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THE IMPACT OF ENVIRONMENTAL REGULATION ON THE CARBON EMISSION EFFICIENCY OF THE LOGISTICS INDUSTRY IN YRD

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Abstract: Against the backdrop of global climate change, the carbon emissions of the logistics industry are becoming increasingly prominent. The research focuses on the impact of environmental regulation on the carbon emission efficiency of the logistics industry, based on the panel data of the Yangtze River Delta region from 2011-2021, the super efficiency SBM model is used to measure the carbon emission efficiency, and the mechanism of the command and market incentive environmental regulation tools is empirically analyzed with the random effect model. It has found that both environmental regulatory tools have a significant positive impact on the carbon emission efficiency of the logistics industry; the improvement of technological innovation level, foreign investment level, and financial development level also helps to enhance the carbon emission efficiency. This study enriches the research perspective on the relationship between environmental regulation and industry carbon emission efficiency, providing a theoretical basis for the agency to formulate scientific and reasonable environmental regulation policies.
Keywords: Environmental regulation; Logistics industry; Carbon emission efficiency; Super efficient SBM model; Random effect model

1 INTRODUCTION

Global climate change has become one of the most pressing challenges facing humanity in the 21 century [1]. With the signing of the Paris Agreement, agencys are working to reduce greenhouse gas emissions in order to limit the rise in global average temperature [2]. The logistics industry, as an important support for economic and social development, has been developing rapidly in recent years and at the same time has brought about a large amount of carbon emissions, putting pressure on the regional ecological environment [3]. According to the International Energy Agency (IEA), the transportation sector accounts for nearly a quarter of the world's total carbon emissions, and logistics activities, as an important part of the sector, have a huge potential for reducing emissions. How to realize carbon emission reduction while promoting the development of the logistics industry has become an urgent issue.

Environmental regulation, as an important means for the agency to regulate economic development and environmental protection, has received widespread attention due to its impact on carbon emission efficiency, research results are not consistent. One view is that environmental regulations increase compliance costs for businesses, and driven by the goal of maximizing profits, businesses may be unwilling to invest in technological innovation, resulting in higher pollutant emissions [4,5]. More scholars believe that reasonable environmental regulations can force high energy consuming and high polluting enterprises to innovate production technology and upgrade pollution control technology, thereby reducing pollutant emissions [6-8]. The effects and mechanisms of heterogeneous environmental regulatory tools on carbon emissions are different [9], and there is spatial heterogeneity in the carbon reduction effects of different regions and manufacturing industries [10,11]. Scholars have proposed an inverted U-shaped relationship between environmental regulation and carbon emission [12], where a green paradox effect exists when environmental regulation is at a low level, and innovative emission reduction effects begin to emerge after reaching a threshold [13].

A review of the existing literature reveals that most research perspectives focus on the macro-regional level or traditional energy-consuming industries such as industry and manufacturing, and pay insufficient attention to the logistics industry, which is a modern service industry that is both basic and high-growth in nature [14]. Taking the Yangtze River Delta (YRD) region as a research unit, this study constructs a super-efficient SBM model with undesired outputs to systematically measure the carbon emission efficiency of the logistics industry from 2011 to 2021, and empirically examines the paths of the two types of environmental regulatory tools based on the random-effects model. On the theoretical level, this study expands the application scenarios of environmental regulation theory in the service industry by revealing the industry-specificity of the carbon emission efficiency of the logistics industry and the law of regulatory tool adaptation; on the methodological level, the combination of the super-efficient SBM model with the panel data model provides methodological innovation for the multi-dimensional evaluation of environmental policy effects. The study can, on the one hand, provide a decision-making basis for the agency to formulate a more scientific and reasonable environmental regulation policy, and promote the coordinated development of the logistics industry and environmental protection; on the other hand, it can help to guide the logistics enterprises to strengthen the technological innovation and management innovation, to improve the efficiency of carbon emission, to reduce the operation cost and to enhance the market competitiveness.

