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Research on the High-Quality Coupling and Coordinated Development of the Ecological Environment and Economy in Lianyungang

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Abstract: This paper is based on the current status of ecological environment and high-quality economic development in Lianyungang. It employs the entropy weight method to calculate the weights of relevant indicators from 2017 to 2024 and uses the system coordination degree model to measure the coupling level between the two. The research results show that the ecological environment quality in Lianyungang has continued to improve, the level of economic development has steadily increased, and the coordination between ecological environment and economic development has gradually strengthened year by year. The coupling degree has shown an overall upward trend, with the coordination relationship between the two systems evolving from mild imbalance (economic development being hindered) to a state of barely coordinated balance.

Keywords: Ecological Environment; High-Quality Economic Development; Entropy Rights Method; Coupling Coordination Degree.

1. Introduction

Green and low-carbon development is an inevitable requirement for China's economic transformation and high-quality development. It represents a broad and profound systemic transformation of society and the economy. As an important node city at the intersection of the Belt and Road Initiative, the development of Lianyungang has attracted widespread attention. In recent years, with the in-depth implementation of the Belt and Road Initiative and the Yangtze River Delta integration strategy, Lianyungang has achieved remarkable results in its socio-economic development. However, while the city has experienced rapid economic growth, it also faces challenges such as tightening resource and environmental constraints and ecological degradation.

Regional coordinated development is a dynamic process that requires mutual promotion and complementary advantages among various elements within a region. As the eastern bridgehead of the New Eurasian Continental Bridge and one of China's first coastal open cities, Lianyungang boasts both port economy characteristics and ecological resource advantages. Currently, Lianyungang is at a critical stage of high-quality development. How to maintain rapid economic growth while protecting its unique marine ecological environment and achieving a virtuous cycle between high-quality economic development and ecological protection is an urgent issue that needs to be addressed.

To achieve sustainable development in Lianyungang, it is essential to strike a balance between high-quality economic development and ecological environmental protection. On the one hand, high-quality economic development relies on a sound ecological environment; on the other hand, a healthy ecological environment also requires the support of high-quality economic development. Studying the interactive mechanisms between ecological environment and high-quality economic development of Lianyungang, and analyzing their dynamic coupling relationship, holds significant importance for establishing a green and low-carbon development system with unique characteristics of Lianyungang. This not only aids in achieving the goal of building a "strong, prosperous, beautiful, and high-quality" new port city but also paves the way for coastal port cities to explore a new path where high-quality economic development and ecological protection advance in tandem.

2. Research Status

In recent years, research on the coordinated relationship between ecological environment and economic development has increasingly attracted academic attention, with a steady stream of research findings emerging. Existing studies primarily exhibit the following characteristics: In terms of research methods, quantitative analysis techniques such as the coupling coordination degree model, entropy method, and spatial econometric analysis are widely employed; In terms of theoretical foundations, they integrate multidisciplinary theoretical frameworks from ecological economics, environmental economics, and regional development theory; In terms of research scope, studies include macro-level analyses of national strategic regions such as the Yangtze River Economic Belt and the Yellow River Basin, meso-level studies focused on specific provinces and cities, as well as micro-level explorations of typical counties. These studies provide important references for deepening our understanding of the interactive relationship between regional ecological environments and economic systems.

2.1. Research Related to River Basins and Urban Agglomerations

Domestic scholars have conducted systematic research on the coordinated development of ecological environment and economy in large river basins such as the Yangtze River Economic Belt and the Yellow River Basin, as well as urban agglomerations. Li Min et al. (2025) constructed a coupled coordination model and a PVAR model to reveal the interactive relationship between ecological environment and high-quality economic development in the Yangtze River

Economic Belt. They found that the coordination level exhibits a spatial differentiation pattern of "downstream > midstream > upstream," and that the short-term negative impact of the economy on the ecological environment weakens over time [1]. Su Xijun et al. (2025) focused on resource-based cities in the Yellow River Basin, finding that the coordination level of their "ecological-economic" system exhibits a spatial distribution of "upstream > middle > downstream," and pointed out that per capita GDP and industrial structure upgrading are important influencing factors [2]. Hong Lei et al. (2024) studied 27 central cities in the Yangtze River Delta and found that forest coverage and economic structure are key factors influencing the degree of coupling coordination, with Zhejiang Province showing the most significant improvement [5]. He Gang et al. (2024) studied the Huai River Basin and found that although the coordination of its water resources-economy-society-environment system has improved, it remains in a state of moderate imbalance, with inter-regional differences being the primary constraining factor [6]. Xiao Zhouyan et al. (2023) compared China's three major urban agglomerations and found that the Yangtze River Delta and Pearl River Delta regions exhibit stronger spatial radiation effects from market mechanisms and government regulation [9]. Gao Linxuan et al. (2020) noted that the coupling coordination of economic development, spatial development, and environmental evolution in the broader Yangtze River Delta region exhibits a spatial pattern of "high in the east and south, low in the north and west" [19].

