# Research on Coordinated Development of Regional Economy and Green Logistics in Liaoning Province

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**Abstract.** Under the background of "double carbon", as an important field of energy saving and carbon reduction, the green and low-carbon development of logistics industry is of great significance for promoting the high-quality development of regional economy. This paper selects 20 indicators related to regional economy and green logistics in Liaoning Province from 2011 to 2022, assigns weights with entropy method, and empirically analyzes the coordination and integration development of the two systems by constructing a coupling coordination degree model. The grey correlation method is introduced to enrich the analysis results. The results show that the coupling coordination degree of regional economy and green logistics in Liaoning fluctuates between 0.211 and 0.752, showing a certain degree of coordination and correlation, showing a two-way interactive relationship, and showing a slow growth trend. Finally, according to the analysis results, corresponding countermeasures and suggestions are proposed, laying a certain foundation for the sustainable development of regional economy and green logistics in Liaoning .

**Keywords:** regional economy, green logistics, entropy weighting method, coupling coordination degree

## 1 Introduction

With the intensification of global climate change, countries have put forward the goal of carbon peak and carbon neutrality. Driven by the goal of "dual carbon", Liaoning needs to explore a new development model to adapt to the future development trend. As two important forces for the sustainable development of Liaoning Province, regional economy and green logistics have a profound internal relationship. The collaborative optimization of the two can provide new development ideas and methods, and has important practical significance for promoting the sustainable development of Liaoning Province.

Existing literature mainly focuses on the impact of economy and logistics industry: Kovaleva (2022)[1] explores the important role of commercial logistics in regional economic development by organizing tangible processes and coordinating members' welfare in the process; Saidi (2020)[2] investigated the relationship between logistics


C. W. K. Chen et al. (eds.), *Proceedings of the 9th International Conference on Engineering Management and the 2nd Forum on Modern Logistics and Supply Chain Management (ICEM-MLSCM 2024)*,
Advances in Engineering Research 243,
https://doi.org/10.2991/978-94-6463-531-7_17

and economic growth in developing countries, and the results showed that transport and logistics infrastructure contributed to sustainable economic growth. Zhuang et al. (2021)[3] constructed a logistics economic benefit model and used Shapley value method to explore the logistics economic benefits of first-tier cities in China. Song et al. (2023)[4] explored the manufacturing field and the logistics field develop in harmony, and analyzed their spatial interaction effects by using SDM. The results showed that logistics industry played a greater supporting role in manufacturing industry. Ye et al. (2023)[5] constructed panel data, studied the relationship between economy and low-carbon logistics, and put forward corresponding suggestions to lay the foundation for promoting the development of green logistics. Zhang et al. (2024) [6] explores the evolutionary coupling coordination degree and spatial linkage between urban socio-economic and ecological environment, and puts forward policy recommendations. Zeng et al. (2023) [7] established the impact model of high-quality growth of e-commerce and analyzed the impact mechanism of logistics density on high-quality growth of e-commerce. Ju et al. (2023) [8] explored the relationship between the development of e-commerce and green logistics, confirming that e-commerce, green logistics, green power generation, good governance and the popularization of information and communication technologies have a beneficial role in advancing the sustainable development goals. Yao et al. (2024) [9] using DEA and Malmquist index, analyzed the efficiency of low-carbon logistics in the Beijing-Tianjin-Hebei region from both static and dynamic perspectives. Wang et al. (2021) [10] used vector autoregressive and vector error correction models to study the causal relationship between China's logistics infrastructure and economic development.

To sum up, on the one hand, the coordinated development of logistics industry and economy is the key to realize logistics to promote economy, and certain results have been achieved, but there is still room for expansion of research on the integrated development of regional economy and green logistics; On the other hand, the "green" is not obvious in the selection of green logistics indicators, and there are still some deficiencies. Finally, the research method is relatively simple, subjectivity is strong, does not reflect the dynamic evolution process.

Therefore, this paper chooses Liaoning Province as the research sample, constructs a relatively comprehensive index system of regional economy and green logistics. Based on the relevant data from 2011 to 2022, the entropy weighting method is used to calculate the index weight, and the coupling coordination degree model is constructed, the grey correlation method is introduced for analysis, which enricfies the research method and content. In order to realize the positive interaction and synergism between them, relevant suggestions are put forward to provide a strong theoretical support for the coordinated development of Liaoning regional economy and green logistics.

## 2 Regional Economy and Green Logistics Index System Framework

### 2.1 Data Sources

The data used to construct the evaluation system are mainly from Liaoning Provincial Statistical Yearbook, China Energy Statistical Yearbook and China Environmental

Statistical Yearbook.

