Hindawi
Scientific Programming
Volume 2022, Article ID 5891909, 9 pages
https://doi.org/10.1155/2022/5891909

*Research Article*

# Coordinated Development of Logistics Development and Low-Carbon Environmental Economy Base on AHP-DEA Model

**Jinlan Wang, Huiwen Li, and Huifang Guo**

*Management School, Hainan University, Haikou 570208, China*

Correspondence should be addressed to Huiwen Li; 20125300210017@hainanu.edu.cn

Received 3 December 2021; Revised 26 December 2021; Accepted 6 January 2022; Published 2 February 2022

Academic Editor: Le Sun



With the intensification of global environmental pollution and the overexploitation of resources and energy, low-carbon environmental economy (LCEE) has become the important means for countries in the world to achieve sustainable economic, resource, and environmental development. Therefore, the research on the coordinated development of logistics development and LCEE is very necessary in the development of our country's LCEE. Firstly, this paper discusses the development level of logistics industry in Hainan Province from five aspects: energy consumption, carbon emission, carbon productivity, economic benefit index, and carbon emission efficiency. Secondly, choose carbon emission intensity to represent the development level of low-carbon economy. Based on the efficiency coefficient method, coefficient of variation method, linear weighting method, spatial description method, and system evolution equation method, the coordination measurement method is adopted. Finally, the coordinated development of logistics development and low-carbon environmental economy in Hainan Province is analyzed. On this basis, this paper puts forward the related promotion strategies for the coordinated development of logistics development and logistics industry in Hainan. The research results show that the system coupling degree in Hainan Province is about 0.9, indicating that the logistics industry and the low-carbon economic subsystem have a relatively high degree of coupling development. Compared with other provinces, Hainan's level of coupled and coordinated development is at the upstream level.

## 1. Introduction

The LCEE is my country's face of global warming, high resource and energy consumption, high pollutant emissions, and increasingly severe atmospheric environment, so as to promote my country to seize the future economic and industrial development and raise the commanding heights. At present, countries all over the world are fiercely competing in new energy and new technologies, which also poses a very serious challenge to the development of my country's LCEE, but at the same time it is also a huge opportunity for the development of LCEE.

Literature [1] found that there is an interactive relationship by studying the relationship between the logistics industry and the regional economy. Logistics industry is more important in the development of regional economy, which affects the speed and efficiency of regional economy [2]. LCEE is the main line of controlling greenhouse gases such as carbon dioxide and changing energy [3], production, and lifestyles. The low-carbon environmental economic model [4] is a win-win model for the coordinated development of ecological environment and economic environment. The manufacturing industry and the logistics industry [5–9] are interdependent, but the linkage between the two will cause a lot of pollution, and we can promote the low carbonization of the two to reduce pollution. The logistics industry has been greatly developed after the emergence of e-commerce [10], and the logistics industry has become an important pillar industry for regional economic development. Nowadays, the logistics industry not only plays an important pillar role in the regional economy but also becomes a restrictive element of the speed and efficiency of the regional economy. There are still some problems in my country's logistics management [12], which lead to unreasonable resource allocation and serious waste. Concentrated, efficient, and economical [13–15] use of resources is an important way to achieve a low-carbon environment and economic development. The development of modern logistics has a certain positive effect on the intensive use of resources. To achieve low-carbon environmental economic development, it is necessary to further integrate and utilize existing logistics resources and strengthen the construction and connection of logistics infrastructure. It is of great significance to learn from foreign experience [16], explore my country's logistics development in a low-carbon environment economy, strengthen international strategic low-carbon logistics planning, formulate specific low-carbon logistics policies and regulations, and standardize low-carbon logistics goals. Green logistics has become one of the important directions for the development of modern logistics industry [17]. In order to promote the healthy development of green logistics, relevant departments must seize new opportunities and strive to build a trading support system consisting of an emission standard system, a trading rule system, and a supporting platform system.

## 2. The Coordinated Development of Logistics and LCEE

Coordination is the interaction and mutual influence between two or more systems. Coordination is in the nature of the development process overall effect of the interaction between the various elements of the system or generated, emphasizing the mutual cooperation between elements to achieve a stable and orderly development process.

Measurement methods play a great role in all fields of society; in the social and economic field, the main utilization aspects are the compound system such as the coupling of economy and ecological environment, the coupling of industry and urban development, and the coupling of economy and human settlement environment. The main research direction is the role of the relationship between subsystems in promoting the benign interactive development of the compound system. Coordination measurement methods mainly include the following: based on efficiency coefficient, coefficient of variation method, linear weighted sum method, spatial description method, system evolution equation method, etc., as shown in Table 1.

Comparing and analyzing the advantages and disadvantages of the above coordination measurement methods based on the efficiency coefficient method can better reflect the coordinated development of logistics economy, so this paper chooses the efficiency coefficient method to analyze the coordinated development of logistics economy.

## 3. DEA Model

*3.1. Carbon Emission Estimation Method.* At present, there is no special statistical data or calculation standard of carbon emissions in China, so we can only estimate carbon emissions. In this paper, the IPCC inventory method is chosen, which uses the carbon emission coefficient and energy consumption in the National Greenhouse Gas Inventory Guide. Its advantages are easy to obtain data and wide application range. Therefore, referring to other literature studies, this paper selects the IPCC inventory preparation method to estimate carbon emissions, and the specific calculation formula is defined.

$$C^t = \sum_{i=1}^{n} E_i^t \theta_i \delta_i. \tag{1}$$

Here, $C^t$ is the carbon emission of regional logistics in the $t$ period, $E_i^t$ is the energy consumption in the $t$ period $i$, including raw coal, coke, crude oil, gasoline, kerosene, diesel, fuel oil, natural gas, and liquefied petroleum gas (nine types of energy), $\theta_i$ is the reference coefficient of the $i$-th energy converted into standard coal, and $\delta_i$ is the carbon emission coefficient of the $i$-th energy.

