Study on the Carbon Emission Efficiency of the Logistics Industry in the Yangtze River Delta Region

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Abstract: In order to cope with climate warming, control greenhouse gas emissions and realize the "double carbon" goal, it is necessary for China to improve the carbon emission efficiency of the logistics industry (LCEY). Therefore, in order to realize the emission reduction and efficiency of the logistics industry, this paper measures, evaluates and improves the LCEY in China's Yangtze River Delta region. Firstly, the evaluation index system of the LCEY is constructed from the perspective of inputs and outputs, and the input indexes mainly include the labor population, fixed capital inputs and energy consumption in the logistics industry, and the desired outputs include the output value of the logistics industry, cargo turnover, and the non-desired outputs are the CO_2 emissions, which are measured using the Super-SBM model; secondly, the Tobit model is used to analyze the influencing factors of LCEY in the Yangtze River Delta; finally, countermeasure suggestions to improve the LCEY are put forward, the aim is to provide methodological and theoretical underpinnings for the LCEY's management and research, and to provide a basis for the policies formulation.

Keywords: Carbon Emission Efficiency; Logistics Industry; DEA Model; Tobit Model

1. Introduction

As technology advances, environmental pollution is becoming an increasingly serious problem and carbon emissions are rising, leading to an intensification of the greenhouse effect and global climate change. By 2035, China's carbon emissions are expected to reach 10^3 billion tons, posing a huge challenge to environmental sustainability. As a result, China made a commitment to the international community in its speech to the 75th United Nations General Assembly: to strive for carbon peaking by 2030 and carbon neutrality by 2060. The logistics industry (LT) is an important support for the operation of social and economic system, and its energy consumption is among the highest in all industries, making it one of the fastest growing sectors in terms of carbon emissions. Responding to the challenge of the "dual carbon" target and realizing low-carbon transformation and sustainable development has become an important development issue for the logistics industry. The Yangtze River Delta (YRID) is one of the most famous and developed economic circles in China, with a strong demand for the LT development. The study of the LCEY in the YRID region has great practical significance in realizing the sustainable development of the logistics industry (LTSD) and the dual-carbon goal.

2. Literature Review

The development of low carbon economy makes many scholars pay attention to economic development and carbon emissions, and currently the world needs to pay attention to the issue of reducing carbon emissions while promoting economic development[1]. Some scholars believe that improving the efficiency of carbon emissions (CEY) is an effective solution[2]. Regarding the connotation of carbon emission efficiency, existing studies generally categorize it into single-factor CEY and total-factor CEY[3]. The total factor CEY considers the role played by political, economic, technological and other factors in carbon emission, and includes the efficiency values of multiple production factors, which is more comprehensive and reasonable than the single-factor CEY[4]. Currently, the CEY in the academic world generally refers to the total factor carbon emission efficiency. Drawing on existing research, this paper considers that the LCEY is the unification of economic, social and environmental benefits, and seeks to obtain more economic output and social benefits with as little carbon emissions as possible.

In terms of measuring the LCEY, the measurement methods are mainly divided into parametric and non-parametric methods, and the Stochastic Frontier Analysis (SFA) method is the classical parametric method, which was firstly put forward by Aigner in 1977, and it measures the carbon emission efficiency by establishing the stochastic error term and the production function[5]. However, for the efficiency of multi-input and multi-output (MIMO) production systems, the SFA method has obvious shortcomings in evaluation. As a non-parametric relative efficiency evaluation method, DEA can effectively make up for the above deficiencies, and has absolute advantages in dealing with the efficiency evaluation of MIMO, and has been widely used by scholars, among which the three-phase DEA and the super-efficient SBM model are the most widely used[6].

Regarding the factors influencing the LCEY, Ma Fei and other scholars have explored the panel Tobit model using the six dimensions of the economic development level, infrastructure construction, energy structure, scientific and technological level, the market openness degree and the opening up degree to the outside world[7]. Chu Lixia and other scholars used Tapio decoupling model and LMDI model, based on the data of Shandong Province from 2000 to 2020, to analyze the characteristics of the overall development of carbon emissions in Shandong Province and the various factors affecting the carbon emissions, and to provide certain policy suggestions for Shandong Province to reduce the carbon emissions and achieve the LTSD[8].

