4664***	2.2647**	-5.9077**
	(0.9144)	(9.0333)	(-0.8653)	(-5.0559)	(3.8887)	(2.3084)	(-2.5451)
industry	9.8649**	56.1388***	29.8307	-28.0797**	60.1768***	18.2965***	24.1762***
	(2.4622)	(8.9108)	(1.6071)	(-2.4156)	(8.1468)	(8.0314)	(3.1367)
regulation	10.9297	-48.8888***	-12.2599	99.8160***	-1.3228	-2.4645	44.7947***
	(1.5263)	(-3.4438)	(-0.6544)	(5.1455)	(-0.1377)	(-0.4883)	(4.7575)
urban	-26.6095***	77.2942***	147.6500***	45.5248***	50.6320***	-6.7646**	88.7645***
	(-7.3295)	(5.4327)	(11.1110)	(4.3989)	(3.7007)	(-2.1363)	(8.8244)
human	357.3221***	-1.5e+03***	-1.1e+03***	196.8781	-2.5e+02*	203.9556***	-3.2e+02**
	(5.6333)	(-8.4965)	(-3.7139)	(0.9475)	(-1.7822)	(4.4796)	(-2.3947)
_cons	11.7052***	-31.8292***	-27.6559***	-2.3223	-32.8801***	-3.1220	-33.9481***
	(3.7994)	(-4.9693)	(-3.0355)	(-0.2352)	(-5.5561)	(-1.0685)	(-5.6638)
Individual fixed	yes	yes	yes	yes	yes	yes	yes
Time fixed	yes	yes	yes	yes	yes	yes	yes
P value	57.33***	26.03***	31.67***				
N	132	96	132	180	180	72	288
adj. R^2	0.501	0.688	0.506	0.265	0.446	0.767	0.315

7. Conclusions and Policy Recommendations

This study investigated the impact of digital trade on the level of green and low - carbon development and its mechanisms of action. It also examined the moderating role of industrial structure transformation and the mediating effects of resource - use efficiency and economies of scale. The study was empirically tested using panel data from 30 Chinese provinces over the period 2011 - 2022. The main conclusions are as follows:

Digital trade promotes the level of green and low - carbon development and reduces carbon emission intensity. This conclusion remains robust after robustness tests.

Digital trade reduces carbon emission intensity through resource - use efficiency and economies of scale. Industrial structure transformation positively moderates the carbon - reducing effect of digital trade.

Heterogeneity analysis shows that the effect of digital trade on carbon reduction is more significant in the central and western regions, areas with imperfect digital infrastructure, and non-pilot areas, respectively, due to the small space for emission reduction due to the mature development of the eastern region, the urgent need for transformation of traditional industries, the existing policy constraints of the pilot group, and the remarkable low-carbon achievements.

Based on the above conclusions, the following policy recommendations are made:

7.1. National level

Under the guidance of the 'dual control' goals, to promote the deep integration of digital trade with green and low-carbon development, two key approaches are essential. First, enhance the construction of digital trade infrastructure. This involves prioritizing the deployment of digital communication networks and cloud computing centers in high-carbon industrial regions in central and western China, equipped with renewable energy power supply to reduce carbon emissions. Second, attract social capital through policies such as preferential carbon emission reduction trading and tax incentives, establish green and low-carbon funds, and accelerate the application of 5G and IoT in areas like energy-saving monitoring and smart grids, thereby strengthening the technological foundation for low-carbon development.

Second, establish a dual-control oriented digital trade standard and regulatory framework. Develop carbon footprint accounting standards that cover the entire product lifecycle and set low-carbon trading rules for sectors like cross-border e-commerce and digital finance. Utilize a cross-departmental collaboration platform to implement a dual-track management system for digital trade enterprises, assessing their carbon emission intensity and controlling total emissions. Promote a low-carbon certification system for enterprises and use a consumption points system to incentivize demand-side emission reductions. In the short term, reduce energy consumption in digital trade through infrastructure upgrades and standardization. In the long term, integrate these measures into the 'dual control' assessment to achieve a synergistic advancement of digital empowerment and low-carbon development.

Industrial transformation: help low - carbon industries expand into international markets through digital trade and promote the transformation of high - energy - consuming industries towards green intelligent manufacturing. Enhanced incentives: introduce tax incentives and subsidy policies to encourage enterprises to conduct research and development of low - carbon technologies and innovation of business models in digital trade (Shen *et al.* 2024). Recognise outstanding enterprises.

