International Journal of Energy
ISSN: 2957-9473 | Vol. 5, No. 1, 2024

The Impact of Digital Economy Development on Carbon Emission Efficiency in the Logistics Industry

Lingjian Meng *

School of business administration, Anhui University of Finance and Economics, Bengbu, Anhui 233000, China

* **Corresponding author Email**: 1965045274@qq.com

Abstract: The digital economy has become an important engine of economic change, which has a complex impact on the carbon emission efficiency of the logistics industry. This study takes the panel data of 30 provinces in China from 2012 to 2021 as samples, measures the carbon emission efficiency of the logistics industry and the development level of the digital economy in each province by applying the super-efficiency SBM model and entropy value method, and constructs a two-way fixed-effects model to investigate the impact of the development of the digital economy on the carbon emission efficiency of the logistics industry. The results of the study show that the level of China's digital economy development shows a significant growth trend, and there are obvious differences between provinces and regions; the digital economy has a "U" curve effect on the carbon emission efficiency of the logistics industry, which first decreases and then increases. The carbon emission efficiency of the logistics industry is a wind vane for the green development of the logistics industry. Through the empirical analysis of the digital economy on the carbon emission efficiency, the U-shaped relationship between the digital economy and the carbon emission efficiency of the logistics industry has been clarified, which can help to guide the digital economy to serve the logistics industry, and play the role of a scientific reference for the government to grasp the overall situation of the carbon emission efficiency of China's logistics industry. The study will help to guide the digital economy to serve the logistics industry and provide a scientific reference for the government to grasp the overall situation of carbon emission efficiency in China's logistics industry.

Keywords: Digital Economy; Carbon Emission Efficiency in Logistics; Two-way Fixed Effect Model.

1. Introduction

Global warming is one of the most serious challenges facing the world today, and the 14th Five-Year Plan has clearly set out the goals of "carbon peaking" and "carbon neutrality", which China is actively addressing. China is actively responding to the dual challenges of maintaining economic growth and promoting energy conservation and emission reduction. The logistics industry, as a high-carbon emitting industry second only to the industrial and energy production industries, needs to be more efficient and sustainable [1]. As a high-carbon emitting industry, second only to industry and energy production, the logistics industry needs to operate in a more efficient and sustainable manner, and improving the carbon emission efficiency of the logistics industry has become a key part of realizing the goals of carbon peaking and carbon neutrality. With the rapid development and popularization of information technology, the digital economy is affecting the production of traditional industries at an unprecedented speed and scale, and becoming a new driving force for economic development [2].

The application of digital technologies to improve the operational efficiency of the logistics industry, such as big data analytics, the Internet of Things (IoT), intelligent warehousing systems, and electric transportation tools, is transforming the way the logistics industry operates, resulting in increased industry efficiency, lower costs, and reduced carbon emissions [3]. Promoting the green transformation of the logistics industry through digitalization and promoting energy saving and emission reduction while maintaining the efficiency growth of the logistics industry are the key development directions of China's logistics industry. Against this background, the questions to be explored in this paper are: What is the level of development of the digital economy? What is the carbon emission efficiency of the logistics industry? How does the development of digital economy affect the carbon emission efficiency of logistics industry? In this paper, we will study the intrinsic connection between the digital economy and the carbon emission efficiency of the logistics industry, analyze the level of development of the digital economy and the current situation of the carbon emission efficiency of the logistics industry, and test the impact of the development of the digital economy on the carbon emission efficiency of the logistics industry from the perspective of empirical evidence, so as to provide a powerful initiative for the green transformation of the global logistics industry and the response to climate change, and to contribute to the construction of a more sustainable and greener future.