In terms of countermeasures to improve the LCEY, the research mostly focuses on incentive countermeasures, and puts forward countermeasure suggestions by studying the mechanism of the influencing factors and the spatial and temporal evolution of the CEY. Scholars generally look for influencing factors from economic, social and environmental aspects[9].

Existing research results have laid a good foundation for the study of LCEY, but in general, the number, breadth and depth of the studies need to be further improved: (1) Existing studies generally take the economic output as the only indicator for measuring the LCEY, ignoring other outputs of the logistics industry, such as the environmental and social benefits, and failing to measure carbon emission results from a systematic perspective; (2) The YRID region is one of the most developed place in China, and the LT has become an important industry and a new economic growth point for its economy, while there are fewer studies on the LCEY in the YRID.

Therefore, this paper studies the LCEY in the YRID region and puts forward countermeasure suggestions for the low-carbon development of the LT in the YRID region, which have great practical significance to a certain extent.

3. Evaluation Indicator System

As a new industry, China lacks specialized logistics statistics, so this paper refers to the research of most scholars and treats the transportation, warehousing and postal sector as the LT[10]. On the basis of relevant research results, and the principles of scientificity, comprehensiveness, precision and operability, we construct the evaluation index system of LCEY, and classify the evaluation indexes of LCEY into two aspects, namely, inputs and outputs, as shown in Table 1. The data involved in the evaluation index system come from China Statistical Yearbook, China Energy Statistical Yearbook and development bulletin of provinces and cities.

Regarding the input indicators, drawing on the selection of factor indicators by Ma Fei and other scholars, the input indicators of the logistics system are selected from human, financial and material resources, and the most representative indicators are labor force, fixed capital and energy inputs; regarding the output indicators, the logistics sector's overall turnover and output value are taken as the desired outputs, and the carbon dioxide emissions are taken as the non-desired outputs. Input indicators include: (1) The number of the LT employees. (2) Annual amount of fixed capital investment. (3) Energy Consumption. Output indicators include: (1) Output value of the LT: the output value of the LT from 2012 to 2021 in the statistical yearbook. (2) Comprehensive turnover of the LT: this indicator includes cargo turnover and passenger turnover, mainly considering three modes of transportation: road, railroad and waterway, and the turnover from 2012 to 2021 is selected. (3) Carbon dioxide emissions from the LT: the energy consumption of the LT in the Energy Statistics Yearbook was selected, and then calculated according to the calculation method of IPCC2006.

Table 1. Evaluation Index System of LCEY

Form	Level 1 indicators	Secondary indicators	Unit	Code
Input indicators	Human factors	Number of employees of the logistics industry	10^4 people	X_1
	capital element	Annual volume of fixed capital investment	billions	X_2
	Energy elements	Energy consumption	10^4 tons standard coal	X_3
Output indicators	Expected outputs	Output value of the logistics industry	billions	Y_1
		Consolidated logistics turnover	billion ton kilometres	Y_2
	Non-expected outputs	CO_2 emissions from logistics	10^4 tons	Y_3

For energy consumption of the LT, first, the CO_2 emissions due to various energy consumption are measured in accordance with the reference method provided by IPCC (2006), and then the resulting values are summed up by the following formula:

$$CO_2 = \sum_i^n CO_{2i} = \sum_i^n \sum_i^n Ei \times nNCVi \times CEFi \times COFi \times (44 \div 21) \qquad (1)$$

In Equation (1), Ei is the consumption of the ith energy source, NCV_i is the average heat generation (collated from the energy yearbook of the YRID region from 2012 to 2021), CEFi is the carbon emission factor provided by the IPCC, COFi is the carbon oxidation factor (which was defaulted to 1 by the IPCC 2006), and 44 and 21 represent the carbon dioxide and carbon molecular weight. Synthesizing the energy consumption structure of the LT, the energy is divided into five categories shown in Table 2:

Table 2. Data Related to the Five Energy Sources

renewable energy	crude oil	diesel	gasoline	diesel fuel	petroleum
Average low level heat generation (kJ/kg)	20908	43070	43070	42652	38931
Carbon emission factor (kg CO_2 /106 kJ)	25.8	18.9	19.6	20.2	15.3

4. Research Methodology and Modeling

4.1 LCEY's Calculation Model

In order to address the measurement bias of the traditional DEA model, this paper uses the SBM-DEA model, because its objective function has a slack variable. In it, a decision-making unit (DMU) with an efficiency score of 1 is considered to be very efficient. Suppose there are n independent decision-making units DMU_j (j=1,2,...,n), each with m input variables $X=(x_{1k},x_{2k},\ldots,x_{mk})$ and q output variables $Y=(y_{1k},y_{2k},\ldots,y_{qk})$. Therefore, the expression of the SBM model is.

$$\min \rho = \frac{1+\frac{1}{m}\left(\sum_{i=1}^{m} s_i^{-}/x_{ik}\right)}{1-\frac{1}{q}\left(\sum_{r=1}^{q} \frac{s_r^{+}}{y_{rk}}\right)} \qquad (2)$$

$$\text{s.t.}\begin{cases} \sum_{j=1,j\neq k}^{n} x_{rj}\lambda_j - s_i^{-} \le x_{ik} \\ \sum_{j=1,j\neq k}^{n} y_{rj}\lambda_j - s_r^{+} \ge y_{ik} \\ \lambda_j, s_i^{-}, s_r^{+} \ge 0 \\ i=1,2,\ldots m, r=1,2,\ldots,q, j=1,2,\ldots n(j\neq k) \end{cases} \qquad (3)$$

Where: ρ is the measured LCEY; i and r represent the input and output decision-making units, respectively; S_i^{+} and S_i^{-} are the slack variables; and λ_j is the weight vector.

4.2 Influencing Factors Determination of LCEY

In this paper, economic development, industrial structure, energy structure and population size are selected as influencing factors. Among them, the measurement model is as follows:

$$Yit\begin{cases} Y_{it}^{*}=\alpha i+\sum \beta_i X it+\varepsilon it \\ 0, Y_{it}^{*}\leq 0 or\ Y_{it}^{*}>1 \end{cases} \quad (4)$$

Where: Y_{it}^{*} is the restricted dependent variable with broken tails; Y_{it} is the restricted dependent variable; α_i is a vector of intercept terms indicating individual variability; X_{it} is the independent variable; β_i is the estimated parameter of it; ε_{it} is a random perturbation term obeying a normal distribution; *i* represents the region; *t* represents the year.

5. Empirical Analysis

5.1 Carbon Emission Efficiency Measurement Results

The YRID region plays a significant role in China's economic development, and in the first quarter of 2021, the YRID accounted for 24.55% of the total national economy, and the integrated development of the YRID is a major strategy implemented by China. This paper measures, evaluates and analyzes the LCEY in three provinces and one city in the YRID, to understand the shortcomings of it in terms of carbon emission, and to make suggestions for promoting the low-carbon development of the LT in the YRID and even the whole country.

First, based on the SBM-DEA model shown above, and combined with the queried input and output index data of the LT in the YRID region, the scale of the LCEY in the three provinces and one city, as well as the trend of the change (increase or decrease) over the ten-year period, which includes the scale of technical efficiency (CRS), the scale of pure technical efficiency (VRS), and the scale effect (SE), are calculated, as shown in Table 3.

From Table 3, we can see the differences of the LCEY in the YRID region. The LCEY in Zhejiang Province is relatively stable, with a fluctuating growth trend; Jiangsu Province has been decreasing, which is related to Jiangsu Province's favoring of economic development, and also reflects the direction of Jiangsu Province's development in the future, which is to move towards green and low-carbon development; Anhui Province has the highest LCEY, but it is on a decreasing trend; and Shanghai City has been increasing. The LCEY in Jiangsu Province, Zhejiang Province and Shanghai Municipality is mainly driven by pure technical efficiency, and Anhui Province is mainly driven by scale efficiency, which has a bearing on the faster development of Anhui Province in the last few years.