*3.2. Carbon Productivity.* Carbon productivity is the GDP output efficiency per unit of carbon dioxide, and its role is to reflect the economic benefits produced by the unit of carbon dioxide emissions. Carbon productivity is also defined as the reciprocal relationship between "carbon average" and "unit carbon emission intensity". The process of reducing carbon emissions is the process of increasing carbon productivity, and the decline of carbon intensity indicates the improvement of carbon productivity. The specific calculation formula is as follows:

$$\text{carbon productivity} = \frac{\text{output}}{CO_2 \text{ emission}}. \tag{2}$$

*3.3. Carbon Emissions Per Capita.* Social and economic development should not only consider the carrying capacity of ecological environment, more consideration should be given to the rational distribution, but also been unanimously recognized internationally. Per capita carbon emissions can exclude the influence of regional population size, so per capita carbon emissions can better reflect the characteristics of total carbon emissions. The calculation formula is as follows:

$$\text{carbon emissions per capita} = \frac{CO_2 \text{ emissions}}{\text{number of people}}. \tag{3}$$

*3.4. Economic Efficiency Index (EEI).* The rapid growth of social economy is closely related to regional carbon emissions. Therefore, this paper draws lessons from other literature studies. The EEI is used to measure the relationship between GDP and carbon emissions in various provinces of China. That is, the EEI is equal to the proportion of the contribution rate of logistics industry to GDP and the contribution rate of logistics industry carbon emissions to overall carbon emissions. If the proportion of carbon emissions of logistics industry in a province is greater than the contribution rate of GDP, it indicates that the economic efficiency is relatively low. The logistics industry in the province and other banks interact in carbon emissions, whereas the regional economic efficiency is relatively high.

Table 1: System evolution equation method.

| Method | Formula | Advantages and disadvantages |
|---|---|---|
| Multivariable synthesis method | $C = \sum_{i=1}^{n} w_i U_A(u_i)$ where $A$ is the stable region of the system; effect of $U_A(u_i)$ as variable $u_i$ on system order | The calculation is simple and easy to operate, and the reference index determination is inconsistent and the comparability is poor |
| Efficiency coefficient method | $C = \left\{f(X)g(Y)/[f(X)+g(Y)/2]^2\right\}^k D = C, T; T = \alpha f(x) + \beta g(y)$ where $f(x)$ and $g(y)$ are evaluation functions; $C \in [0,1]$; $D$ is coordination degree, $T$ is comprehensive evaluation index, and $\alpha$ and $\beta$ are weights | It is simple and easy to introduce order parameters, and it is difficult to select reasonable indexes |
| Coefficient of variation method | $C = \alpha c_m + \beta c_n + \gamma c_u$ where $\alpha, \beta$, and $\gamma$ are coefficients; $c_m, c_n$, *an d* $c_u$ are subsystems | The model is simple, the principle is clear, and the selection of the two system indexes should be accurate and representative |
| Spatial description method | $I_{XY}(C(t)) = 1 - \sqrt{\alpha_1 [I_x(t) - I_{XY}(t)]^2 - \alpha_2 [I_Y(t) - I_{XY}(t)]^2}$. Among them, $X$ and $Y$ are two subsystems; $I_x(t)$ and $I_Y(t)$ are the degrees of development of two subsystems; $I_{XY}(t)$ is the average level of the development of two subsystems; $\alpha_1$ and $\alpha_2$ are the weights | Analyze the coordination degree from static and dynamic; to calculate the coordination degree of multisystem, the model is complex and the amount of calculation is large |
| **System evolution equation** | $\mathrm{d}x(t)/\mathrm{d}t = f(x_1, x_2 \ldots x_n) V_A = \mathrm{d}A/\mathrm{d}t\, V_B = \mathrm{d}B/\mathrm{d}t \tan\theta = V_A/V_B$. Among them, $A$ and $B$ are two subsystems; $V_A$ and $V_B$ are the evolution rates of the two subsystems; $\theta$ is the coupling degree of the coupled system | Considering the dynamic changes of the system with time, the coordination degree of the system is divided into absolute coordination degree and relative coordination degree, which is complicated in operation and requires high continuity of indicators and data |

$$\mathrm{EEI} = \frac{GL_i/G_I}{CL_i/C_i}, \tag{4}$$

where $GL_i$ and $G_I$ are the output value of logistics industry and GDP of each province and the carbon emissions of logistics industry in $CL_i$ and $C_i$ and the total carbon emissions of each province.

*3.5. Calculation Method of Carbon Emission Efficiency.* Carbon emission efficiency refers to the maximum output capacity under constant input, or the minimum input required for a certain output. The DEA model has been used to study carbon emission efficiency in many literature studies. DEA models include CCR, BCC, etc. The CCR model takes decision-making efficiency as the final goal and constructs the DEA model with constant return to scale. Adding constraints to the CCR model becomes the BCC model. The traditional DEA and BCC models are constructed to measure the technical efficiency of carbon dioxide emissions. The BCC model can be expressed as follows:

$$\mathrm{Min}\left[\theta_{i_0} - \varepsilon\left(e^T s^+ + e^T s^-\right)\right], \tag{5}$$

$$\text{s.t.} \left\{ \sum_{i=1}^{N} x_i \lambda_i + s^- = \theta_{i_0} x_{i_0} \sum_{i=1}^{N} y_i \lambda_i - s^+ = y_{i_0} \sum_{i=1}^{N} \lambda_i = 1, \quad \lambda_i \geq 0,\ i = 1, 2, \ldots, n s^+ \geq 0, s^- \geq 0. \right. \tag{6}$$

Here, $s^+$ and $s^-$ are slack variables, $e^T$ is the unit row vector, $\theta_{i_0}$ is the relative efficiency value of the decision-making unit, and $\lambda$ is the weight vector.

## 4. Analysis of the Characteristics of the Logistics Industry

*4.1. Carbon Emissions of the Logistics Industry in Provinces.* According to formula (1), the carbon emissions of logistics industry in China's provinces from 2016 to 2019 are calculated, as shown in Table 2.