Resource - use and economies of scale level: Promote digital resource management systems to help enterprises achieve precise monitoring and refined management of raw materials, energy, and other resources. Encourage enterprises to undertake resource recycling projects. Establish resource recycling industry chains through digital trade platforms to increase the recycling rate of resources. Set up reward mechanisms for resource - use efficiency to recognise and reward enterprises that perform well in resource - use. Stimulate enterprises' enthusiasm for improving resource - use efficiency.

Leverage economies of scale in digital trade: support digital trade platform enterprises to grow stronger through mergers and acquisitions and strategic cooperation. Integrate market resources and expand platform scale. Encourage enterprises to use digital trade platforms to expand into international markets and conduct cross - border e - commerce business. Increase the market coverage of products and services to achieve economies of scale. At the same time, guide enterprises to focus on green and low - carbon development while expanding their scale. Incorporate carbon emission reduction targets into corporate development strategies to achieve a win - win situation between economic and environmental benefits.

Industrial structure level. Accelerate digital transformation of industrial structure: develop plans for the digital transformation of industrial structure. Clarify the goals and paths of digital transformation for various industries. For traditional high - energy - consuming industries such as steel and chemical industries, encourage enterprises to use digital technologies to transform production processes. Increase automation and intelligence levels to reduce energy consumption. At the same time, vigorously cultivate emerging digital industries such as big data, artificial intelligence, and e - commerce. Optimise the industrial structure and enhance the positive moderating effect of digital trade on carbon emission reduction.

Establish a coordinated development mechanism for industrial structure transformation and digital trade: strengthen communication and cooperation between different industries. Promote information sharing and resource integration between traditional and digital trade industries through industry associations and industrial alliances. In formulating industrial policies and approving projects, the government should focus on guiding the coordinated advancement of industrial structure transformation and digital trade. Prioritise support for enterprises that actively participate in digital trade and promote the optimisation of industrial structure.

7.2. Regional level

Eastern region: Encourage digital trade technology innovation and application: Given the already high energy and production efficiency in the eastern region, focus on promoting frontier technology innovation in the field of digital trade, such as the application of blockchain in supply - chain management, to precisely optimise resource allocation and further explore the potential for carbon emission reduction. Establish special scientific research funds to support cooperation between enterprises, universities, and research institutions in conducting key technology research projects on the integration of digital trade and green and low - carbon development. Promote digital trade industry upgrading: Guide digital trade enterprises in the eastern region to transform towards high - value - added, low - energy - consuming industrial links, such as developing digital creative and digital financial service industries. Further improve the quality and efficiency of digital trade to achieve higher - quality low - carbon development within the limited space for carbon emission reduction.

Central and western region: Increase policy support for digital trade. The government should introduce a series of preferential policies for the development of digital trade in the central and western regions, such as tax exemptions, financial subsidies, and land preferences, to attract more digital trade enterprises to settle and promote industrial agglomeration. At the same time, strengthen the training and introduction of digital trade talents in the central and western regions. This can be achieved through talent exchange programmes with the eastern region and by offering relevant majors in local universities to enhance the reserve of digital trade talents. Promote deep integration of traditional industries and digital trade: In combination with the rapid industrialisation and urbanisation process in the central and western regions, guide traditional manufacturing, agriculture, and other industries to use digital trade platforms to introduce advanced technologies and management experience. Improve the digital level of industries, increase energy - use efficiency, and reduce carbon emission intensity. For example, promote digital production technologies in the manufacturing industry in the central region and use digital trade to expand the sales channels for green agricultural products in the western region.

Digital trade development level. Support digital trade-underdeveloped regions: establish special funds to provide technical transformation subsidies to traditional high -carbon industries in digital trade - underdeveloped regions. Help them introduce digital technologies to optimise production processes. Build technology exchange platforms to promote exchanges between enterprises in these regions and those in developed regions. Quickly draw on mature digital trade low - carbon technologies and accelerate the pace of industrial transformation and upgrading.

Implementation of carbon emission trading pilot policies: develop policies that integrate carbon trading with digital trade. Set up special funds to encourage enterprises to use digital technologies to optimise carbon trading and achieve a win - win situation.