### 2.2 Index System Construction

In the selection of regional economic indicators, regional economy and green logistics are taken as the target layer. In the regional economic target layer, economic structure level, income consumption level and economic growth level are selected as the first-level indicators, and 10 indicators such as industrial output value, gross regional product and per capita consumption expenditure are taken as the second-level indicators. In the target layer of green logistics, logistics resource input, logistics operation ability and logistics environment elements are selected as the first-level indicators, and 10 indicators such as the number of logistics industry employees, freight turnover and energy consumption of logistics industry are selected as the second-level indicators. The construction of regional economy and green logistics development index system in Liaoning is shown in Table 1.

### 2.3 Entropy Weighting Method to Obtain Weight

In order to avoid the deviation caused by the subjective level, the entropy weighting method is used to determine the weight of the two subsystems, so as to ensure its objectivity and scientificity. Assuming that there are a research object and b evaluation indicators, the processing steps of entropy weighting method are as follows:

(1) Standardized data processing:

$$\text{Positive: } X_{ij}' = \frac{X_{ij} - \min\left(X_j\right)}{\max\left(X_j\right) - \min\left(X_j\right)} \tag{1}$$

$$\text{Negative: } X_{ij}' = \frac{\max\left(X_j\right) - X_{ij}}{\max\left(X_j\right) - \min\left(X_j\right)} \tag{2}$$

In the formula, $i$ represents the year, $j$ represents the evaluation index, $X_{ij}$ represents the JTH evaluation index of the year $i$, which is the value that has not been standardized, $X_{ij}'$ is the standardized value.

(2) Index normalization processing:

$$P_{ij} = \frac{X_{ij}'}{\sum_{i=1}^{a} X_{ij}'} \tag{3}$$

In the formula, $\sum_{i=1}^{a} X_{ij}'$ is the sum of all years for item $j$. $P_{ij}$ is the value of the indicator after normalization.

(3) Calculate the entropy of the JTH index:

$$E_j = -\frac{1}{\ln(a)} \sum_{i=1}^{a} P_{ij} \ln(P_{ij}) \tag{4}$$

(4) Calculate the weight of the JTH indicator:

$$W_j = \frac{1 - E_j}{\sum_{j=1}^{b} 1 - E_j} \tag{5}$$

The greater the weight, the more important the indicator. The weights of regional economy and green logistics indicators in Liaoning are shown in Table 1.

**Table 1.** Evaluation system of regional economy and green logistics index and weights of each index in Liaoning

| Target layer | Primary index | Secondary index | unit | symbol | Index weight |
|---|---|---|---|---|---|
| Regional economy | Economic structure level | Output value of primary industry | Hundred million | $X_1$ | 0.0515 |
| | | Output value of secondary industry | Hundred million | $X_2$ | 0.0446 |
| | | Output value of tertiary industry | Hundred million | $X_3$ | 0.2314 |
| | Income consumption level | Per capita disposable income | yuan | $X_4$ | 0.1817 |
| | | Per capita consumption expenditure | yuan | $X_5$ | 0.1337 |
| | | Consumer price index | % | $X_6$ | 0.0004 |
| | Economic growth level | Gross regional product | Hundred million | $X_7$ | 0.0985 |
| | | Total retail sales of consumer goods | Hundred million | $X_8$ | 0.0824 |
| | | Local finance general public budget revenue | Hundred million | $X_9$ | 0.0624 |
| | | Gross regional product per capita | yuan | $X_{10}$ | 0.1136 |
| Green logistics | Logistics resource input | Number of employees in the logistics industry | people | $Y_1$ | 0.0155 |
| | | Length of pier in coastal port | meter | $Y_2$ | 0.0250 |
| | | Total length of transport route | kilometre | $Y_3$ | 0.0144 |
| | | Capacity of trucks | car | $Y_4$ | 0.0607 |
| | Logistics operation capability | Total output value of logistics industry | Hundred million | $Y_5$ | 0.0854 |
| | | Volume of freight traffic | Ten thousand tons | $Y_6$ | 0.0204 |
| | | Freight turnover | 100 million ton-kilometers | $Y_7$ | 0.2637 |
| | Logistics environment elements | Logistics industry wastewater discharge | Ten thousand tons | $Y_8$ | 0.4832 |
| | | Solid waste production | Ten thousand tons | $Y_9$ | 0.0179 |
| | | Energy consumption of logistics industry | Tons of standard coal | $Y_{10}$ | 0.0136 |

# 3 Construction of Evaluation Model of Coupling Coordination Degree

## 3.1 Coupling Degree Model Construction

Coupling refers to the state of mutual influence between systems. Coupling coordination model can analyze the coordination degree between two systems and reflect the interaction and dependence degree between systems. In order to study the integrated development level of regional economy and green logistics in Liaoning Province, the coupling and coordination relations between regional economy and green logistics are deeply analyzed by the coupling coordination degree model.