The carbon emissions of logistics industry in China's provinces maintained a rapid growth trend from 2016 to 2019, and there were great differences and imbalances in carbon emissions among provinces. At present, the development of China's logistics industry depends on energy consumption, mainly traditional coal and oil. Although the logistics industry has grown rapidly, it has led to more carbon dioxide emissions. Therefore, the development of China's logistics industry needs to change to the development mode of low emission, high efficiency, and high energy efficiency and get rid of the traditional extensive

Table 2: Carbon emissions of the logistics industry in China's provinces from 2016 to 2019 (unit: 10,000 tons).

| Province | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|
| Beijing | 443.9 | 558.4 | 648.1 | 684.8 |
| Tianjin | 179.6 | 236.2 | 284.1 | 335.7 |
| Hebei | 486.6 | 537.2 | 569.8 | 701.1 |
| Shanxi | 333.5 | 473.1 | 524 | 553.8 |
| Inner Mongolia | 654.2 | 776.9 | 934.1 | 1083.2 |
| Liaoning | 844.5 | 982.7 | 1123.2 | 1289.7 |
| Jilin Province | 200.3 | 254.8 | 290.4 | 351.1 |
| Heilongjiang | 267.4 | 281.9 | 505.8 | 571.7 |
| Shanghai | 951 | 1034.1 | 1092.5 | 1103.2 |
| Jiangsu | 561.5 | 681.9 | 853.5 | 1004.6 |
| Zhejiang | 578.1 | 730 | 819.5 | 915.6 |
| Anhui Province | 242.7 | 379 | 467.4 | 577.9 |
| Fujian | 337.4 | 440.2 | 504.7 | 598.3 |
| Jiangxi | 213.2 | 269.3 | 327.2 | 383.9 |
| Shandong | 1089.3 | 1451.3 | 1676.5 | 2126.1 |
| Henan | 497.5 | 599.3 | 709.8 | 757.1 |
| Hubei | 590.2 | 684.6 | 842.5 | 999.4 |
| Hunan | 355 | 455.1 | 548.5 | 613.3 |
| Guangdong | 1062.3 | 1379.5 | 1582.1 | 1826.7 |
| Guangxi | 309.4 | 378.5 | 448.3 | 581.7 |
| Hainan | 80.7 | 152.7 | 176.6 | 178.9 |
| Chongqing | 267.1 | 342.4 | 400.1 | 451.6 |
| Sichuan | 470.4 | 622.5 | 699.5 | 782.1 |
| Guizhou | 206.7 | 257.4 | 330.6 | 427.7 |
| Yunnan | 352.3 | 387.9 | 519.3 | 595.1 |
| Shaanxi | 332.3 | 476.7 | 561.3 | 604 |
| Gansu Province | 200.7 | 226 | 241.2 | 245.2 |
| Qinghai | 38.1 | 59.9 | 75.7 | 76.2 |
| Ningxia | 34.7 | 62.8 | 86.9 | 96.6 |
| Xinjiang | 316.8 | 347.9 | 374.4 | 484.9 |

development mode, high energy consumption, and high pollution development mode.

The growth of coal and oil consumption in Hainan Province is not high from 2016 to 2019 in Table 3. Combined with Table 2, logistics industry level is lower than that of a province with large carbon emissions, but it provides a good environment for promoting the coordinated development of logistics development and LCEE.

*4.2. Carbon Productivity Analysis.* Carbon productivity, that is, the carbon emissions generated by unit GDP growth, is a relative indicator to measure the efficiency of carbon emissions and can also reflect the dependence of economic growth on high energy consuming industries. Therefore, this paper selects carbon productivity to measure the carbon emission level of regional logistics industry, and calculates the carbon productivity of logistics industry according to formula (2). The results are shown in Table 4.

As can be seen from Table 4, from 2013 to 2019, the carbon productivity of logistics industry in 30 provinces showed great differences. It can be seen that the carbon productivity of logistics industry in Hainan Province is on the rise and the growth rate is relatively large. The carbon productivity is as high as 20,000 yuan/ton of coal. The carbon productivity of logistics industry is much higher than that of other provinces. It means that Hainan Province pays more attention to the quality of economic growth while the logistics industry is growing rapidly, and can effectively use the input of science and technology, resources, and environment, so that the logistics industry has been effectively developed under the LCEE, and the good effect of coordinated development between logistics development and LCEE has been achieved.

*4.3. Economic Efficiency Index Analysis.* According to formula (4), the EEI of logistics industry in China's provinces from 2013 to 2019 is calculated, as shown in Table 5.

As can be seen from Table 5, on the whole, the EEI of Hainan Province from 2013 to 2019 was less than 0.5. It shows that the development of logistics industry in Hainan Province depends on the development mode of high energy input and high carbon emission output to a great extent, and the low level of energy utilization efficiency in the development of logistics industry means that the utilization of energy efficiency in the development of logistics industry in Hainan Province needs to be improved urgently. However, in 2018–2019, the EEI of Hainan Province has greatly increased to 0.93. Combined with Table 4, it shows that Hainan Province is actively developing LCEE, changing the development mode of logistics industry, and striving to achieve coordinated development of logistics development and LCEE.

*4.4. Calculation of Carbon Emission Efficiency of the Logistics Industry.* In this paper, DEAP2.1 software is used to solve formulas (5) and (6), and the carbon emission efficiency of logistics industry in 30 provinces of China from 2013 to 2019 is calculated. The results are shown in Table 6.

The carbon emission efficiency of logistics industry in Hainan Province is about 0.8 in Table 6, and the carbon emission efficiency is relatively high, indicating that Hainan Province pays more attention to the effective utilization of labor, capital, energy, and environment. Improving the utilization rate of all elements of logistics development is also conducive to the transformation of logistics development mode to low carbon and promotes the coordinated development of logistics development, low-carbon environment, and economy.