References

Abedin, M. Z., Goldstein, M. A., Huang, Q., & Zeng, H. (2024). Forward-looking disclosure effects on stock liquidity in China: Evidence from MD&A text analysis. *International Review of Financial Analysis*, *95*, 103484.

Azmeh, S., Foster, C., & Echavarri, J. (2020). The international trade regime and the quest for free digital trade. *International Studies Review*, *22*(3), 671-692.

Chang, H., Ding, Q., Zhao, W., Hou, N., & Liu, W. (2023). The digital economy, industrial structure upgrading, and carbon emission intensity——empirical evidence from China's provinces. *Energy Strategy Reviews*, *50*, 101218.

Chen, Y., & Gao, Y. (2022). Comparative analysis of digital trade development strategies and governance approaches. *Journal of Digital Economy*, *1*(3), 227-238.

Cheng, Y., & Yao, X. (2021). Carbon intensity reduction assessment of renewable energy technology innovation in China: A panel data model with cross-section dependence and slope heterogeneity. *Renewable and Sustainable Energy Reviews*, *135*, 110157.

Combes, J. L., Renard, M. F., & Tapsoba, S. J. A. (2019). Provincial public expenditure in China: a tale of pro-cyclicality. *Economic Change and Restructuring*, *52*, 19-41.

Dai, S., Tang, D., Li, Y., & Lu, H. (2025). Digital trade, trade openness, FDI, and green total factor productivity. *International Review of Financial Analysis*, *97*, 103777.

Diamantouros, A., Marchesano, R., Rzyczniak, G., & Hardy, B. (2015). Survey of pharmacy preceptors' expectations and experiences with students on rotations in an inaugural combined BScPhm/PharmD class. *The Canadian Journal of Hospital Pharmacy*, *68*(6), 450.

Dong, F., Hu, M., Gao, Y., Liu, Y., Zhu, J., & Pan, Y. (2022). How does digital economy affect carbon emissions? Evidence from global 60 countries. *Science of The Total Environment*, *852*, 158401.

Dong, K., Yang, S., & Wang, J. (2023). How digital economy lead to low-carbon development in China? The case of e-commerce city pilot reform. *Journal of Cleaner Production*, *391*, 136177.

Dong, Z., Xia, C., Fang, K., & Zhang, W. (2022). Effect of the carbon emissions trading policy on the co-benefits of carbon emissions reduction and air pollution control. *Energy Policy*, *165*, 112998.

Duan, K., Qin, C., Ma, S., Lei, X., Hu, Q., & Ying, J. (2025). Impact of ESG disclosure on corporate sustainability. *Finance Research Letters*, 107134.

Feng, N., & Ge, J. (2024). How does fiscal policy affect the green low-carbon transition from the perspective of the evolutionary game? *Energy Economics*, *134*, 107578.

Han, S., Wang, B., Ao, Y., Bahmani, H., & Chai, B. (2023). The coupling and coordination degree of urban resilience system: A case study of the Chengdu–Chongqing urban agglomeration. *Environmental Impact Assessment Review*, *101*, 107145.

He, W., & Xu, Y. (2018). Cross-border electronic commerce development present situation and the innovation research in China. *American Journal of Industrial and Business Management*, *8*(8), 1825-1842.

Hong, J., Shi, F., & Zheng, Y. (2023). Does network infrastructure construction reduce energy intensity? Based on the "Broadband China" strategy. *Technological Forecasting and Social Change*, *190*, 122437.

Ismail, N. W. (2021). Digital trade facilitation and bilateral trade in selected Asian countries. *Studies in Economics and Finance*, *38*(2), 257-271.

Jiang, M., & Yu, X. (2025). Enhancing the resilience of urban energy systems: The role of artificial intelligence. *Energy Economics*, *144*, 108313.

Lee, C. C., Olasehinde-Williams, G., & Gyamfi, B. A. (2023). The synergistic effect of green trade and economic complexity on sustainable environment: A new perspective on the economic and ecological components of sustainable development. *Sustainable Development*, *31*(2), 976-989.

Li, G., Chen, X., & You, X. Y. (2023). System dynamics prediction and development path optimization of regional carbon emissions: A case study of Tianjin. *Renewable and Sustainable Energy Reviews*, *184*, 113579.