2. Literature Overview

2.1. Studies on the Digital Economy

Digital economy refers to a series of economic activities in which digital resources are the key production factors, modern information networks are the important carriers, and the effective use of information and communication technologies is the important driving force for efficiency improvement and optimization of the economic structure [4]. The measurement of the development level of digital economy is also increasingly rich. Most scholars analyze the connotation of digital economy, build the evaluation index system of digital economy development level, and use entropy weight method, coefficient of variation method, entropy weight TOPSIS method, entropy value method, principal component analysis and other methods to measure the level of digital economy development [5-9]. Some scholars also innovate on top of the basic measurement methods, such as Xiang Yu and Zhao Jingmei, who use the entropy weight method combined with the linear combination method to measure the development level of regional digital economy [10].

The section headings are in boldface capital and lowercase letters. Second level headings are typed as part of the succeeding paragraph (like the subsection heading of this paragraph). All manuscripts must be in English, also the table and figure texts, otherwise we cannot publish your paper. Please keep a second copy of your manuscript in your office. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use the paper for the book or journal in question. When receiving the paper, we assume that the corresponding authors grant us the copyright to use.

2.2. Studies on Carbon Emission Efficiency in the Logistics Industry

The carbon emission efficiency of the logistics industry not only considers the carbon emission of the logistics industry, but also comprehensively considers the interaction between input factors such as labor and capital and output factors such as economic output and carbon emission, which can objectively reflect the low carbon development level of the logistics industry. It can objectively reflect the level of low-carbon development of the logistics industry. The main methods of logistics industry carbon emission efficiency include Data Envelopment Analysis (DEA), Super Efficiency SBM model (SBM), and Stochastic Frontier Analysis (SFA) and Stochastic Frontier Analysis (SFA) [11-13]. At present, scholars are more likely to explore the impact of energy intensity, industrial structure, industrial agglomeration, government regulation, scientific and technological innovation and other important factors on the carbon emission efficiency of the logistics industry [14-16], but not enough attention has been paid to the impact of the digital economy on the carbon emission efficiency of the logistics industry.

2.3. Studies on the Impact of Digital Economy Development on Carbon Emission Efficiency of Logistics Industry

The application of digital technology can promote the development of intelligent logistics and modern logistics [17], The application of digital technology can promote the development of smart logistics and modern logistics, optimize the logistics operation process, improve the efficiency of logistics operation, and empower the low-carbon transformation of the logistics industry [18]. The application of digital technology can promote the development of intelligent logistics and modern logistics. For example, the application of digital technologies such as Internet of Things, big data analysis and cloud services can optimize logistics transportation routes and improve loading rates, thus significantly improving logistics transportation efficiency and reducing carbon emissions.[19] The application of artificial intelligence can assist in warehouse automation and improve warehousing efficiency.[20] Blockchain and Internet of Things (IoT) technologies can improve supply chain transparency, real-time monitoring and optimization of the supply chain, thus reducing unnecessary energy consumption.[21] . The development of the digital economy significantly improves the integration level of the manufacturing and logistics industries, promotes the integration of the logistics industry and the development of the manufacturing industry, significantly promotes carbon emission reduction in the manufacturing and transportation industries, and improves the operational efficiency of the logistics industry.[22, 23] The digital economy has significantly reduced the carbon emissions of manufacturing and transportation industries and improved the operational efficiency of logistics industry. Zhong Wen et al. found that the digital economy significantly inhibits carbon emissions in the logistics industry, and the marginal impact decreases with the increase of quartiles [24].

In summary, existing research on digital economy, carbon emission efficiency of logistics industry and the impact of digital economy on logistics industry has been relatively rich, but there are still deficiencies: first, regarding the measurement of digital economy, the connotation of digital economy is rich, and the establishment of evaluation indexes of digital economy is still under continuous exploration. Secondly, there is insufficient theoretical research and empirical analysis focusing on the impact of the digital economy on the carbon emission efficiency of the logistics industry, which may lead to insufficient in-depth research in this key area and mismatch with the urgent need for carbon emission reduction in the logistics industry. Third, existing studies are inconclusive about the relationship between the digital economy and the carbon emission efficiency of the logistics industry. Previous studies have argued that digital economy development can improve the operational efficiency of the logistics industry as well as energy utilization, but some scholars have also argued that digital economy development exacerbates the carbon emissions of the logistics industry, which reflects the complexity of the field and the need for more in-depth empirical studies to explore the impact of digital economy development on the carbon emission efficiency of the logistics industry. Based on the panel data of 30 provinces in China from 2012 to 2021, this paper empirically examines the impact of the digital economy on carbon emissions in the logistics industry, which enriches the research related to the digital economy and carbon emission efficiency in the logistics industry, and has certain practical significance for policy formulation.