Table 3. Scale of LCEY in Three Provinces and One City in YRID, 2012-2021

year	region	CRS	VRS	SE	RTS
2012	Zhejiang	2.211	1.108	1.995	lower
2013	Zhejiang	0.773	0.874	0.884	rise
2014	Zhejiang	1.037	1.048	0.990	rise
2015	Zhejiang	0.833	1.026	0.812	rise
2016	Zhejiang	0.794	1.000	0.794	rise
2017	Zhejiang	1.018	1.015	1.003	rise
2018	Zhejiang	0.730	0.840	0.869	rise
2019	Zhejiang	1.082	1.228	0.881	rise
2020	Zhejiang	1.078	1.298	0.831	rise
2021	Zhejiang	1.313	1.257	1.044	rise
2012	Jiangsu	1.956	1.239	1.578	lower
2013	Jiangsu	1.459	1.078	1.353	lower
2014	Jiangsu	1.343	1.089	1.233	lower
2015	Jiangsu	1.483	1.090	1.361	lower
2016	Jiangsu	1.608	1.133	1.419	lower
2017	Jiangsu	1.495	1.137	1.314	lower
2018	Jiangsu	1.467	1.151	1.274	lower
2019	Jiangsu	1.504	1.155	1.302	lower
2020	Jiangsu	1.582	1.345	1.176	lower
2021	Jiangsu	0.907	1.084	0.836	lower
2012	Anhui	0.683	1.587	0.430	rise
2013	Anhui	6.066	1.554	3.903	lower
2014	Anhui	5.120	1.400	3.657	lower
2015	Anhui	4.425	1.301	3.401	lower
2016	Anhui	4.312	1.310	3.291	lower
2017	Anhui	2.545	1.289	1.975	lower
2018	Anhui	2.685	1.323	2.030	lower
2019	Anhui	2.669	1.385	1.927	lower
2020	Anhui	2.595	1.293	2.007	lower
2021	Anhui	2.487	1.289	1.929	lower
2012	Shanghai	1.003	1.769	0.567	rise
2013	Shanghai	1.110	1.390	0.799	rise
2014	Shanghai	1.316	1.753	0.751	rise
2015	Shanghai	1.108	1.624	0.683	rise
2016	Shanghai	1.076	1.633	0.659	rise
2017	Shanghai	1.197	1.779	0.673	rise
2018	Shanghai	1.154	1.831	0.630	rise
2019	Shanghai	1.346	2.062	0.653	rise
2020	Shanghai	1.782	3.214	0.554	rise

5.2 Analysis of Factors Affecting LCEY

Based on the above value of LCEY in the YRID region from 2012 to 2021, Tobit regression analysis was carried out using Stata16 software, and the results see Table 4.

Table 4. Tobit Calculation Results

te	Coef.	Std. Err.	z	P>z
economic development	-0.821	1.293	-0.64	0.525
industrial structure	-25.627	21.871	-1.17	0.241
energy structure	0.900	7.903	0.11	0.909
demographic	-59.223	23.865	-2.48	0.013
_cons	4.932	1.325	3.72	0.000

According to the regression results, the economic development and the LCEY show a negative correlation, with a coefficient of -0.8, which indicates that the faster the economic development, the lower the LCEY, and the higher the opposite. The faster the economic development, the scale and demand of the LT will increase, if there is no corresponding technology update and operation management, the LCEY will increase. This law is not in line with the law of economic development and carbon emission reduction of the LT, contrary to the basic economic laws, the economy is certainly moving forward, in order to better promote economic development and carbon emission reduction business of the LT, should make timely adjustments to this.

The correlation coefficient between industrial structure and the LCEY is -25.63, indicating that the current industrial structure of the YRID region is not conducive to the reduction of LCEY. Optimizing the industrial structure can adjust the direction of economic development, reduce the reliance on high-pollution and high-energy-consumption industries, and scale down the scale and influence of overdeveloped and underdeveloped industries, thus improving the economy efficiency. In addition, industrial restructuring can also promote green technology innovation and the development of environmental protection industries, guide enterprises to implement low-carbon production and lifestyle, and promote green consumption and ecological protection, thus realizing a virtuous cycle of economic development and environmental protection. In order to accelerate the emission reduction of the LT, the industrial structure of the YRID region should be optimized and upgraded appropriately, because the two are complementary to each other.