## 5. Analysis of Coordinated Development between Logistics Development and LCEE

*5.1. Construction of the Evaluation Index System.* Low energy consumption, low emission, and high efficiency are the advantages of LCEE. LCEE requires China to transform to low carbon. The evaluation idea of coordinated development of logistics industry and low-carbon economy is shown in Figure 1. Firstly, after a large number of literature retrieval, the index system is sorted out; second, scientific treatment of indicators; thirdly, obtain the original data of indicators by inquiring the statistical yearbook; and fourthly, this paper analyzes the coordination degree and coupling degree between logistics industry and low-carbon economy by using

Table 3: Total energy consumption structure between Hainan Province and the whole country.

| Year | Coal | | Oil | |
|---|---|---|---|---|
| | Hainan | Whole country | Hainan | Whole country |
| 2016 | 30.72 | 71.1 | 39.22 | 18.8 |
| 2017 | 30.02 | 70.3 | 40.68 | 18.3 |
| 2018 | 32.12 | 70.4 | 41.68 | 17.9 |
| 2019 | 31.63 | 68 | 40.34 | 19 |

Table 4: Carbon productivity of the logistics industry in China's provinces from 2013 to 2019.

| Province | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Hainan | 1.83 | 1.87 | 2.12 | 2.21 | 2.53 | 2.58 | 2.51 |
| Beijing | 1.13 | 0.92 | 1.04 | 1.17 | 1.26 | 1.25 | 1.29 |
| Tianjin | 1.57 | 1.49 | 2.05 | 2.25 | 2.31 | 2.33 | 2.15 |
| Hebei | 2.34 | 2.49 | 2.83 | 3.25 | 3.66 | 3.69 | 3.37 |
| Shandong | 1.29 | 1.12 | 1.15 | 1.3 | 1.49 | 1.58 | 1.61 |
| Shanghai | 0.79 | 0.91 | 1.03 | 1.01 | 1.14 | 1.19 | 1.2 |
| Jiangsu | 0.77 | 0.75 | 0.84 | 0.85 | 1.05 | 1.17 | 1.07 |
| Zhejiang | 1.32 | 1.4 | 1.4 | 1.36 | 1.49 | 1.44 | 1.38 |
| Guangdong | 1.33 | 1.57 | 1.58 | 1.68 | 1.11 | 1.17 | 1.08 |
| Fujian | 0.77 | 0.74 | 0.65 | 0.73 | 0.82 | 0.84 | 0.85 |
| Shaanxi | 1.27 | 1.26 | 1.24 | 1.33 | 1.5 | 1.5 | 1.44 |
| Shanxi | 1.92 | 1.76 | 1.27 | 1.15 | 1.29 | 1.29 | 1.21 |
| Inner Mongolia | 1.88 | 1.77 | 1.75 | 1.78 | 1.95 | 2.08 | 1.95 |
| Henan | 1.52 | 1.55 | 1.51 | 1.54 | 1.6 | 1.8 | 1.75 |
| Hubei | 1.28 | 1.5 | 1.22 | 1.2 | 1.41 | 1.39 | 1.28 |
| Hunan | 1.72 | 1.81 | 1.41 | 1.28 | 1.38 | 1.57 | 1.72 |
| Jiangxi | 0.81 | 0.83 | 0.97 | 1.02 | 1.05 | 1.14 | 1.07 |
| Anhui | 1.32 | 1.3 | 1.59 | 1.58 | 1.77 | 1.84 | 1.9 |
| Gansu Province | 1.18 | 1.16 | 1.18 | 1.18 | 1.34 | 1.71 | 1.41 |
| Qinghai | 0.98 | 0.99 | 1.03 | 1.14 | 1.35 | 1.33 | 1.15 |
| Ningxia | 0.96 | 0.73 | 0.62 | 0.61 | 0.72 | 0.8 | 0.77 |
| Xinjiang | 0.97 | 0.96 | 1.05 | 1.01 | 1.17 | 1.23 | 1.27 |
| Guangxi | 1.07 | 1.05 | 0.86 | 0.85 | 0.93 | 0.97 | 0.95 |
| Chongqing | 0.77 | 0.73 | 1.6 | 1.62 | 1.84 | 1.82 | 1.8 |
| Sichuan | 0.55 | 0.59 | 0.49 | 0.38 | 0.43 | 0.47 | 0.45 |
| Guizhou | 0.92 | 0.88 | 0.92 | 0.9 | 1.01 | 1.09 | 1.08 |
| Yunnan | 0.87 | 0.97 | 0.99 | 0.99 | 1.21 | 1.36 | 1.4 |
| Liaoning | 0.86 | 0.82 | 0.92 | 0.98 | 1.01 | 1 | 0.95 |
| Jilin Province | 1.25 | 1.3 | 2.01 | 1.95 | 2.22 | 2.28 | 2.06 |
| Heilongjiang | 0.55 | 0.57 | 0.63 | 0.61 | 0.71 | 0.8 | 0.86 |

index standardization data and weight, so as to provide theoretical basis for the coordinated development of logistics development and LCEE in China.

The construction principles of evaluation index system are as follows: 1. Scientific principle; 2. the principle of low carbonization; and 3. dynamic principle. China's logistics industry has high GDP, low energy utilization rate, and high carbon emissions. Under the constraint of resources and environment, it depends on resource elements and has a great impact on ecological environment. The proposal of low-carbon economy can promote the transformation of China's logistics industry to low-carbon development mode, so as to consume less resources, improve energy utilization rate, reduce carbon emissions and obtain higher output, and realize the sustainable development of resources and environment. Referring to the relevant literature research results,

Table 5: Economic benefit index of the logistics industry in each province from 2013 to 2019.