3. Research Design and Description of Variables

3.1. Modeling

3.1.1. Super-efficient SBM Model

DEA and SBM models have certain advantages in solving the efficiency measurement problem of multiple inputs and multiple outputs, but traditional radial models do have some limitations, including the inability to deal with input-output slackness, the difficulty of distinguishing between decision-making units with the same maximum efficiency value of 1, and the failure to take into account the condition of undesired outputs, etc. [25]. These limitations may make it insufficiently accurate and comprehensive in measuring, for example, carbon emission efficiency. Therefore, the application of the non-expected super-efficiency SBM model can better overcome these shortcomings and provide a more comprehensive and accurate measurement.

$$min \qquad \rho = \frac{1+\frac{1}{m}\sum_{t=1}^{m}\frac{s_i^-}{x_{ik}}}{1-\frac{1}{q_1+q_2}\left(\sum_{s=1}^{q_1}\frac{s_r^+}{y_{rk}}+\sum_{t=1}^{q_2}\frac{s_t^{z-}}{z_{tk}}\right)}$$

$$s.t. \quad \begin{cases} X\lambda \le x_k - s^- \\ Y\lambda \le y_k + s^+, \\ Z\lambda \le z_k - s^{z-}, \\ \frac{1}{q_1+q_2}(\sum_{s=1}^{q_1}\frac{s_r^+}{y_{rk}}+\sum_{t=1}^{q_2}\frac{s_t^{z-}}{z_{tk}}) > 0; s^-, s^+, \lambda > 0, \\ i = 1,2,\cdots,m; s = 1,2,\cdots,q_1; t = 1,2,\cdots,q_2; j = 1,2,\cdots,n, (j \ne k), \end{cases}$$

Where: there are n decision-making units DMUs of carbon emission efficiency in China's logistics industry, each DMU has m input indicators, q_1 desired output indicators and q_2 non-desired output indicators. x is the input variable, y is the desired output, z is the non-desired output, s^- .s^+ and s^{z-} are the relaxation variables of x , y ,and z, respectively. ρ is the carbon emission efficiency of the logistics industry of each evaluation unit. emission efficiency of each evaluation unit.

3.1.2. Two-way Fixed Effects Model

In order to examine the impact of the level of digital economy development on the carbon emission efficiency of the logistics industry, a two-way fixed effect model is constructed:

$$\mathrm{LCE}_{it} = \beta_0 + \beta_1 DED_{it} + \beta_2 DED_{it}^2 + \beta_3 Control_{it} + \mu_i + \gamma_t + \varepsilon_{it}$$

where the explanatory variable LCE_{it} is the carbon emission efficiency of the logistics industry in province i in year t and the core explanatory variable DED_{it} is the level of development of the digital economy in province i in year t. In order to verify the nonlinear relationship between digital economy development and logistics industry carbon emission efficiency, the squared terms of the digital economy development level are included in the model. $Control_{it}$ are control variables for energy intensity (EI), government support (GOV), industrial agglomeration (IA), industrial structure (IS), science and technology innovation (RD). μ_i ,γ_t , and ε_{it} denote individual fixed effects, time fixed effects, and random error terms, respectively.

3.2. Selection of Variables

3.2.1. Explained Variables

In this paper, the carbon emission efficiency (LCE) of the logistics industry of 30 provinces in China, except Hong Kong, Macao, Taiwan and Tibet, for each year from 2012 to 2021 is selected as the explanatory variable. The super-efficiency SBM model based on non-desired output is chosen to measure the carbon emission efficiency of the logistics industry by taking the labor, capital and energy of the logistics industry as the input indicators, the real GDP of the logistics industry as the desired output indicator, and the carbon dioxide emission as the non-desired output indicator. emissions as a non-desired output indicator to measure the carbon emission efficiency of the logistics industry. The price variables are deflated at constant 2012 prices. Specific measurement indicators are shown in Table 1.