2 METHOD

2.1 Modeling

In this paper, the random effects model is used to investigate the impact of two environmental regulation tools on the carbon emission efficiency of the logistics industry. Random effects model (REM) treats the regression coefficients in the original fixed effects model as random variables, which is mainly used for modeling and analyzing panel data and longitudinal data, and it is an effective tool for solving the correlation problem of statistical data due to clustering. Compared with the fixed-effects model, the random-effects model requires fewer model coefficients to be estimated and has a higher degree of freedom in the model [15]. This means that in the case of limited data sample size, the random effects model can better utilize the data and improve the model fitting effect and prediction accuracy. The specific formula is as follows:

$$Y_{it} = \alpha_i + X_{it}^{\mathrm{T}}\beta_{it} + u_i + \omega_{it}\# \tag{1}$$

Where $i = 1,2,\cdots,N$ is different individuals in the panel data; $t = 1,2,\cdots,T$ is different time in the panel data. Y_{it} is the explained variable, here is the carbon emission efficiency of the logistics industry; X_{it} is the explanatory variable, $X_{it} = \left(X_{1,it}, X_{2,it}, \cdots, X_{k,it}\right)^{\mathrm{T}}$, including the two environmental regulation tools of command and market incentive ; α_i denotes the unknown parameter ; u_i is the random error term of the i th individual.

2.3 Explained Variables

Carbon emission efficiency refers to the maximum economic growth and minimum CO_2 emissions that can be obtained with no increase in capital, labor and energy inputs, which means more economic output and better quality of life with less carbon emissions. In our research, the carbon emission efficiency of the logistics industry is modeled by the super-efficient SBM model that takes into account the undesired output [16]. The specific calculation formula is as follows.

$$\begin{gathered} min\rho^* = \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{X_{ik}}}{1-\left[\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{rk}^g}+\sum_{t=1}^{s_2}\frac{s_r^b}{y_{tk}^b}\right)\right]} \\ s.t.\, x_{ik} \geq \sum_{j=1,j\neq k}^{n} x_{ij}\,\lambda_j - s_i^- \\ y_{ik} \geq \sum_{j=1.j\neq k}^{n} y_{tj}^b\,\lambda_j - s_t^b \\ 1-\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{rk}^g}+\sum_{t=1}^{s_2}\frac{s_r^b}{y_{tk}^b}\right) > 0 \\ s^- 、 s^g 、 s^b 、 \lambda \geq 0 \end{gathered} \tag{2}$$

Where n denotes the decision unit; s_1 denotes the desired output element; m denotes the production input element; s_2 means the undesired output element; s^g is the undesired output element; s^- is the undesired output element; s^b denotes the undesired output element; λ is the vector of weights; k is the unit being evaluated; and ρ^* is the efficiency value of the decision unit.

The study takes capital, labor and energy inputs as the input indicators for measuring the carbon emission efficiency of the logistics industry. The capital input indicator is the capital stock of the logistics industry in each province and city, which will be calculated by using the perpetual inventory method (PIM) at constant price. The labor input indicator is expressed by the number of employees in the logistics industry in each province. The energy input indicator is expressed by the energy consumption of logistics industry in each province (municipality directly under the central agency) .

The output indicator is divided into two indicators: desired output and non-desired output. The desired output indicator is chosen to be represented by the value added of the logistics industry . The non-desired output will be characterized by the carbon emissions of the logistics industry [17]. The calculation of carbon emissions is based on the formula provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories prepared by the Interagencyal Panel on Climate Change [18] . The formula is shown below.

$$CO_2 = \sum CO_{2,i} = \sum E_i \times NCV_i \times CEF_i \times COF_i \times \frac{44}{12} \tag{3}$$

Where, i indicates the type of final energy consumption, this research selects kerosene, natural gas, raw coal, diesel, fuel oil, gasoline and electricity as the main sources of energy consumption in the logistics industry, and the detailed data are shown in Table 2. NCV indicates the low-level heat production; CEF is the carbon content; COF is the carbon oxidation rate ;44 and 12 indicate the molecular weight of carbon dioxide and carbon, respectively; and $NCV_i \times CEF_i \times COF_i \times \frac{44}{12}$ means the way of calculating the carbon emission coefficients of the respective fossil fuels.