The energy structure is positively correlated with the LCEY, with a coefficient of 0.9, i.e., the more energy consumption, the higher the LCEY, and vice versa, the lower it is. To reduce the LCEY, it is necessary to optimize the energy structure, reduce the dependence on fossil energy, gradually promote new energy technologies, develop and use renewable energy, and achieve a double reduction in energy consumption and emissions. Therefore, the adjustment and optimization of the energy structure is urgent.

Population is inversely proportional to the LCEY, indicating that the more population is invested in the LT, the lower the CEY, which indicates that there is redundancy in the input of the LT practitioners in the YRID region, and that adjustments should be made to the positions functions of practitioners to maximize the subjective initiative of the personnel and make contribution to the development of the LT.

5.3 Results Adjustment of LCEY's Influencing Factors

To guarantee the reliability of the findings, the first calculations were again tested for robustness to ensure that the t-value was greater than 2 or less than -2 and the p-value was less than 0.05 to ensure that the coefficients were significant, and the regression results were calculated separately using the Stata16 software, the results are shown in Table 5.

Table 5. Regression Analysis Adjustment Results

te	Coef.	Std. Err.	z	P>z
economic development	0.821	0.393	2.09	0.038
industrial structure	25.627	10.871	2.36	0.019
energy structure	-0.900	0.403	-2.23	0.027
demographic	-59.223	23.865	-2.48	0.013
_cons	4.932	1.325	3.72	0.000

The robustness test is to check the robustness of the model to ensure the robustness and reliability of the results. According to the results of the robustness test, the effects of the four major influencing factors on the LCEY have reached a significant level after systematic adjustment, which means that the effects of these factors on the LCEY are stable. And the impact direction of these explanatory variables on the dependent variable is consistent with the Tobit regression results, which indicates that the data of Tobit regression model is well fitted and the conclusion is reliable.

6. Countermeasures and Suggestions

6.1 Improve Energy Efficiency and Develop Clean Energy Sources

The above study shows that the energy structure and the LCEY has a high influence degree of 0.9, which can be concluded that the optimization of energy structure can effectively reduce the LCEY. Compared with the other three provinces, Shanghai's energy structure is more rational and higher than the average efficiency of the other three provinces. Therefore, Shanghai's experience in energy structure can provide a reference for other provinces and cities. The development of logistics will be affected by economic development. First of all, it is necessary to improve the energy utilization rate of natural gas, improve work efficiency and energy efficiency, and gradually lessen the high carbon emission factor of coal, oil and other energy sources. In addition, the choice of vehicles should be gradually replaced by new energy vehicles and trucks, so as to fundamentally control the high LCEY.

6.2 Improving Logistics Technology and Developing Low-Carbon Logistics

Energy efficiency can be improved by optimizing the industrial structure, thus reducing carbon emissions. From the measurement results, the standard error of the industrial structure is greater than 10, indicating that there is a large gap between the industrial structure of the provinces and cities in the YRID region, and the industrial structure of the LT needs to be adjusted and optimized. The faster the economy develops, the scale and demand of the LT will increase, and if there is no corresponding technological update and operation management, the LCEY will increase. However, if logistics enterprises carry out technological innovation and effective operation and management, they can realize low-carbon economic development, and the LCEY can be gradually reduced while rapid economic development. Logistics enterprises can integrate logistics resources by establishing cooperative relationships with suppliers and customers and establishing a supply chain cooperation system. By integrating relevant logistics resources, logistics enterprises can coordinate the use of logistics resources, improve the efficiency of logistics resources, reduce redundant logistics activities and traffic congestion, reduce logistics costs and energy consumption, and ultimately realize the purpose of reducing carbon emissions. In addition, logistics enterprises should strengthen the research and implementation of green transportation technologies, continuously develop new energy, logistics integration and other technologies, in order to improve transportation efficiency, reduce carbon emissions, and gradually realize low-carbon development and provide logistics services.