Table 1. Indicators for measuring the carbon emission efficiency of the logistics industry

Level 1 indicators	Secondary indicators	Tertiary indicators
Inputs	labor	Railroad, road, water, air, pipeline, multimodal transport, transport agency, loading and unloading, warehousing, postal workers cumulative
	principal	Fixed asset investment in the logistics industry
	renewable energy	The 7 types of energy with the largest proportion of one-time energy consumption in the logistics industry are uniformly converted into standard coal, standard coal = energy consumption * conversion factor
Expected outputs	Real GDP of the logistics industry	Value added of the logistics industry sector
Non-expected outputs	CO2 Discharge	Logistics CO2 emissions = energy consumption * carbon emission factor

Referring to the studies of other scholars, data related to the transportation, storage and postal industry were used to replace the data of the logistics industry for the analysis [26,27]. The specific energy-consuming fuels and corresponding conversion factors are referred to the China Energy Statistics Yearbook. The specific energy consumption fuels and the corresponding conversion coefficients refer to China Energy Statistics Yearbook, as shown in Table 2. The specific calculation method of carbon emissions from the logistics industry is as follows [28]. The specific calculation method of carbon emission from logistics industry is as follows.

$$\begin{aligned} CE &= \textstyle\sum_{i=1}^{n} AD_i \times NCV_i \times O_i \times CC_i \\ &= AD_i \times EF_i \end{aligned}$$

CE represents the CO2 emissions from the logistics industry, while AD_i, NCV_i, O_i, CC_i and EF_i represent the consumption of i fuels, net calorific value, oxidation rate of the logistics industry, carbon content per unit of net calorific value, and carbon emission factor, respectively. Please refer to Table 2 for the measurement results.

Table 2. Table of carbon emission factors

Main types of energy consumption in the logistics industry	raw coal	gasoline	diesel fuel	diesel	petroleum	fuel oil	liquefied petroleum gas
Conversion factor (kg standard coal/kg)	0.714	1.471	1.457	1.471	1.330	1.429	1.714
Carbon emission factor (t carbon/t standard coal)	0.409	0.828	0.834	0.798	0.584	0.871	0.784

3.2.2. Core Explanatory Variables

According to the "14th Five-Year Plan for the Development of the Digital Economy", "Statistical Classification of the Digital Economy and its Core Industries (2021)", and with reference to the research of other scholars [6, 29], this paper argues that the digital economy includes not only the infrastructure that guarantees the sustained development of the digital economy, as well as the digital technology that promotes the development of real industries and innovation, integration of digital technology to promote the development of real industry, innovation, digital industry, but also includes the digital environment to carry the development of digital economy. Among them, digital infrastructure as the cornerstone of the development of digital economy; the integrated development of digital industry is the core of the digital economy; the digital economic environment is the carrier of the development of the digital economy, to ensure the sustainable development of the digital economy. Therefore, this paper focuses on the three dimensions of digital infrastructure, digital industry development and digital economic development environment, and builds the evaluation index system of digital economic development level (Table 3). The entropy method is an objective assignment method that objectively assesses the weights of multiple factors based on the principle of information entropy, reducing the influence of subjective bias [9].