Li, G., Wu, H., Jiang, J., & Zong, Q. (2023). Digital finance and the low-carbon energy transition (LCET) from the perspective of capital-biased technical progress. *Energy Economics*, *120*, 106623.

Li, G., Zhang, R., Feng, S., & Wang, Y. (2022). Digital finance and sustainable development: Evidence from environmental inequality in China. *Business Strategy and the Environment*, *31*(7), 3574-3594.

Li, R., Li, L., & Wang, Q. (2022). The impact of energy efficiency on carbon emissions: evidence from the transportation sector in Chinese 30 provinces. *Sustainable Cities and Society*, *82*, 103880.

Li, Y., Cong, R., Zhang, K., Ma, S., & Fu, C. (2024). Four-way game analysis of transformation and upgrading of manufacturing enterprises relying on industrial internet platform under developers' participation. *Journal of Asian Architecture and Building Engineering*, 1–22.

Li, Y., Yang, X., & Ma, S. (2025). The Efficiency Measurement and Spatial Spillover Effect of Green Technology Innovation in Chinese Industrial Enterprises. *Sustainability*, *17*(7), 3162.

Li, Y., Zheng, Z., Zhao, M., & Liu, Z. (2024). How does digital trade impact urban carbon emissions efficiency? Evidence from

China's cross-border e-commerce pilot zones. *Journal of Cleaner Production*, *456*, 142363.

Liu, H., Cong, R., Liu, L., Li, P., & Ma, S. (2025). The impact of digital transformation on innovation efficiency in construction enterprises under the dual carbon background. *Journal of Asian Architecture and Building Engineering*, 1–18.

Liu, X., Zhang, X., & Sun, W. (2022). Does the agglomeration of urban producer services promote carbon efficiency of manufacturing industry? *Land Use Policy*, *120*, 106264.

Lu, R., & Zeng, H. (2023). VIX and major agricultural future markets: dynamic linkage and time-frequency relations around the COVID-19 outbreak. *Studies in Economics and Finance*, *40*(2), 334-353.

Lu, R., Xu, W., Zeng, H., & Zhou, X. (2023). Volatility connectedness among the Indian equity and major commodity markets under the COVID-19 scenario. *Economic Analysis and Policy*, *78*, 1465-1481.

Ma, S., & Appolloni, A. (2025). Can financial flexibility enhance corporate green innovation performance? Evidence from an ESG approach in China. *Journal of Environmental Management*, *387*, 125869.

Ma, S., H. Yan, D. Li, H. Liu and H. Zeng. (2025a). The Impact of Agricultural Mechanisation on Agricultural Carbon Emission Intensity: Evidence from China. *Pakistan Journal of Agricultural Sciences*. *62*: 99-110.

Ma, S. Liu, H., Li, S., Lyu, S.& Zeng, H. (2025b). Quantifying the Relative Contributions of Climate Change and Human Activities to Vegetation Recovery in Shandong Province of China. *Global NEST Journal*.

Ma, S., Wen, L., and Yuan, Y. (2024). Study on the coupled and coordinated development of tourism, urbanization and ecological environment in Shanxi Province, *Global NEST Journal*, *26*(4).

Nham, N. T. H., & Bao, N. K. Q. (2023). Nonlinear effects of digitalization on export activities: An empirical investigation in European countries. *Technological and Economic Development of Economy*, *29*(3), 1041-1079.

Ni, L., Wen, H., & Ding, X. (2024). Impact of digital trade policy on regional carbon efficiency: a quasi-experimental study in China. *Scientific Reports*, *14*(1), 28871.

Obobisa, E. S. (2024). An econometric study of eco-innovation, clean energy, and trade openness toward carbon neutrality and sustainable development in OECD countries. *Sustainable Development*, *32*(4), 3075-3099.

Oteng-Abayie, E. F., Duodu, E., Oduro, S., & Tawiah Baidoo, S. (2023). Greening the future: Unveiling the link between industrial structure upgrading and pollution emission in sub-Saharan Africa. *Cogent Economics & Finance*, *11*(2), 2257069.

Pan, J., Du, L., Wu, H., & Liu, X. (2024). Does environmental law enforcement supervision improve corporate carbon reduction performance? Evidence from environmental protection interview. *Energy Economics*, *132*, 107441.

Rodrik, D. (2018). What do trade agreements really do? *Journal of economic perspectives*, *32*(2), 73-90.