Table 2 Detailed Data Sheet for Energy Measurement

Energy source	Average low calorific value (kJ/kg)	Carbon content per unit calorific value (kJ/kg)	Carbon oxidation rate	Conversion standard coal factor (Kgce/Kg)	Carbon emission factor (kg-CO2/kg)

raw coal	20908	26.37	0.94	0.7143	1.9003
crude oil	41816	20.1	0.98	1.4286	3.0202
diesel	43070	18.9	0.98	1.4714	2.9251
gasoline	43070	19.5	0.98	1.4714	3.0179
diesel fuel	42652	20.2	0.98	1.4571	3.0959
fuel oil	41816	21.1	0.98	1.4286	3.1705
liquefied petroleum gas	50179	17.2	0.98	1.7143	3.1013
petroleum	38931kJ/m3	15.3	0.99	1.215 Kgce/m3	2.1622 kg-CO2/m3
electrical power	-	-	-	0.404Kgce/Kw.h	-

2.3 Explanatory Variables

Scholars have categorized environmental regulatory tools into three main types, namely, command, market incentive and voluntary [19]. Generally speaking, the command environmental regulatory tools is the agency to use coercive means to order enterprises to implement the environmental standards set by the agency to reduce the enterprise pollution of the environment, this kind of regulatory tools are effective, but the implementation cost is higher. Market incentive environmental regulation tools can effectively reduce the mandatory orders, reduce the cost of agency intervention, to a certain extent, can improve the efficiency of environmental governance. Voluntary environmental regulation tools generally refer to the voluntary behavior of enterprises to actively reduce the environmental impact of enterprises. Considering the practical limitations and data deficiencies of voluntary environmental regulation tools in the logistics industry, two environmental regulation tools are selected, namely, command and market incentive, to study their impact on the carbon emission efficiency of logistics enterprises. The strength of the command environmental regulation tool is characterized by summing up the freight cost of treating wastewater and waste gas facilities with the value added of industry, and the market incentive environmental regulation testing tool is expressed by the ratio of the completed investment in industrial pollution control to GDP [20].

2.4 Control Variables

2.4.1 Technology level of innovation

The technological innovation of logistics enterprises is conducive to the realization of cost reduction and efficiency, reduction of carbon dioxide emissions and reduction of environmental pollution [21]. Used entropy value method to comprehensively evaluate the four indicators of R&D personnel, R&D expenditure, the number of invention patent authorization and technology market turnover in each region, and reflected the level of technological innovation in each region by the method of comprehensive evaluation.

2.4.2 Level of human capital

Human capital is one of the key factors driving economic growth. A high level of human capital helps to enhance the country's industrial competitiveness and promote technological innovation and industrial upgrading, thereby promoting sustained economic growth [22]. The human capital indicator is expressed as the ratio of students enrolled in higher education to the total population of the region.

2.4.3 Level of foreign investment

Foreign investment usually brings in large amounts of capital, which helps to increase domestic investment and promote capital formation, thereby boosting economic growth [23]. These funds can be used for infrastructure construction, technological research and development, industrial upgrading, and many other aspects, providing impetus for economic development. The indicator is expressed in terms of the share of foreign direct investment in GDP.

2.4.4 Level of agency intervention

The level of agency intervention may directly affect the enthusiasm of logistics enterprises to actively reduce carbon emissions, and the indicator is expressed as the proportion of local agency general public budget expenditure to GDP [24].

2.4.5 Level of financial development

The level of financial development can be measured in a number of dimensions, including the number and size of financial institutions, the size of the capital market, financial depth, financial breadth, financial efficiency and financial stability. In the text, the deposit and loan balances of financial institutions in each province as a percentage of GDP are used to express this.

3 CASE STUDY

3.1 Background

The Yangtze River Delta(YRD) region is one of the most economically dynamic and innovative city clusters in China, covering 41 cities in Shanghai, Jiangsu, Zhejiang and Anhui Provinces, with a total area of about 358,000 square kilometers. As the intersection hub of the "Belt and Road" and the Yangtze River Economic Belt, YRD has the world's largest port clusters (Shanghai Port, Ningbo Zhoushan Port, etc.) and a dense transportation network, and its logistics industry accounts for more than 30% of the country's total, with an annual cargo volume of more than 20 billion tons. However, the rapid economic growth and the expansion of logistics demand have also brought about significant pressure on carbon emissions: carbon emissions from the transportation sector in YRD account for about 20% of the total regional emissions, with logistics activities contributing more than 60% of the total.

3.2 Results

3.2.1 Carbon emission efficiency

Based on the above data of input-output related indicators of the logistics industry, the carbon emission efficiency of the logistics industry in YRD from 2011 to 2021 is measured, and the results are shown in Table 3.