Table 3. Indicator system for evaluating the level of development of the digital economy

Primary indicators	**Secondary indicators**	**Tertiary indicators**	**unit (of measure)**
digital infrastructure	software infrastructure	Internet pages per 100 population	classifier for individual things or people, general, catch-all classifier
		Internet domain names per 100 people	classifier for individual things or people, general, catch-all classifier
	Hardware infrastructure	Internet broadband access ports per square kilometer	classifier for individual things or people, general, catch-all classifier
		Cell phone base stations per square kilometer	classifier for individual things or people, general, catch-all classifier
		Length of long-distance fiber-optic cable lines per square kilometer	kilometer
Digital industry development	digital industrialization	Total telecommunication services	billions
		Revenue from software operations	billions
		Income from information technology services	billions
	Industrial Digitization	E-commerce sales	billions
		Percentage of enterprises engaged in e-commerce transactions	%
		Websites per 100 businesses	classifier for individual things or people, general, catch-all classifier
		Digital Inclusive Finance Index	/
digital economy development environment	Digital Living Environment	Cell phone penetration rate	Departments/100 persons
		Mobile Internet penetration	Households/100 persons
	Digital Talent Environment	Employed in information, software and information technology services	all the people
	Digital innovation environment	Patent applications granted	classifier for individual things or people, general, catch-all classifier
		Full-time equivalent of R&D personnel	man-year

3.2.3. Control Variables

In order to improve the reliability of the results of the impact of the digital economy on the carbon emission efficiency of the logistics industry, with reference to the existing studies, this paper selects energy intensity (EI), government support (GOV), industrial agglomeration (IA), industrial structure (IS), and scientific and technological innovation (RD) as the control variables from the aspects of energy consumption, governmental regulation, scale effect, structural effect, and technological effect, respectively [30]. The calculation methods of control variables and their influence pathways are shown in Table 4.

Table 4. Indicators of control variables

variable name	calculation method	Pathways of influence	note
Energy intensity (EI)	Energy consumption/gross regional product	Energy intensity is the relationship between energy consumption per unit and output, and unreasonable energy intensity will generate the necessary energy consumption and constrain the sustainable development of the logistics industry	energy consumption
Government support (GOV)	Logistics fiscal expenditure/total fiscal expenditure	Government support, including investment, regulations, tax policies and R&D funding, can encourage logistics companies to adopt more environmentally friendly technologies and operational practices, improve the productivity of the logistics industry and promote sustainable development.	The role of government regulation
Industrial Agglomeration (IA)	Logistics Industry Location Quotient Index	Industrial agglomeration can produce synergistic effects within a certain region, which helps to reduce the distance of logistics transportation, improve the efficiency of resource utilization and prompt logistics enterprises to pursue efficiency more, thus potentially reducing carbon emissions.	scale effect
Industrial Structure (IS)	Value added of tertiary sector/GDP	The digital and logistics industries are both tertiary industries, and the characteristics of the industrial structure usually have some positive impact on the carbon efficiency of the logistics industry, which is usually more likely to adopt environmentally friendly technologies and innovations to improve efficiency.	structural effect
Science, technology and innovation (RD)	R&D investment intensity	Science and technology innovation can shape a more environmentally friendly and efficient logistics and transportation system by promoting the application of advanced technologies.	technological effect

3.3. Data Sources and Descriptive Statistical Analysis

Considering data availability, this paper selects 2012-2021 as the sample interval, excludes data from Hong Kong, Macao, Taiwan and Tibet, and selects panel data from 30 provinces (autonomous regions and municipalities directly under the central government) in China. The data in the main table are derived from China Statistical Yearbook, China Information Yearbook, China Energy Statistical Yearbook, China Tertiary Industry Statistical Yearbook, China Information Industry Yearbook and National Bureau of Statistics. Table 5 shows the results of descriptive statistical analysis with 300 valid values.