Salman, M., Wang, G., & Zha, D. (2022). Modeling the convergence analysis of sustainable production and consumption in terms of ecological footprints and human development index in Belt and Road Initiative countries. *Sustainable Production and Consumption*, *30*, 233-254.

Seyoum, B., & Ramirez, J. (2019). Economic freedom and trade flows: A moderated mediation model of inward foreign direct investment (FDI) and government stability. *Journal of Economic Studies*, *46*(4), 985-1006.

Shahzad, F., Fareed, Z., Wan, Y., Wang, Y., Zahid, Z., & Irfan, M. (2023). Examining the asymmetric link between clean energy intensity and carbon dioxide emissions: The significance of quantile-on-quantile method. *Energy & Environment*, *34*(6), 1884-1909.

Shen, D., Guo, X., & Ma, S. (2024). Study on the Coupled and Coordinated Development of Climate Investment and Financing and Green Finance of China. *Sustainability*, *16*(24), 11008.

Shen, D., Zhao, X., Lyu, S., Liu, H., Zeng, H., & Ma, S. (2025). Qualification and construction enterprise innovation – quasi-natural experiments based on specialized, high-end and innovation-driven "small giant" enterprises. *Journal of Asian Architecture and Building Engineering*, 1–19.

Shen, N., & Peng, H. (2021). Can industrial agglomeration achieve the emission-reduction effect? *Socio-Economic Planning Sciences*, *75*, 100867.

Shi, X., Liu, Y., & Yu, Z. (2024). Unveiling the Catalytic Role of Digital Trade in China's Carbon Emission Reduction under the Dual Carbon Policy. *Sustainability*, *16*(12), 4900.

Shi, Z., Wei, Y., & Xing, X. (2025). Does the deepening of digital trade rules improve GVC positioning?–A product-level analysis. *Chinese Management Studies*.

Suh, J., & Roh, J. (2023). The effects of digital trade policies on digital trade. *The World Economy*, *46*(8), 2383-2407.

Tan, L., Yang, Z., Irfan, M., Ding, C. J., Hu, M., & Hu, J. (2024). Toward low-carbon sustainable development: Exploring the impact of digital economy development and industrial restructuring. *Business Strategy and the Environment*, *33*(3), 2159-2172.

Tian, K., Zhang, Y., Li, Y., Ming, X., Jiang, S., Duan, H., ... & Wang, S. (2022). Regional trade agreement burdens global carbon emissions mitigation. *Nature communications*, *13*(1), 408.

Tong, L., Wang, C., Qi, Q., Ma, S., and Mei, J. (2024). Study on the Impact of China's Digital Economy on Agricultural Carbon Emissions, *Global NEST Journal*, *26*(6).

Tong, Z., Ding, Y., Ma, S., & Yan, H. (2025). How to Mitigate Climate Change? Dynamic Linkages between Clean Energy and Systemically Important Banks. *Global NEST Journal*.

Wang, C., Liu, H. and Ma, S. (2024). Analysis of the effect of digital financial inclusion on agricultural carbon emissions in China, *Global NEST Journal*, *26*(8).

Wang, L., Zhou, Z., Chen, Y., Zeng, L., & Dai, L. (2024). How Does Digital Inclusive Finance Policy Affect the Carbon Emission Intensity of Industrial Land in the Yangtze River Economic Belt of China? Evidence from Intermediary and Threshold Effects. *Land*, *13*(8), 1127.

Wang, S., Wang, X., & Chen, S. (2022). Global value chains and carbon emission reduction in developing countries: does industrial upgrading matter? *Environmental Impact Assessment Review*, *97*, 106895.

Wang, Y., Liu, J., Zhao, Z., Ren, J., & Chen, X. (2023). Research on carbon emission reduction effect of China's regional digital trade under the "double carbon" target--combination of the regulatory role of industrial agglomeration and carbon emissions trading mechanism. *Journal of Cleaner Production*, *405*, 137049.

Wang, Z. and Ma, S. (2024). Research on the impact of digital inclusive finance development on carbon emissions—Based on the double fixed effects model", *Global NEST Journal*, *26*(7).

Wang, Z., Wang, F., & Ma, S. (2025). Research on the Coupled and Coordinated Relationship Between Ecological Environment and Economic Development in China and its Evolution in Time and Space. *Polish Journal of Environmental Studies*, *34*(3).