First of all, before calculating the coupling degree, the evaluation model of the two subsystems needs to be constructed, and the calculation method is as follows:

$$\begin{aligned} U_1 &= \mathrm{W}_j' \times P_{ij} \\ U_2 &= \mathrm{W}_j'' \times P_{ij} \end{aligned} \tag{6}$$

Where, $U_1$ is the comprehensive development index of regional economy, $U_2$ is the comprehensive development index of green logistics, $W_{ij}'$ is the weight of the secondary index of regional economy, and $W_{ij}''$ is the weight of the secondary index of green logistics.

Secondly, a coupling degree model is constructed to reveal the development mechanism, interaction and influence relationship between regional economy and green logistics. The coupling function is as follows:

$$C = \left[ \frac{U_1 \times U_2}{\left( \frac{U_1 + U_2}{2} \right)^2} \right]^{\frac{1}{2}} = \frac{2\sqrt{U_1 \times U_2}}{U_1 + U_2} \tag{7}$$

In the formula, $U_1$ represents the comprehensive development index of regional economy, $U_2$ represents the comprehensive development index of green logistics, and $C$ represents the coupling degree of regional economy and green development. In the calculation process of the coupling degree of the two, the value of $C$ is [0,1]. The closer the value of $C$ is to 1, the higher the coupling between the two subsystems of regional economy and green logistics is. The more inconsistent it is.

## 3.2 Construction of Coupling Coordination Degree Model

Only using the coupling degree model to judge the coordination degree of regional economy and green logistics cannot fully reflect the real situation and dynamic coordination degree of the development of the two systems. When the development of regional economy and green logistics is coupled, there may still be a situation that the development of a certain system is low. Therefore, in order to more clearly judge the actual situation of the development of the two, this paper introduces the coupling co-

ordination degree model. To further explore the dynamic evolutionary path of coupling coordination between regional economy and green logistics, the coupling coordination degree model is as follows:

$$D = \sqrt{C \times E} \tag{8}$$

$$E = aU_1 + bU_2 \tag{9}$$

Where $D$ is the coupling coordination degree between the two subsystems, $E$ is the comprehensive coordination index, and a and b are the weight values of the two systems respectively. In this paper, regional economy and green logistics are all important, so $a$=$b$=0.5 is taken for subsequent calculation.

Based on previous studies, this paper divides the coupling coordination degree between regional economic development system and green logistics development system into ten levels ranging from extreme imbalance to high quality coordination. The coupling coordination degree level is divided as shown in Table 2:

**Table 2.** Classification of coupling coordination degree

| Coupling coordination degree D | Coordination level | Degree of coordination | Coupling coordination degree D | Coordination level | Degree of coordination |
|---|---|---|---|---|---|
| （0，0.1] | 1 | hyperdysregulation | （0.5，0.6] | 6 | Forced coordination |
| （0.1，0.2] | 2 | Severe disorder | （0.6，0.7] | 7 | Primary coordination |
| （0.2，0.3] | 3 | Moderate dysregulation | （0.7，0.8] | 8 | Intermediate coordination |
| （0.3，0.4] | 4 | Mild disorder | （0.8，0.9] | 9 | Good coordination |
| （0.4，0.5] | 5 | Borderline disorder | （0.9，0.10] | 10 | Quality coordination |

# 4 Empirical Analysis

## 4.1 Calculation and Analysis of Coupling Coordination Degree

According to the above formula, using SPSS, the development situation of regional economy and green logistics in Liaoning Province from 2011 to 2022 is calculated, as shown in Table 3. According to the measurement results, the time series curve is shown in Figure 1.

The average coupling coordination degree of regional economy and green logistics in Liaoning Province from 2011 to 2022 is 0.584. On the whole, regional economy and green logistics are barely coordinated, although slightly ups and downs, they have a certain stability, indicating that regional economy and green logistics have strong interaction and high correlation degree, and generally show a growing trend and slow change.