Table 5. Descriptive statistical analysis

variant	notation	sample size	average value	upper quartile	(statistics) standard deviation	minimum value	maximum values
Carbon emission efficiency in the logistics industry	LCE	300	0.420	0.344	0.284	0.083	1.401
Level of development of the digital economy	DED	300	0.102	0.064	0.109	0.009	0.677
Level of development of the digital economy^2	DED^2	300	0.022	0.004	0.053	0.000	0.458
energy intensity	EI	300	0.036	0.032	0.016	0.014	0.086
government support	GOV	300	0.064	0.060	0.025	0.023	0.191
industrial agglomeration	IA	300	0.665	0.826	0.539	0.026	1.942
industrial structure	IS	300	0.484	0.477	0.095	0.309	0.839
technological innovation	RD	300	1.737	1.480	1.149	0.450	6.530

4. Analysis of Empirical Results

Based on the panel data of 30 provinces (autonomous regions and municipalities directly under the central government) in China except Hong Kong, Macao, Taiwan and Tibet from 2012 to 2021, in order to control the effects of individual differences in samples and the macroeconomic environment, this paper uses a two-way fixed-effects model to conduct regression, and considers the clustering of the robust standard errors to eliminate the effects of heteroskedasticity, and the results are shown in Table 6.

Columns (1) and (2) enable to explore the effect of the primary term of the level of digital economy development on the carbon emission efficiency of the logistics industry, in which column (1) does not include the control variables and column (2) includes the control variables. The results show that the carbon emission efficiency of logistics industry is significantly negatively correlated with the level of development of digital economy when the control variables are not added, and this result is no longer significant after the control variables are added. To further explore the nonlinear relationship between digital economy and carbon emission efficiency of logistics industry, columns (3) and (4) add the quadratic term of the level of digital economy development on the basis of columns (1) and (2), and the results show that the coefficients of the primary term of the level of digital economy development are significantly negative and the coefficients of the quadratic term are significantly positive. This shows that there is a significant "U" curve relationship between the level of development of digital economy and the carbon emission efficiency of logistics industry, and if we only consider the impact of the primary term of the level of development of digital economy on the carbon emission efficiency of logistics industry, we are bound to misjudge the relationship between the digital economy and the carbon emission efficiency of logistics industry.

Table 6. The results

	(1)	(2)	(3)	(4)
	LCE	LCE	LCE	LCE
DED	-1.546**	-0.726	-4.052***	-3.293**
	(0.659)	(0.527)	(0.835)	(1.452)
DED^2			3.123***	3.139**
			(0.994)	(1.435)
EI		3.945		3.479
		(2.979)		(2.687)
GOV		-0.967		-1.108
		(0.813)		(0.827)
IA		0.255***		0.262***
		(0.083)		(0.083)
IS		0.620		0.708*
		(0.374)		(0.393)
RD		-0.114*		-0.071
		(0.068)		(0.068)
cons	0.516***	0.273	0.629***	0.318
	(0.048)	(0.236)	(0.082)	(0.237)
sample size	300	300	300	300
R^2	0.150	0.297	0.182	0.327
fixed time	Y	Y	Y	Y
Province fixed	Y	Y	Y	Y
inflexion point			0.649	0.525

From column (4) the inflection point is 0.525, combined with Table 6, it can be seen that from the national and three large regions level, the average development level of the digital economy is located on the left side of the inflection point, indicating that at this stage, the digital economy does not enhance the carbon emission efficiency of the logistics industry, but rather reduces the carbon emission efficiency of the logistics industry; from the level of the provinces, Beijing was located in 2019 on the right side of the inflection point, indicating that the development of the digital economy has significantly improved the carbon emission efficiency of the logistics industry in Beijing's logistics industry carbon emission efficiency Guangdong, Shanghai 2021 digital economy development score of 0.485 and 0.459, respectively, close to the inflection point, the rest of the provinces of the digital economy development level is farther away from the inflection point, which indicates that the difference in the level of the digital economy development of the provinces is huge, and its impact on the logistics industry carbon emission efficiency is also obvious differences.

Overall, there is a "U" type relationship between the digital economy and the carbon emission efficiency of the logistics industry, and the current digital economy is in the first half of the curve, and does not improve the carbon emission efficiency of the logistics industry, but rather play an inhibitory role. This may be due to the late start of China's digital economy development, the overall level is low, when the level of digital economic development has not reached a certain height, the digital economy of the logistics industry carbon emission reduction effect is less than its promotion of the logistics industry economic growth incidental to the carbon emissions effect, resulting in a reduction in the overall carbon emissions efficiency of the logistics industry. In addition, the development of the digital economy will increase electricity consumption, which will also increase carbon emissions. Therefore, provinces still need to vigorously develop the digital economy to cross the inflection point as soon as possible and realize the "digital carbon reduction" effect of the logistics industry.