| Province | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Hainan | 0.35 | 0.28 | 0.35 | 0.33 | 0.36 | 0.31 | 0.93 |
| Beijing | 0.22 | 0.15 | 0.19 | 0.17 | 0.17 | 0.12 | 0.28 |
| Tianjin | 0.54 | 0.38 | 0.55 | 0.6 | 0.57 | 0.47 | 0.84 |
| Hebei | 1.03 | 1.06 | 1.16 | 1.29 | 1.4 | 1.28 | 3.13 |
| Shandong | 0.53 | 0.39 | 0.43 | 0.4 | 0.38 | 0.39 | 0.77 |
| Shanghai | 0.23 | 0.22 | 0.27 | 0.2 | 0.22 | 0.16 | 1.58 |
| Jiangsu | 0.55 | 0.47 | 0.48 | 0.45 | 0.5 | 0.49 | 0.83 |
| Zhejiang | 0.44 | 0.35 | 0.33 | 0.28 | 0.31 | 0.22 | 0.85 |
| Guangdong | 0.49 | 0.44 | 0.53 | 0.47 | 0.29 | 0.25 | 0.81 |
| Fujian | 0.23 | 0.2 | 0.18 | 0.17 | 0.19 | 0.16 | 0.3 |
| Shaanxi | 0.25 | 0.21 | 0.23 | 0.21 | 0.23 | 0.18 | 0.48 |
| Shanxi | 0.37 | 0.28 | 0.21 | 0.15 | 0.17 | 0.13 | 0.64 |
| Inner Mongolia | 0.29 | 0.21 | 0.29 | 0.29 | 0.29 | 0.25 | 0.64 |
| Henan | 0.31 | 0.25 | 0.28 | 0.24 | 0.24 | 0.23 | 0.67 |
| Hubei | 0.38 | 0.38 | 0.33 | 0.31 | 0.36 | 0.32 | 0.8 |
| Hunan | 0.29 | 0.25 | 0.2 | 0.16 | 0.19 | 0.19 | 0.94 |
| Jiangxi | 0.23 | 0.19 | 0.23 | 0.18 | 0.18 | 0.14 | 0.51 |
| Anhui | 0.28 | 0.21 | 0.26 | 0.21 | 0.21 | 0.2 | 0.71 |
| Gansu | 0.23 | 0.18 | 0.22 | 0.18 | 0.2 | 0.21 | 0.39 |
| Qinghai | 0.19 | 0.15 | 0.18 | 0.18 | 0.27 | 0.25 | 0.54 |
| Ningxia | 0.68 | 0.44 | 0.37 | 0.3 | 0.33 | 0.29 | 0.4 |
| Xinjiang | 0.13 | 0.1 | 0.12 | 0.08 | 0.12 | 0.1 | 0.47 |
| Guangxi | 0.21 | 0.17 | 0.16 | 0.13 | 0.15 | 0.11 | 0.35 |
| Chongqing | 0.19 | 0.13 | 0.28 | 0.24 | 0.26 | 0.19 | 1.79 |
| Sichuan | 0.2 | 0.16 | 0.14 | 0.09 | 0.11 | 0.08 | 0.29 |
| Guizhou | 0.36 | 0.29 | 0.33 | 0.27 | 0.28 | 0.25 | 0.81 |
| Yunnan | 0.6 | 0.56 | 0.56 | 0.45 | 0.53 | 0.5 | 1.27 |
| Liaoning | 0.27 | 0.25 | 0.3 | 0.26 | 0.26 | 0.21 | 0.66 |
| Jilin | 0.4 | 0.5 | 0.72 | 0.57 | 0.58 | 0.79 | 1.15 |
| Heilongjiang | 0.37 | 0.34 | 0.39 | 0.34 | 0.39 | 0.37 | 1.05 |

this paper selects the evaluation index from three aspects: economic aggregate, economic scale, and economic benefit for regional economy, and selects the logistics subsystem from three aspects: logistics industry scale, logistics industry structure, and logistics benefit, and constructs the index system of coordinated development between logistics industry and low-carbon economy, as shown in Table 7.

*5.2. Coordinated Development Model.* The efficiency coefficient of logistics industry and low-carbon economy subsystem to system order can be expressed as follows:

$$u_{ij} = \begin{cases} \dfrac{x_{ij} - \beta_{ij}}{\alpha_{ij} - \beta_{ij}}, \\ \\ \dfrac{\alpha_{ij} - x_{ij}}{\alpha_{ij} - \beta_{ij}}. \end{cases} \quad (7)$$

In formula (7), $u_{ij}$ is the contribution degree of the variable $x_{ij}$ to the efficiency function of the coupled system, and $\alpha_{ij}$ and $\beta_{ij,}$ respectively, represent the upper and lower limit values of the sequence parameter of the stability critical point of the coupled system.

Because the logistics industry subsystem and the low-carbon economy subsystem are interactive but different, the

Table 6: Carbon emission efficiency of the logistics industry in each province from 2013 to 2019.

| Province | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Hainan | 0.82 | 0.87 | 0.83 | 0.78 | 0.72 | 0.69 | 0.88 |
| Beijing | 0.85 | 0.88 | 1.02 | 0.83 | 0.78 | 0.68 | 0.98 |
| Tianjin | 0.77 | 0.73 | 1.02 | 0.68 | 0.73 | 0.74 | 0.98 |
| Hebei | 0.57 | 0.56 | 0.76 | 0.73 | 0.78 | 0.71 | 0.85 |
| Shandong | 0.68 | 0.63 | 0.61 | 0.52 | 0.6 | 0.55 | 0.88 |
| Shanghai | 0.69 | 0.6 | 1.02 | 0.85 | 0.81 | 0.82 | 0.98 |
| Jiangsu | 0.72 | 0.69 | 1.02 | 0.77 | 0.84 | 0.83 | 0.8 |
| Zhejiang | 0.73 | 0.82 | 0.82 | 0.81 | 0.79 | 0.72 | 0.97 |
| Guangdong | 0.66 | 0.63 | 1.02 | 0.8 | 0.88 | 0.84 | 0.82 |
| Fujian | 0.77 | 0.72 | 0.81 | 0.67 | 0.66 | 0.68 | 0.98 |
| Shaanxi | 0.81 | 0.79 | 0.74 | 0.72 | 0.78 | 0.75 | 0.83 |
| Shanxi | 0.57 | 0.65 | 0.78 | 0.77 | 0.84 | 0.8 | 0.74 |
| Inner Mongolia | 0.64 | 0.68 | 0.79 | 0.7 | 0.77 | 0.74 | 0.75 |
| Henan | 0.68 | 0.67 | 0.85 | 0.85 | 0.85 | 0.8 | 0.76 |
| Hubei | 0.66 | 0.75 | 0.94 | 0.89 | 0.92 | 0.89 | 0.89 |
| Hunan | 0.72 | 0.65 | 0.72 | 0.7 | 0.73 | 0.71 | 0.66 |
| Jiangxi | 0.75 | 0.67 | 0.78 | 0.81 | 0.85 | 0.83 | 0.78 |
| Anhui | 0.8 | 0.82 | 0.88 | 0.88 | 0.94 | 0.91 | 0.89 |
| Gansu | 0.89 | 0.78 | 1.02 | 0.92 | 1.01 | 0.99 | 0.85 |
| Qinghai | 0.6 | 0.58 | 0.7 | 0.68 | 0.76 | 0.72 | 0.74 |
| Ningxia | 0.68 | 0.56 | 0.81 | 0.8 | 0.83 | 0.75 | 0.98 |
| Xinjiang | 0.63 | 0.72 | 0.84 | 0.8 | 0.82 | 0.83 | 0.98 |
| Guangxi | 0.66 | 0.66 | 0.76 | 0.75 | 0.61 | 0.6 | 0.98 |
| Chongqing | 0.53 | 0.51 | 0.55 | 0.45 | 0.52 | 0.51 | 0.74 |
| Sichuan | 0.51 | 0.47 | 0.54 | 0.52 | 0.57 | 0.56 | 0.89 |
| Guizhou | 0.61 | 0.69 | 0.75 | 0.76 | 0.69 | 0.69 | 0.93 |
| Yunnan | 0.49 | 0.46 | 0.49 | 0.45 | 0.53 | 0.49 | 0.98 |
| Liaoning | 0.68 | 0.71 | 0.54 | 0.53 | 0.54 | 0.51 | 0.98 |
| Jilin | 0.58 | 0.53 | 0.57 | 0.55 | 0.64 | 0.57 | 0.69 |
| Heilongjiang | 0.42 | 0.49 | 0.58 | 0.57 | 0.57 | 0.51 | 0.73 |