Table 3 Carbon Emission Efficiency of the Logistics Industry in YRD, 2011-2021

Region	Anhui	Zhejiang	Jiangsu	Shanghai
2011	0.2742	0.4517	0.2632	0.6324
2012	0.2493	0.4564	0.2714	0.6523
2013	0.5408	0.7008	0.2725	0.6173
2014	0.5271	0.7033	0.2851	0.6267
2015	0.5162	0.7117	0.2810	0.6604
2016	0.5141	0.7556	0.2856	1.7966
2017	0.4134	0.9635	0.2818	0.6693
2018	0.4072	1.0382	0.2504	0.6867
2019	0.4258	0.6691	0.2843	0.6215
2020	0.4235	1.4613	0.2868	0.6160
2021	0.5200	0.6691	0.2831	0.6254
average value	0.4374	0.7801	0.2769	0.7459

Table 3 shows that the average value of carbon emission efficiency of the logistics industry in YRD during the study period is about 0.56, with more obvious regional differences. Shanghai has the highest mean value of carbon emission efficiency (0.7459), which is closely related to its highly intensive logistics system (e.g., automated warehousing, popularization of new energy means of transport) and strict environmental protection policies. Zhejiang has the second highest average efficiency value (0.7801), but it fluctuates greatly due to the promotion of "smart logistics" pilot projects in Hangzhou and Ningbo and the expansion of carbon trading pilot projects. Anhui and Jiangsu have lower efficiency averages (0.4374 and 0.2769, respectively), reflecting the fact that the logistics industry in these two provinces still relies on traditional high-carbon modes, with a high proportion of road transportation and a coal-based energy structure. Jiangsu as a major manufacturing province, has logistics demand deeply tied to industrial activities, making low-carbon transition more difficult.

3.2.2 Measuring the intensity of environmental regulation

The calculation results of the environmental regulation intensity of the logistics industry in YRD from 2011 to 2021 are shown in Table 4.

Table 4 Measurement of Environmental Regulatory Intensity

Region	Shanghai		Jiangsu		Zhejiang		Anhui	
	ER1	ER2	ER1	ER2	ER1	ER2	ER1	ER2
2011	0.0106	0.0003	0.0008	0.0006	0.0088	0.0005	0.0095	0.0005
2012	0.0095	0.0005	0.0013	0.0007	0.0100	0.0008	0.0092	0.0006
2013	0.0082	0.0002	0.0007	0.0010	0.0095	0.0015	0.0096	0.0020
2014	0.0073	0.0007	0.0008	0.0007	0.0093	0.0016	0.0111	0.0007
2015	0.0077	0.0007	0.0008	0.0008	0.0094	0.0013	0.0121	0.0007
2016	0.0077	0.0017	0.0012	0.0009	0.0101	0.0012	0.0102	0.0015
2017	0.0077	0.0013	0.0009	0.0005	0.0104	0.0007	0.0108	0.0008
2018	0.0072	0.0002	0.0008	0.0008	0.0101	0.0006	0.0104	0.0005
2019	0.0074	0.0007	0.0009	0.0006	0.0106	0.0005	0.0108	0.0007
2020	0.0080	0.0002	0.0009	0.0005	0.0107	0.0007	0.0120	0.0006
2021	0.0065	0.0002	0.0006	0.0001	0.0007	0.0002	0.0101	0.0003

Overall, Anhui has long been a leader in command environmental regulation and, as a latecomer, has relied more on administrative tools such as mandatory closure of over-standardized firms and higher sewage charges to make up for the lack of market mechanisms. Shanghai and Zhejiang have lower levels of command environmental regulation, but market incentive environmental regulation tools are widely used, reflecting a preference for market mechanisms to guide emissions reductions. In Jiangsu, the intensity of both types of regulation is low, probably because the policy design does no effectively combine the two types of tools, resulting in insufficient incentives to reduce emissions. The average value of market incentive environmental regulation in YRD is only 0.001, indicating that market-based tools such as emissions trading and green subsidies have not yet formed a scale effect in the logistics industry.

3.3 Empirical Analysis of Environmental Regulation on the Carbon Emission Efficiency of Logistics Enterprises

3.3.1 Descriptive statistical analysis of the sample

The descriptive statistical results are detailed in Table 5.