Among the control variables, the coefficient of industrial agglomeration (IA) is positive with a p-value of less than 0.01, passing the 1% significance test. This indicates that as the degree of industrial agglomeration increases, it can significantly improve the efficiency of carbon emissions in the logistics industry. This is due to the fact that industrial agglomeration can produce synergistic effects in a certain region, which helps to reduce the logistics transportation distance, improve the efficiency of resource utilization and prompt logistics enterprises to pursue efficiency more, thus potentially reducing carbon emissions. The coefficient of industrial structure (IS) is positive, with a p-value less than 0.1, which indicates that industrial structure is significantly positively correlated with the carbon emission efficiency of the logistics industry, and that increasing the proportion of tertiary industry and optimizing the industrial structure have a contributing effect on the improvement of the carbon emission efficiency of the logistics industry.

5. Conclusion

The level of China's digital economy development shows a significant growth trend between 2012 and 2021, and there are obvious differences between provinces and regions. The digital economy has a "U" curve effect on the carbon emission efficiency of the logistics industry, which is first reduced and then improved. There is a direct U-shaped relationship between the digital economy and the carbon emission efficiency of the logistics industry, and the level of development of the digital economy is in the first half of the curve, which does not improve the carbon emission efficiency of the logistics industry, but rather plays an inhibitory role. The upgrading of industrial structure and industrial agglomeration have obvious promotion effects on the improvement of carbon emission efficiency of logistics industry.

Therefore, it is crucial to correctly understand the relationship between the development of digital economy and the carbon emission efficiency of the logistics industry. At present, China's digital economy has a relatively low level of development, which negatively affects the carbon emission efficiency of the logistics industry; however, the positive effects of the digital economy should not be denied, and the development of the digital economy should be accelerated to quickly pass the inflection point of the digital economy, so that the digital carbon reduction effect can be realized as soon as possible.

Acknowledgments

This work was supported by the Graduate Student Research and Innovation Fund Program of Anhui University of Finance and Economics (ACYC2022031).

References

[1] Li Xiaomei, Huang Jun. Evolutionary characteristics and convergence analysis of logistics carbon emission efficiency in Chinese provinces[J]. World Geography Research, 2023.

[2] Fu Xiaodong. Digital economy: A new driving force for China's economic development[J]. People's Forum, 2020(21): 20-23.

[3] LI Jinlin, CHEN Litai, LIU Mei. Impact of Internet development on regional green economy efficiency in China[J]. China Population-Resources and Environment, 2021,31 (10): 149-157.

[4] Li Xiaohua. New features of the digital economy and the formation mechanism of the new momentum of the digital economy [J]. Reform, 2019(11):40-51.

[5] ZHAO Tao, ZHANG Zhi, LIANG Shangkun. Digital economy, entrepreneurial activity and high-quality development - Empirical evidence from Chinese cities[J]. Management World, 2020, 36(10):65-76.

[6] LI Shunyong, ZHANG Ruixuan, ZHANG Jiaxuan, et al. A study on measuring the development level of digital economy in Chinese provinces[J]. Productivity Research, 2022(12):38-42.

[7] Sheng B, Liu YY. A study on the measurement and spatial differentiation characteristics of China's digital economy development index[J]. Nanjing Social Science, 2022(01):43-54.

[8] Sun Yuanxu, Lei Na, Liu Xiaoqian. Can digital economy promote urban-rural integrated development? --Empirical Evidence from 268 Cities in China[J]. Southern Finance, 2024.

[9] WANG Jun, ZHU Jie, LUO Xi. Development level and evolution measurement of China's digital economy[J]. Research on Quantitative and Technical Economics, 2021,38 (07): 26-42.