Among them, the period from 2013 to 2018 belongs to the transitional coordination stage. In 2011, D reached the lowest value of 0.211, and in 2017, D reached the maximum value of more than 0.7, with an increase of 256%. It has been in the intermediate coordination state for five consecutive years, and has achieved remarkable progress from moderate disorder to intermediate coordination. From 2020 to 2022, the coupling coordination degree will decrease significantly, from intermediate coordination to the verge of imbalance. In general, although the coordination of these two systems in Dalian has been continuously optimized, it still needs to be improved. In order to explore the reason of D value decline, grey correlation analysis was carried out.

**Table 3.** Coupling degree, coordination index and coupling coordination degree of regional economy and green logistics in Liaoning from 2011 to 2022

| A given year | Regional economic comprehensive development index U1 | Green logistics comprehensive development index U2 | Coupling degree C value | Coordination index T value | D value of coupling coordination degree | Coordination level | Degree of coupling coordination |
|---|---|---|---|---|---|---|---|
| 2011 | 0.0572 | 0.1018 | 0.149 | 0.298 | 0.211 | 3 | Moderate dysregulation |
| 2012 | 0.0641 | 0.1032 | 0.622 | 0.383 | 0.488 | 5 | Borderline disorder |
| 2013 | 0.0700 | 0.0979 | 0.820 | 0.422 | 0.588 | 6 | Forced coordination |
| 2014 | 0.0755 | 0.1083 | 0.858 | 0.551 | 0.687 | 7 | Primary coordination |
| 2015 | 0.0767 | 0.1027 | 0.920 | 0.555 | 0.715 | 8 | Intermediate coordination |
| 2016 | 0.0806 | 0.0870 | 0.992 | 0.518 | 0.717 | 8 | Intermediate coordination |
| 2017 | 0.0850 | 0.0850 | 1.000 | 0.565 | 0.752 | 8 | Intermediate coordination |
| 2018 | 0.0911 | 0.0730 | 0.960 | 0.565 | 0.737 | 8 | Intermediate coordination |
| 2019 | 0.0961 | 0.0645 | 0.853 | 0.578 | 0.702 | 8 | Intermediate coordination |
| 2020 | 0.0952 | 0.0538 | 0.389 | 0.538 | 0.457 | 5 | Borderline disorder |
| 2021 | 0.1037 | 0.0538 | 0.378 | 0.626 | 0.486 | 5 | Borderline disorder |
| 2022 | 0.1051 | 0.0535 | 0.323 | 0.663 | 0.463 | 5 | Borderline disorder |

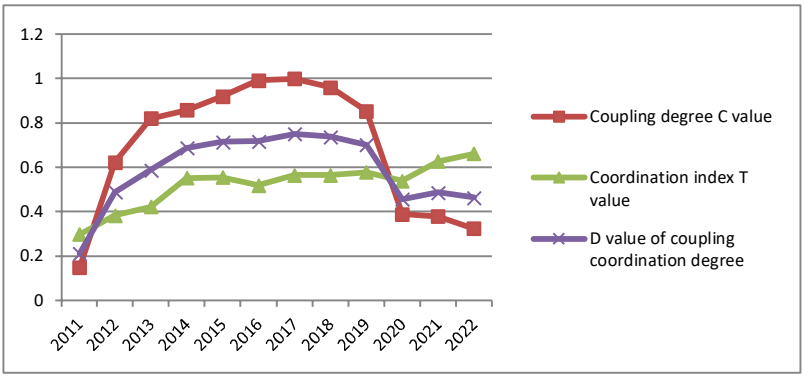


**Fig. 1.** Change trend of coupling degree, coordination index and coupling coordination degree between regional economy and green logistics

### 4.2 Grey Relational Degree Analysis

In this paper, grey correlation method is used to explore the impact of green logistics indicators on regional economic development in Liaoning Province. 10 indicators of green logistics are taken as comparison sequence and 10 indicators of regional economy are taken as reference sequence. First, the index is dimensionless, where $X_i$ is the comparison sequence, $Y_i$ is the reference sequence, and $k$ is the index:

$$x_i(k) = \frac{x_i(k)}{x_i(1)} \tag{10}$$

Secondly, the correlation coefficient and correlation degree are calculated:

$$\xi_i(k) = \frac{\min_i \min_k \left|y(k) - x_i(k)\right| + \rho \min_i \min_k \left|y(k) - x_i(k)\right|}{\left|y(k) - x_i(k)\right| + \rho \min_i \min_k \left|y(k) - x_i(k)\right|} \tag{11}$$

$$r_i = \frac{1}{m}\sum_{k=1}^{m} \xi_i(k) \tag{12}$$

After calculation, the results are shown in Table 4, and the correlation degree of all indicators is in a moderate range. Among them, the $X_{10}$ correlation degree of energy consumption in logistics industry is 0.677, ranking first, indicating that the economic development of Liaoning Province still depends on energy consumption, and the development of green logistics in logistics industry, as an important field of energy consumption, has become a necessary trend. According to the analysis of $D$ value in Table 3, the reason why the decline of $D$ value in recent three years is on the verge of imbalance may be that compared with the comprehensive development index of regional economy, the development of green logistics system is not good, the attention paid to the green development of logistics industry is insufficient, and the development is blind and extensive.