Table 5 Descriptive statistics of the sample

Item	Sample size	Minimum value	Maximum values	Average value	(statistics) Standard deviation	Upper quartile
Carbon emission efficiency	44	0.249	1.797	0.560	0.309	0.524
Command environmental regulation	44	0.001	0.012	0.007	0.004	0.009
Market-Incentivized Environmental Regulation	44	0.000	0.002	0.001	0.000	0.001
Level of human capital	44	0.016	0.025	0.020	0.002	0.021
Level of agency intervention	44	0.119	0.256	0.177	0.045	0.169
Level of financial development	44	2.202	6.291	3.761	1.289	3.384
Level of foreign investment	44	0.015	0.048	0.031	0.010	0.032
Level of technological innovation	44	0.061	1.010	0.309	0.225	0.253

3.3.2 Empirical analysis

Table 6 shows the results of a random effects test with logistics industry carbon emission efficiency as the dependent variable, two environmental regulatory tools, and five control variables as explanatory variables.

Table 6 Random effects model results

Item	Coef	Std.Err	*t*	*p*	95% CI
Command Environmental Regulation Tool	46.878	11.138	4.209	0.000**	25.047~68.708
Market incentive-based environmental regulation tools	253.761	125.051	2.029	0.050*	8.665~498.856
Level of technological innovation	1.249	0.558	2.238	0.032*	0.155 to 2.343
Level of foreign investment	15.023	7.266	2.068	0.046*	0.782~29.264
Level of financial development	0.118	0.016	7.593	0.000**	0.087~0.148
Level of agency intervention	-0.466	0.750	0.621	0.539	-1.936~1.004
Level of human capital	-45.067	26.067	1.729	0.092	-96.156~6.023

The random effects modeling results lead to the following conclusions.

First, the command environmental regulation tools have a positive and significant impact on the carbon emission efficiency of the logistics industry. It shows that the agency's introduction of mandatory policies is conducive to the regulation of logistics enterprises to improve themselves, improve the efficiency of their own carbon emissions to reduce carbon dioxide emissions, and reduce environmental pollution.

Secondly, market incentive environmental regulatory tools will have a significant positive impact on the carbon emission efficiency of the logistics industry. It shows that the agency's full use of market-based instruments (e.g., adjusting sewage charges, granting subsidies for energy-saving and emission reduction policies, and adjusting the proportion of taxes and fees for logistics enterprises) can effectively motivate logistics enterprises to take the initiative to make environmental protection-related strategic adjustments.

Third, the level of technological innovation has a significant positive impact on the carbon emission efficiency of the logistics industry. It indicates that the higher the technological innovation level of logistics enterprises themselves, the higher the carbon emission efficiency of the enterprises. This result is the same as most scholars' research results [25,26,27].

Fourth, the impact of foreign investment level on the carbon emission efficiency of the logistics industry is positively significant, indicating that the higher the level of foreign investment, the higher the carbon emission efficiency of the logistics industry will also increase. Foreign investment is often accompanied by the introduction of advanced technology and management experience, which can improve the operational efficiency and energy utilization efficiency of logistics enterprises and thus reduce carbon emissions. Foreign investment may also change the energy structure of logistics enterprises, such as increasing the proportion of renewable energy used and reducing fossil energy consumption, thus reducing carbon emissions.

Fifth, the level of financial development will have a significant positive effect on the carbon emission efficiency of the logistics industry, indicating that as the level of financial development increases, the carbon emission efficiency of the logistics industry will also increase. This may be because the higher the financial development, the more it helps to reduce the financing cost of logistics enterprises and improve the convenience of financing. This makes it easier for logistics enterprises to obtain funds for technological upgrading, equipment renewal and green transformation, thus improving carbon emission efficiency.

Sixth, the regression coefficients of the degree of agency intervention and the level of human capital on the carbon emission efficiency of the logistics industry are negative, but neither of them passes the 5% significance test. This means that the view that the higher the degree of agency intervention will inhibit the initiative of logistics enterprises to reduce carbon emission efficiency is not confirmed. At the same time, it does not mean that the higher the level of human capital, the lower the carbon emission efficiency of the logistics industry.