total contribution to the order degree of each parameter in the subsystem is expressed by the integration method, using geometric average method and linear weighted sum method:

$$u_i = \sum_{i=1}^{m} \lambda_{ij} u_{ij}, \quad \sum_{j=1}^{m} \lambda_{ij} = 1. \tag{8}$$

Here, $u_{ij}$ is the order parameter of the system and $\lambda_{ij}$ is the weight of each order parameter.

*5.3. System Coupling Degree Model.* The concept and model of capacitive coupling in physics are introduced in this paper, which is applied to the interaction between multiple subsystems. The coupling model can be expressed as follows:

$$C_n = \left\{ \frac{u_1, u_2 \cdots u_m}{\left[\prod\left(u_i + u_j\right)\right]} \right\}^{1/n}, \quad C \in [0, 1], \tag{9}$$

where $n = 2$; the formula evolves as shown in formula (10), which represents the coupling model of the composite system:

$$C = \sqrt{\frac{(u_1 \times u_2)}{(u_1 + u_2)^2}}. \tag{10}$$

Here, the coupling degree index of logistics industry and low-carbon economy complex system is $C$, which means that the comprehensive evaluation indexes of logistics industry and low-carbon economy development are $u_1$ and $u_2$, respectively.

This paper constructs the coupling coordination function between logistics system and low-carbon economy system to reflect the coupling of the system. The coordination model of the composite system is as follows:

$$T = \alpha u_1 + \beta u_2, \quad D(u_1, u_2) = \sqrt{C \times T}. \tag{11}$$

Here, $T$ is the low-carbon comprehensive development index; $D$ is the coordinated development index; $C, u_1, u_2$ are the same as above; $\alpha$, $\beta$ are undetermined coefficients; and the value is 0.5 in this paper.

*5.4. Criteria for the Division of Coordinated Development.* According to the coupling theory, this paper divides the coordination types of logistics industry and low-carbon economy into six types: $C = 1$ is benign resonance coupling; $0.8 < C < 1$ is high level coupling; $0.5 < C < 0.8$ is the running-in period; $0.3 < C \leq 0.5$ is the antiseptic period; $0 < C \leq 0.3$ is low level coupling; and $C = 0$ is the irrelevant state. The coordination degree of the coupling system between logistics industry and regional economy is divided into twelve types and seven comparative relationship types in Table 8.

*5.5. Correlation Analysis between Logistics Development and Low-Carbon Economy.* Using formula (11), the coordinated development degree of composite system in Hainan Province from 2010 to 2020 is obtained, and the calculation results are shown in Table 9.

The coupling degree of Hainan's logistics industry and low-carbon economic development is in the range of 0.9–1.0, and the coupling degree is at a relatively high level of development, indicating that Hainan's logistics development and LCEE have a relatively high level of coordinated development.

Figure 2 shows that in the process of economic development, the influence of the three industries changes. Because Hainan's economy is a province of tourism economy, the tertiary industry, as a pillar industry, shows a strong economic growth rate and proportion. The development of primary industry and secondary industry is relatively slow and the proportion is small.

In Figure 3, we can see that under the low-carbon economic environment of Hainan Province, the GDP of each region is on the rise. Combining Table 10 and Figure 2, we can see that the tertiary industry where the logistics