Wang, Z., Wu, Q. and Ma, S. (2024). Research on Carbon Emission Peaks in Large Energy Production Region in China —Based on the Open STIRPAT Model, *Global NEST Journal*, *26*(5).

Wang, Z., You, J., Li, T., & Zhang, Y. (2025). The era of digital trade: Exploring new mechanisms and threshold effects for green upgrading of manufacturing companies. *Journal of Environmental Management*, *373*, 123433.

Wen, H., & Zhu, K. (2024). Can digital trade promote the low-carbon development of China's transport sector. *Clean Technologies and Environmental Policy*, *26*(9), 3089-3105.

Wen, L., Ma, S., & Lyu, S. (2024a). The influence of internet celebrity anchors' reputation on consumers' purchase intention in the context of digital economy: from the perspective of consumers' initial trust. *Applied Economics*, 1-22.

Wen, L., Ma, S., and Su, Y. (2024b). Analysis of the interactive effects of new urbanization and agricultural carbon emission efficiency, *Global NEST Journal*, *26*(4).

Wen, L., Ma, S., Wang, C., Dong, B., Liu, H. (2025a). A Study of Green Strategy Choice and Behavioral Evolution of Consumers and Producers under the Double Subsidy Policy. *Polish Journal of Environmental Studies*.

Wen, L., Ma, S., Zhao, G., & Liu, H. (2025b). The Impact of Environmental Regulation on the Regional Cross-Border E-Commerce Green Innovation: Based on System GMM and Threshold Effects Modeling. *Polish Journal of Environmental Studies*, *34*(2).

Wen, L., Xu, J., Zeng, H., & Ma, S. (2025c). The impact of digital services trade in belt and road countries on China's construction green goods export efficiency: a time - varying stochastic frontier gravity model analysis. *Journal of Asian Architecture and Building Engineering*, 1–24.

Wu, Q., Jin, Y. and Ma, S. (2024). Impact of dual pilot policies for low-carbon and innovative cities on the high-quality development of urban economies, *Global NEST Journal*, *26*(9).

Wu, Y., Hou, L., Yuan, Y., Ma, S., & Zeng, H. (2025a). Green credit policy's influence on construction firm ESG performance: a difference in differences estimation. *Journal of Asian Architecture and Building Engineering*, 1-13.

Wu, Y., Zeng, H., Hao, N., & Ma, S. (2025b). The impact of economic policy uncertainty on the domestic value added rate of construction enterprise exports—evidence from China. *Journal of Asian Architecture and Building Engineering*, 1–15.

Xia, W., Ruan, Z., Ma, S., Zhao, J., & Yan, J. (2024). Can the digital economy enhance carbon emission efficiency? Evidence from 269 cities in China. *International Review of Economics & Finance*, 103815.

Yilanci, V., & Kilci, E. N. (2024). A study on the macroeconomic and financial determinants of telecommunication infrastructure: Evidence from Turkiye. *Technology in Society*, *77*, 102573.

Zeng, H. (2024). Risk transmission and diversification strategies between US real estate investment trusts (REITs) and green finance indices. *Kybernetes*.

Zeng, H., & Ahmed, A. D. (2023). Market integration and volatility spillover across major East Asian stock and Bitcoin markets: an empirical assessment. *International Journal of Managerial Finance*, *19*(4), 772-802.

Zeng, H., & Lu, R. (2022). High-frequency volatility connectedness and time-frequency correlation among Chinese stock and major commodity markets around COVID-19. *Investment Management & Financial Innovations*, *19*(2), 260.

Zeng, H., Abedin, M. Z., & Ahmed, A. D. (2024c). Quartile risk dependence between clean energy markets and the US travel and leisure index. *Current Issues in Tourism*, 1-25.

Zeng, H., Abedin, M. Z., & Lucey, B. (2024e). Heterogeneous dependence of the FinTech index with global systemically important banks (G-SIBs). *Finance Research Letters*, *64*, 105424.

Zeng, H., Abedin, M. Z., & Upreti, V. (2024b). Does climate risk as barometers for specific clean energy indices? Insights from quartiles and time-frequency perspective. *Energy Economics*, *140*, 108003.