4 SUGGESTIONS

4.1 Scientific Selection of Environmental Regulatory Instruments

According to the results of the study, command and market incentive environmental regulation tools will have a significant positive impact on the carbon emission efficiency of the logistics industry, the agency should weigh the pros and cons of different environmental regulations, and actively formulate the appropriate regulatory tools according to the specific development situation of different regions, so as to prescribe the right medicine for the problem. For example, in Zhejiang and Shanghai, where the level of economic development and marketization is relatively high, and the carbon emission efficiency of logistics enterprises is at a high level, the relatively low-cost market incentive environmental regulation tools can be chosen to reduce the impact of logistics enterprises on environmental pollution. For Jiangsu Province, although its level of economic development is high, the carbon emission efficiency of its logistics industry is significantly lower, so it should focus on command regulation, by improving the local environmental laws and regulations, and increasing the punishment for excessive emissions in the form of mandatory orders. In the management of carbon emissions in the logistics industry, command and market incentive environmental regulations should be combined to form a management system with complementary advantages. By setting strict carbon emission standards and strengthening policy enforcement, we can ensure that enterprises meet their emission reduction targets.

4.2 Strengthening Technological Innovation

The empirical results show that technological innovation has a significant positive impact on the carbon emission efficiency of the logistics industry, therefore, the agency should actively formulate relevant policies to encourage enterprises to strengthen the research on relevant energy-saving and emission reduction technologies, and encourage logistics enterprises to build an intelligent management system, strengthen human-computer interaction, and reduce management errors. Guiding enterprises from their own cost-effectiveness, exploring the nodes that can be optimized in each supply chain link, jointly building an intelligent supply chain management platform, reducing management costs, improving management efficiency, and thus promoting energy saving and emission reduction.

4.3 Improving Financial Development

Finance is the core of modern economy, and improving the level of financial development can help optimize the allocation of resources and improve the efficiency of the use of funds, thus promoting industrial upgrading, technological innovation and economic growth. According to the results of the study, the level of financial development has a significant positive impact on the carbon emission efficiency of the logistics industry, and the agency should formulate comprehensive measures to rationalize market regulation. For example, it can increase the investment in financial science and technology research and development, and encourage financial institutions to cooperate with science and technology enterprises to jointly promote financial science and technology innovation.

4.4 Increasing the Level of Foreign Investment

Foreign-invested enterprises usually have advanced technology and R&D capabilities. Through cooperation and exchanges with local enterprises, foreign investors can promote the exchange, dissemination and transfer of technology. This helps to improve the technical level and innovation ability of local enterprises to accumulate new recent and technical experience, thus promoting the upgrading and innovation of the whole industry. For the logistics industry, foreign enterprises can not only bring advanced enterprise management experience, but also may introduce advanced logistics management systems, automated warehousing equipment, low-carbon transportation technology, etc., all of which can help improve the overall carbon emission efficiency of the logistics industry.

5 CONCLUSION

This study selects the YRD as the sample, centers on the logistics industry, and uses the super - efficiency SBM model to measure the carbon emission efficiency of the logistics industry. It also empirically tests the effect paths of two types of environmental regulation tools (command and market incentive) through the random effects model. The aim is to uncover the mechanisms of environmental regulation and carbon emission efficiency in densely populated city clusters and provide scientific support for regional green development strategies.

This study finds that both command and market incentive environmental regulation tools significantly and positively affect the carbon emission efficiency of the logistics industry. Besides, improvements in technological innovation, foreign investment, and financial development levels also boost this efficiency. It enriches the perspective on the relationship between environmental regulation and industry specific carbon emission efficiency, offers a theoretical basis for agencys to formulate scientific and reasonable environmental regulation policies. Also, it helps guide logistics enterprises to strengthen innovation, increase carbon emission efficiency, and enhance market competitiveness, propelling the green development of the logistics industry in YRD.

However, the research has limitations. It doesn't fully consider the potential impact of factors like enterprise size and supply chain management on carbon emission efficiency and lacks dynamic analysis of the changing effects of environmental regulation policies over time. For future research, it's suggested to delve into the impact of enterprise - level factors on carbon emission efficiency, apply dynamic analysis methods, and evaluate the long - term effects of environmental regulation policies.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

All authors contributed to the study conception and design. C.W.: Conceptualization, Methodology, Resources, Supervision. A.L.: Writing– original draft, Data curation, Formal analysis, Validation. All authors read and approved the final manuscript.

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