[10] Xiang Yu, Zhao Jingmei. Research on local financial sustainability based on digital economy[J]. China Soft Science, 2023 (03):203-212.

[11] Yao Yuanke. Research on carbon emission efficiency of China's logistics industry based on DEA-BCC model[J]. Economist, 2021(06):143-144.

[12] LI Chen, FENG Wei, SHAO Guilan. Spatial and temporal differentiation of total factor carbon emission efficiency of fisheries in Chinese provinces[J]. Economic Geography, 2018, 38 (05):179-187.

[13] Bibi Z, Khan D, Haq I U. Technical and environmental efficiency of agriculture sector in South Asia: a stochastic frontier analysis approach[J]. Environment, Development and Sustainability, 2021,23:9260-9279.

[14] LIU Chengliang, GUAN Mingming. Spatial evolution and influencing factors of the efficiency of China's logistics industry under low-carbon constraints[J]. Geoscience, 2017,37 (12): 1805-1814.

[15] LIN Xueqin, BIAN Yu, WANG Dai. Characteristics of spatial and temporal evolution of industrial carbon emission efficiency in the Beijing-Tianjin-Hebei region and its influencing factors [J]. Economic Geography, 2021,41(06):187-195.

[16] WANG K W M S Y. Resource Abundance, Industrial Structure and Regional[J]. 2019(60):203-214.

[17] He Liming. Current situation and trend of the development of intelligent logistics in China[J]. China National Condition and National Power, 2017(12):9-12.

[18] SUN Fei, LIU Ying, SUN Chongliang, et al. Mechanisms of digital empowerment on low-carbon transformation of traditional energy industry[J]. Science and Technology Management Research, 2024,44(02):172-180.

[19] Capocasale V, Gotta D, Musso S, et al. A Blockchain, 5G and IoT-based transaction management system for Smart Logistics: an Hyperledger framework: 2021 IEEE 45th Annual Computers, Software, and Applications Conference (COMPSAC) [C], 2021. ieee.

[20] Apruzzese M, Bruni M E, Musso S, et al. 5G and companion technologies as a boost in new business models for logistics and supply chain[J]. Sustainability, 2023,15 (15): 11846.

[21] Negueroles S C, Simón R R, Julián M, et al. A Blockchain-based Digital Twin for IoT deployments in logistics and transportation[J]. Future Generation Computer Systems, 2024.

[22] Feng Y. The Impact of the Digital Economy on the Integration and Development of Manufacturing and Logistics Industries[J]. Frontiers in Business, Economics and Management, 2023,12 (2): 232-239.

[23] She Qunzhi, Wu Liu. Carbon emission reduction effect of digital economy development[J]. Economics, 2022,39(05):14-24.

[24] Zhong W, Yang J, Zheng MG, et al. Effects of digital economy on carbon emissions from logistics industry in Chinese cities and the transmission mechanism[J]. China Environmental Science, 2024,44(01):427-437.

[25] Andersen P, Petersen N C. A procedure for ranking efficient units in data envelopment analysis[J]. Management science, 1993,39(10):1261-1264.

[26] LIU Chengliang, GUAN Mingming. Spatial evolution and influencing factors of the efficiency of China's logistics industry under low-carbon constraints[J]. Geoscience, 2017,37 (12): 1805-1814.

[27] Xu Weigang. Carbon emission efficiency measurement of China's provincial logistics industry based on Super-PEBM model[J]. Journal of Economic Research, 2022(13):38-42.

[28] Shan Y, Guan D, Liu J, et al. Methodology and applications of city level CO2 emission accounts in China[J]. Journal of Cleaner Production, 2017,161:1215-1225.

[29] HE Di, ZHAO Xianzhuo, QI Qi. A study on the measurement, spatial and temporal pattern and regional differences of China's digital economy development level[J]. Industrial Technology and Economics, 2023,42(03):54-62.

[30] Grossman G M, Krueger A B. Economic growth and the environment[J]. The quarterly journal of economics, 1995, 110(2):353-377.