**Table 4.** Grey correlation degree between regional economy and green logistics in Liaoning from 2011 to 2022

| | $X_1$ | $X_2$ | $X_3$ | $X_4$ | $X_5$ | $X_6$ | $X_7$ | $X_8$ | $X_9$ | $X_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 2011 | 0.386 | 0.377 | 0.349 | 0.339 | 0.367 | 0.408 | 0.440 | 0.359 | 0.351 | 0.390 |
| 2012 | 0.527 | 0.445 | 0.527 | 0.461 | 0.597 | 0.434 | 0.476 | 0.463 | 0.506 | 0.466 |
| 2013 | 0.516 | 0.639 | 0.649 | 0.541 | 0.900 | 0.568 | 0.554 | 0.593 | 0.666 | 0.725 |
| 2014 | 0.662 | 0.789 | 0.750 | 0.709 | 0.793 | 0.617 | 0.658 | 0.664 | 0.751 | 0.808 |
| 2015 | 0.773 | 0.740 | 0.819 | 0.866 | 0.438 | 0.857 | 0.750 | 0.725 | 0.621 | 0.854 |
| 2016 | 0.994 | 0.837 | 0.975 | 0.796 | 0.633 | 0.974 | 0.829 | 0.919 | 0.816 | 0.898 |
| 2017 | 0.869 | 0.900 | 0.853 | 0.700 | 0.610 | 0.889 | 0.906 | 0.772 | 0.838 | 1.000 |
| 2018 | 0.656 | 0.644 | 0.668 | 0.601 | 0.681 | 0.740 | 0.715 | 0.635 | 0.674 | 0.761 |
| 2019 | 0.585 | 0.550 | 0.587 | 0.556 | 0.548 | 0.546 | 0.582 | 0.568 | 0.590 | 0.640 |
| 2020 | 0.574 | 0.592 | 0.637 | 0.731 | 0.573 | 0.548 | 0.526 | 0.569 | 0.598 | 0.593 |
| 2021 | 0.495 | 0.491 | 0.516 | 0.574 | 0.523 | 0.486 | 0.462 | 0.505 | 0.505 | 0.515 |
| 2022 | 0.478 | 0.483 | 0.500 | 0.527 | 0.581 | 0.468 | 0.455 | 0.494 | 0.505 | 0.476 |
| Correlation mean | 0.626 | 0.624 | 0.652 | 0.617 | 0.604 | 0.628 | 0.613 | 0.606 | 0.618 | 0.677 |
| Ranking | 4 | 5 | 2 | 7 | 10 | 3 | 8 | 9 | 6 | 1 |

# 5 Conclusions and Countermeasures

## 5.1 Conclusion

By constructing entropy weighting method and coupling coordination degree model, this paper calculated the comprehensive development level of regional economy and green logistics in Liaoning from 2011 to 2022. The calculation results show that the coupling coordination degree of the two systems generally presents a slow rising trend, and the highest coupling coordination degree is 0.752, which is barely at the overall coordination level. The following conclusions are drawn:

First, according to the grey correlation analysis, the energy consumption of the logistics industry is the most closely related to the economic development of Liaoning Province. Therefore, under the background of "double carbon", the logistics industry should accelerate the green and low-carbon transformation.

Second, from 2011 to 2018, with the promulgation of relevant regulations on green logistics, the coordinated and integrated development of regional economy and green logistics was promoted, and the coupling coordination degree was significantly improved; There is a downward trend in the coupling coordination degree from 2020 to 2022, which is due to the reduction of the green development level and insufficient attention of the logistics industry.

## 5.2 Countermeasures

First, the government needs to implement policy guidance, reduce the energy consumption and waste emissions of the logistics industry, strengthen the construction of green logistics personnel, and give play to the role of environmental force, so as to

accelerate the coordinated development of regional economy and green logistics, and enhance innovation.

Second, in the regional economic development of Liaoning, strengthen the development of characteristic industries, always adhere to the opening up, introduce talents, and promote the exchange of resources and information.

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