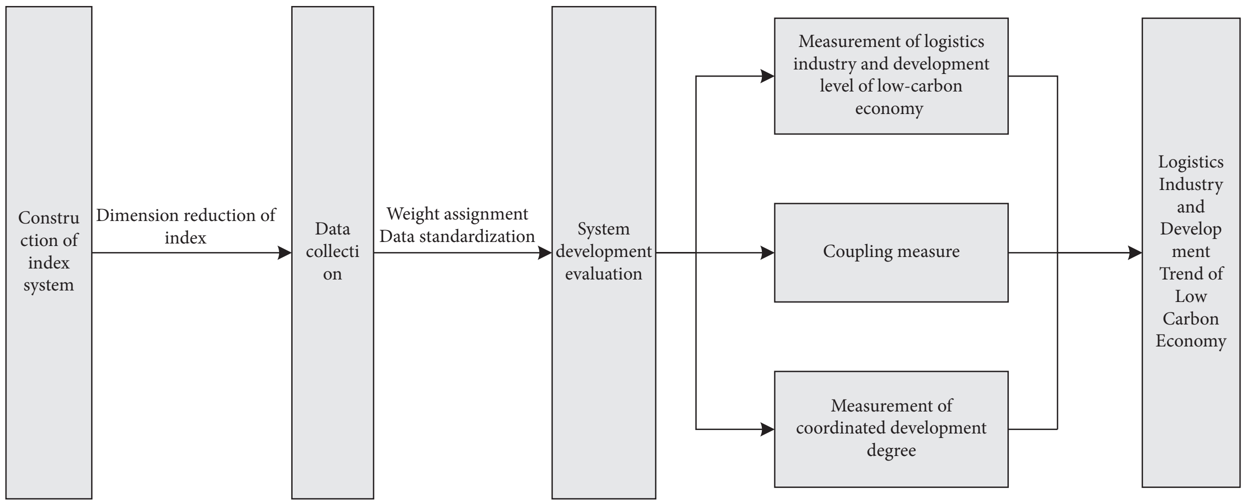


Figure 1: The evaluation idea of coordinated development of logistics industry and low-carbon economy.

Table 7: Evaluation index system of the logistics industry and low-carbon economy system.

| System | First-class index | Secondary index | Indicator interpretation |
|---|---|---|---|
| Economic system | Economic aggregate | Per capita GDP | Reflect the level of regional economic development (100 million yuan) |
| | | Investment in fixed assets of the whole society | Including the construction and purchase of fixed assets (100 million yuan) |

Table 8: Classification and standards of coordinated development of logistics industry and low-carbon economy.

| Degree of coordination | Coupling coordination type | Value range | Types of contrast relation between $u_1$ and $u_2$ |
|---|---|---|---|
| Extreme coordination | Extreme coupling coordination | $0.90 < D \leq 1.0$ | $u_1 < u_2$: logistics industry lagging |
| | High-quality coupling coordination | $0.80 < D \leq 0.90$ | $0.8 < u_1/u_2 \leq 1$: the logistics industry is relatively lagging |
| Highly coordinated | Good coupling and coordination | $0.70 < D \leq 0.80$ | $0.6 < u_1/u_2 \leq 0.8$: the logistics industry is seriously lagging behind |
| | Intermediate coupling coordination | $0.60 < D \leq 0.70$ | $0 < u_1/u_2 \leq 0.6$: the logistics industry is extremely lagging |
| | Primary coupling coordination | $0.50 < D \leq 0.60$ | $u_1 > u_2$: low-carbon economy lagging |
| Moderate coordination | Harmony and coordination | $0.40 < D \leq 0.50$ | $0.8 < u_1/u_2 \leq 1$: low-carbon economy is relatively lagging |
| | Reluctantly reconcile and coordinate | $0.30 < D \leq 0.40$ | $0.6 < u_1/u_2 \leq 0.8$: low-carbon economy severely lagging behind |
| Low coordination | Mild incongruity | $0.20 < D \leq 0.30$ | $0 < u_1/u_2 \leq 0.6$: low-carbon economy extremely lagging |
| | Serious incongruity | $0.10 < D \leq 0.20$ | $u_1 = u_2$: the logistics industry and the low-carbon economy are synchronized |
| | Extremely incongruous | $0 \leq D \leq 0.10$ | |

Table 9: Coupling degree between the logistics industry and low-carbon economy in Hainan.

| Province | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Hainan | 0.95 | 0.92 | 0.93 | 0.9 | 0.91 | 0.89 | 0.93 | 0.97 | 0.92 | 0.93 | 0.98 |

industry of Hainan Province is located accounts for the total production of Hainan Province. About 45% of the value and the tertiary industry GDP value added by Hainan Province's logistics industry far exceeds that of other industries. With a relatively high level of coordinated development of logistics development and LCEE, the logistics industry in Hainan

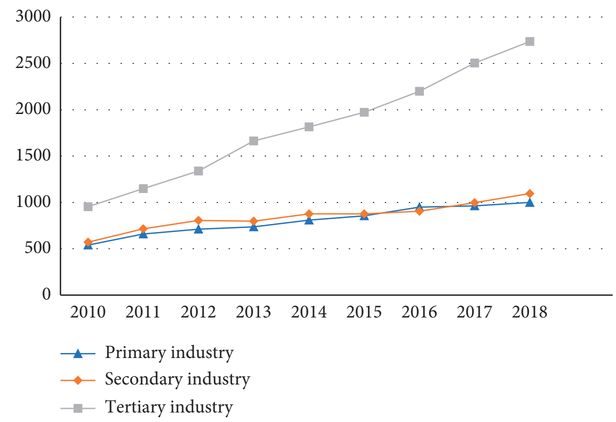


FIGURE 2: Trend chart of added value of three major industries in Hainan Province from 2010 to 2018.

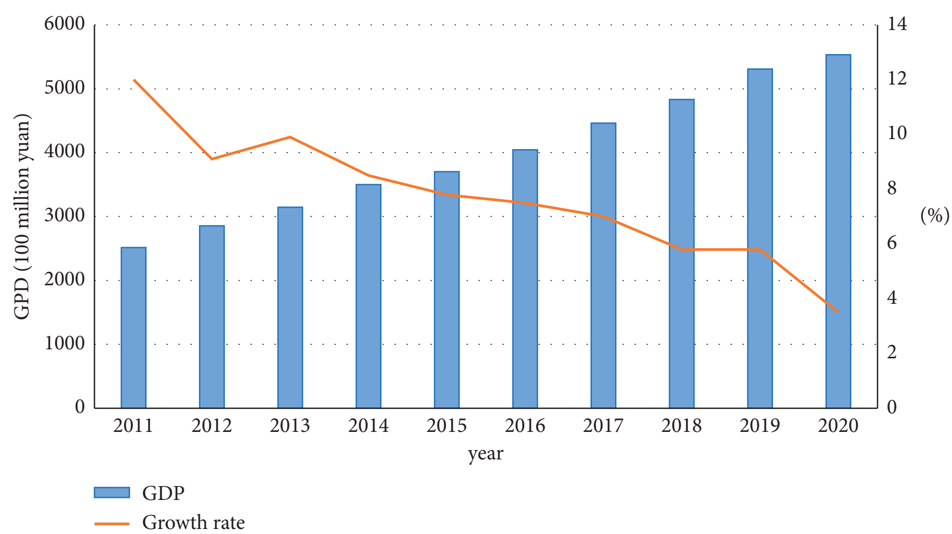


FIGURE 3: The province's GDP in a low-carbon environment from 2011 to 2020.