Zeng, H., Abedin, M. Z., Ahmed, A. D., & Huang, Q. (2025b). Extreme risk connection among the European Tourism, energy and carbon emission markets. *Research in International Business and Finance*, *74*, 102693.

Zeng, H., Abedin, M. Z., Ahmed, A. D., & Lucey, B. (2025a). Quantile and Time–Frequency Risk Spillover Between Climate Policy Uncertainty and Grains Commodity Markets. *Journal of Futures Markets*, *45*(6), 659-682.

Zeng, H., Abedin, M. Z., Ahmed, A. D., & Lucey, B. (2025e). Connectedness and frequency connection among green bond, cryptocurrency and green energy-related metals around the COVID-19 outbreak. *Research in International Business and Finance*, *73*, 102547.

Zeng, H., Abedin, M. Z., Lucey, B., & Ma, S. (2024). Tail risk contagion and multiscale spillovers in the green finance index and large US technology stocks. *International Review of Financial Analysis*, *103865*.

Zeng, H., Abedin, M. Z., Lucey, B., & Ma, S. (2025f). Tail risk contagion and multiscale spillovers in the green finance index and large US technology stocks. *International Review of Financial Analysis*, *97*, 103865.

Zeng, H., Abedin, M. Z., Wu, R., & Ahmed, A. D. (2024a). Asymmetric dependency among US national financial conditions and clean energy markets. *Global Finance Journal*, *63*, 101046.

Zeng, H., Ahmed, A. D., & Lu, R. (2024d). The Bitcoin-agricultural commodities nexus: Fresh insight from COVID-19 and 2022 Russia–Ukraine war. *Australian Journal of Agricultural and Resource Economics*, *68*(3), 653-677.

Zeng, H., Benkraiem, R., Abedin, M. Z., & Hajek, P. (2025c). Transitioning to Sustainability: Dynamic Spillovers Between Sustainability Indices and Chinese Stock Market. *European Financial Management*.

Zeng, H., Huang, Q., Abedin, M. Z., Ahmed, A. D., & Lucey, B. (2025e). Connectedness and frequency connection among green bond, cryptocurrency and green energy-related metals around the COVID-19 outbreak. *Research in International Business and Finance*, *73*, 102547.

Zeng, H., Lu, R., & Ahmed, A. D. (2023). Return connectedness and multiscale spillovers across clean energy indices and grain commodity markets around COVID-19 crisis. *Journal of Environmental Management*, *340*, 117912.

Zeng, H., Wu, R., Abedin, M. Z., & Ahmed, A. D. (2025d). Forecasting Volatility of Australian Stock Market Applying WTC-DCA-Informer Framework. *Journal of Forecasting*.

Zeng, S., Jin, G., Tan, K., & Liu, X. (2023). Can low-carbon city construction reduce carbon intensity? Empirical evidence from low-carbon city pilot policy in China. *Journal of Environmental Management*, *332*, 117363.

Zhang, G., Ma, S., Zheng, M., Li, C., Chang, F., & Zhang, F. (2025). Impact of Digitization and Artificial Intelligence on Carbon Emissions Considering Variable Interaction and Heterogeneity: An Interpretable Deep Learning Modeling Framework. *Sustainable Cities and Society*, 106333.

Zhang, K., Li, Y., Ma, S., Fu, C. (2025). Research on the Impact of Green Technology Innovation in the Manufacturing Industry on the High-Quality Development of the Manufacturing Industry Under Dual Circulation. *Polish Journal of Environmental Studies*.

Zhang, X., Li, G., Wu, R., Zeng, H., & Ma, S. (2025a). Impact of Carbon Emissions, Green Energy, Artificial Intelligence and High-Tech Policy Uncertainty on China's Financial Market. *Finance Research Letters*, 107599.

Zhang, X. Li, D., Yan, H., & Ma, S. (2025b). Does Air pollution affect the green innovation of industrial enterprises? Insights from Urban Sewage Control Policies in China, *Global NEST Journal*.

Zhu, H., Bao, W., & Qin, M. (2024). Impact analysis of digital trade on carbon emissions from the perspectives of supply and demand. *Scientific Reports*, *14*(1), 14540.

Zou, F. Ma, S. Liu, H. Gao, T. and Li, W. (2024). Do Technological Innovation and Environmental Regulation Reduce Carbon Dioxide Emissions? Evidence from China, *Global NEST Journal*, *26*(7).