Secondly, the government should actively play a guiding role, such as formulating and implementing green energy policies, increasing investment in and support for the clean energy industry, and implementing the carbon emissions trading market and environmental protection taxes and fees, among other means, so as to guide logistics enterprises of all sizes in actively adopting low-carbon technologies and gradually realizing low-carbon logistics.

In addition, it can further promote the reduction of LCEY by strengthening the training and management of practitioners, improving their environmental awareness and responsibility, and actively implementing the concept of green logistics. Zhejiang Province, due to the leading development of the e-commerce industry, has well driven the LT's development. The governments and enterprises of Jiangsu and Anhui provinces should learn more from the advanced energy efficiency practices of Zhejiang Province to improve energy efficiency and reduce carbon emissions.

6.3 Optimize the Transport Network and Improve Transport Efficiency

The economy of the YRID region is better in China, with better transportation conditions, however, the regional transportation system is not ideal and transportation is still a major factor in CO_2 production. Therefore, energy efficiency can be gradually improved through a good logistics and transportation network. An efficient logistics and transportation network can be constructed by adopting technical means such as intelligence, internet of things and big data to dynamically manage and control warehouses, vehicles, routes, etc., and to realize information technology synergy, so as to improve the efficiency of logistics and thus reduce carbon emissions. A reasonably located and well-equipped logistics and distribution center can avoid repeated distances and improve transportation efficiency. When designing a logistics park, comprehensive consideration should be given to selecting the best distribution center nodes, transportation and storage places, effectively linking each independent link in transportation and making the links interdependent.

6.4 Improve Life Style and Enhance the Environmental Protection Concept

Reducing carbon emissions should not only focus on the production perspective, but also from the perspective of the residents' lives, emission reduction should be a joint effort of everyone. Continued rapid economic development, gradually increasing production capacity and diversified lifestyles of the population will all lead to an increase of LCEY.

From the above study, it can be seen that the economic development of the YRID region should promote the concept of low carbon and environmental protection, focus on the development of industries, improve relevant supporting facilities, strengthen scientific research and technological development, implement the concept of green environmental protection, improve labor efficiency, and reduce carbon emissions in the production, supply, storage, transportation and sales processes. In daily life, it is necessary to advocate the green living concept for residents, try to travel green, reduce unnecessary online shopping, and reduce the use of disposable items. Starting from ourselves and from small things, we will contribute to the reduction of carbon emissions.

Among the three provinces and cities in the YRID region, the carbon efficiency of Shanghai's LT has been improving over the past ten years, which shows that Shanghai's emission reduction measures for the LT are effective and are useful for the emission reduction work of other provinces and cities. Zhejiang, Jiangsu and Anhui should actively learn from the work experience of Shanghai, and make corresponding adjustments according to the specific conditions of itself, and actively implement. We must persist in the development concept that green waters and green mountains are golden mountains and silver mountains, and adhere to the mutual promotion of economic and environmental development, improve the quality of economic operation, and promote carbon emission reduction in logistics industry.

7. Conclusion

With global warming, reducing carbon emissions has become a task that cannot be delayed. Therefore, studying the LCEY can accelerate the low-carbon green transformation of the LT and promote sustainable development. Based on the statistical yearbook data, this paper adopts the SBM-DEA calculation method to measure and analyze the LCEY by including carbon emission into the overall efficiency of the LT, analyze the difference of the LCEY in YRID region from the perspective of input and output, and explore the effecting factors by using the Tobit, and the results of the calculations can be obtained that the LCEY is inversely proportional to the economic development, industrial structure and demographic factors, and positively proportional to the energy structure. According to the expected setting, the results will be adjusted, which is more conducive to the LCEY improvement. However, this paper still has the following limitations: the evaluation index system of the LCEY needs to be further improved, highlighting the comprehensiveness of economic, environmental and social benefits; the models and methods for measuring the LCEY need to be further corrected and improved, and how to combine the strengths of various approaches is the focus of the next step's research; and the data capacity should be further expanded to include dynamic comparisons and analyses of more provinces and years, so as to measure the LCEY in a more systematic way, and to put forward more effective suggestions for the LT’s low-carbon development.

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