TABLE 10: GDP structure of Hainan Province from 2010 to 2020.

| Industry | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Primary industry | 26.1 | 26.1 | 24.9 | 24.6 | 24.4 | 24.1 | 24 | 22.3 | 21 | 20.35 | 20.5 |
| Secondary industry | 27.7 | 28.3 | 28.2 | 26 | 24.8 | 23.6 | 22.3 | 22 | 23 | 20.07 | 19.1 |
| Tertiary industry | 46.2 | 45.6 | 46.9 | 49.4 | 50.8 | 52.3 | 53.7 | 55.7 | 57 | 58.95 | 60.4 |

Province has been developing rapidly. It has done a very good job in the coordinated development of low-carbon environment and economy.

## 6. Conclusion

The logistics industry is the main driving force of my country's current economic growth and social progress. However, the proposal of an LCEE has brought severe challenges to the subsequent development of my country's logistics industry. The coordinated development of low-carbon environment and economy is also a huge development opportunity. Under the serious threat of the shortage of resources and energy in our country and the destruction of the ecological environment, the coordinated development of logistics and LCEE is imperative. In order to realize the sustainable development of resources, environment, and social economy, it is necessary to study the coordinated development of logistics development and LCEE. Taking Hainan Province as an example, this paper constructs an evaluation index system for the coordinated development of Hainan's logistics development and low-carbon economy and uses a coupling coordination model to measure the coordinated development of China's Hainan Province's logistics industry and low-carbon economy.

## Data Availability

The experimental data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest regarding this work.

## References

[1] L. Zhang, Q. L. Dong, and S. Liang, "A study on the coordinated development of node cities logistics industry and regional economy——based on the panel data of national logistics node cities," *East China Economic Management*, vol. 29, no. 2, pp. 67–73, 2015.

[2] H. Zheng, "Research on the coordinated development of logistics industry and economy in Hebei Province," in *Proceedings of the International Conference on Future Information Technology & Management Engineering*, pp. 321–324, IEEE, Changzhou, China, October 2010.

[3] C. Jianhua, "Study on the coordinated development of circular economy and low carbon economy," in *Proceedings of the 2016 International Conference on Tourism and Development (ICTD2016)*, pp. 233–238, Hainan, China, October 2016.

[4] Z. Q. Wang, W. Q. Tian, and J. Wang, "A research on the development of low-carbon economy based on the view of the logistics industry," *Advanced Materials Research*, vol. 573-574, pp. 955–959, 2012.

[5] M. Lei, H. Yang, X. Xiao, L. Ye, and J. Zhou, "Industry linkage and low-carbon development——based on logistics industry & manufacturing industry," *Meteorological and Environmental Research*, vol. 5, no. 8, pp. 10–22, 2017.

[6] C. Feng, L. Yisheng, and H. Guowei, "Analysis of the development of low-carbon logistics based on a low-carbon economy," in *Proceedings of the International Conference on Low-Carbon Transportation and Logistics, and Green Buildings(LTLGB 2012)*, pp. 673–679, Springer, Beijing, China, May 2013.

[7] M. Qingguo, "Study on the coordinated development of energy resources based on low-carbon economy," *Ecology and Environmental Sciences*, vol. 20, no. 12, pp. 192–195, 2011.

[8] M. Shi, "Environmental pollution and measurement of low-carbon logistics efficiency in China's logistics industry," *Nature Environment and Pollution Technology*, vol. 17, no. 4, pp. 1339–1346, 2018.

[9] J. Bao and H. Li, "Study on the harmonious development of carbon emission and eco-environment in logistics industry --taking beijing-tianjin a- hebei as an example," *IOP Conference Series: Earth and Environmental Science*, vol. 450, no. 1, Article ID 012069, 2020.

[10] W. Qian, Q. Jian, S. O. Business, and J. University, "Research on the coordinated development of logistics industry efficiency and economic growth based on node city," *Journal of Industrial Technological Economics*, vol. 295, no. 5, pp. 21–30, 2018.

[11] H.-l. Zheng, "The research about coordinated development of logistics industry and economy in Hebei province," in *Proceedings of the 2010 International Conference on Future Information Technology and Management Engineering (FITME 2010)IEEE*, pp. 321–324, Jiangsu, China, October 2010.

[12] D. F. Wang and L. Resourcesamp, "Implementation of green logistics management strategy under low carbon economy environment," *Logistics Engineering and Management*, vol. 39, no. 1, pp. 55-56, 2017.

[13] M. Q. Zhang, Y. Zhou, and C. L. Zhou, "A study on coordinated development of logistics industry and regional economy based on symbiotic theory," *Journal of Beijing Jiaotong University*, vol. 11, no. 1, pp. 33–40, 2012.

[14] Z. Tang and L. Zhou, "Empirical research on influence to low carbon economy of logistics industry development," *Ecological Economy*, vol. 32, no. 11, pp. 84–87, 2016.

[15] F. Xie, X. J. Huang, and R. Q. Jiang, "An evaluation on coordinate development of China's modern logistics and low carbon economy," *Journal of Jiangxi University of Finance and Economics*, vol. 93, no. 3, pp. 11–19, 2014.

[16] Q. Ren, "Influence of low carbon logistics industry in foreign countries on development of China's low carbon logistics industry," *Environmental Science and Management*, vol. 43, no. 9, pp. 41–44, 2018.

[17] B. Dong, "Low carbon economy and the development of China's green logistics," *China Circulation Economy Editorial Department*, vol. 25, no. 5, pp. 33–37, 2011.