2.2. Related Research on Regional Multi-systems

This type of research focuses on the spatiotemporal characteristics and influencing factors of regional ecological-economic systems. Wang Xingxing et al. (2024) used the Gansu section of the Yellow River basin as an example and found that the coordination between ecological environment, economic development, and urbanization exhibited a "high in the west, low in the east" distribution, with government capacity and water resources being the primary driving factors [7]. Wen Yuhua (2023) studied Gansu Province and found that the coordination level of its ecological-economic-social system is primarily driven by improvements in the ecological environment, with industrial structure and technological level being the key promoting factors [8]. He Lei et al. (2023) also studied Gansu Province and found that the coupling coordination between high-quality economic development and the ecological environment exhibits a "Z"-shaped upward trend but remains in an antagonistic phase [11]. Zheng Tieming et al. (2022) pointed out that there is regional differentiation in the coupling coordination degree of western cities, with southwestern cities lagging significantly behind northwestern cities [12]. Chen Minghua et al. (2022) studied 78 cities in the central region and found that provincial capital cities mostly belong to the "high coordination—ecological lag" type, with high-quality economic development being the primary constraining factor [13]. Ma Zunping et al. (2020) found that the coupling coordination levels of "Belt and Road" provinces exhibit significant spatial correlation, and the influencing factors for 'Belt' and "Road" provinces differ markedly [18].

2.3. Specific Area Research

Some scholars have conducted case studies to provide policy recommendations for regional coordinated development. Zou Ling et al. (2024) used Jilin Province as an example and found that the coupling coordination degree between urban living environment and economic resilience exhibits a pattern of "higher in the central and eastern regions and lower in the southwestern regions," with economic resilience generally lagging behind [4]. Wang Zhonghua et al. (2023) studied the Songhua River Basin and found that investment adjustments and government capacity have a significant positive impact on coordination, while the role of urbanization levels did not meet expectations [10].Wang Ying et al. (2021) studied 38 districts and counties in Chongqing and found that although the coordination between the economy and the environment has been continuously improving, the overall situation remains out of balance, with marketization levels and industrial structure optimization being the key influencing factors [14]. Zhang Jianwei et al. (2021) pointed out that the coordination between upstream and downstream provinces in the Yellow River Basin has improved rapidly, while midstream provinces have lagged behind [15]. Tang Xiaoling et al. (2021) found that among the cities in the Guanzhong Plain Urban Agglomeration, only Xi'an achieved a good level of coordination, while the overall coordination attraction of the region was weak [16]. Liu Linke et al. (2021) compared the Yellow River Basin with the Yangtze River Economic Belt and found that the former has a lower level of coordination between ecological protection and high-quality development, and the interaction mechanisms between subsystems are not significant [17].

Domestic research has made significant progress in the construction of indicator systems and the analysis of coupling mechanisms, but there are still some shortcomings: first, in terms of research subjects, there is insufficient focus on coastal small and medium-sized cities, especially port cities; second, in terms of indicator system construction, there is a lack of characteristic indicators designed specifically for coastal cities. Therefore, this paper aims to strengthen the construction of characteristic indicator systems for coastal cities and explore the feedback mechanisms between the economy and the ecological environment of coastal cities.

3. Current Status of the Ecological Environment and Economic Development in Lianyungang

3.1. Current State of the Ecological Environment

In 2024, the overall environmental quality of Lianyungang improved, but structural pressures remain. In terms of population density, the city's average population density was 692.7 people per square kilometer, below the provincial average, indicating relatively low environmental carrying capacity pressure. Energy consumption per unit of GDP decreased by 10.67% year-on-year, ranking among the top in the province, demonstrating significant progress in green transformation. However, the absolute value of energy consumption remains higher than that of the southern Jiangsu region. Industrial wastewater discharge was controlled at 52.2 million tons, an increase of 29.9% compared to 2023, with some chemical industrial parks still having relatively high emission intensities. The per capita public green space area reached 15.8 square meters, exceeding the national ecological garden city standard, and the greening coverage rate in built-up areas reached 43.55%, both achieving relatively optimal levels. Farmland area remained stable at 3,711.28 square kilometers, maintaining the ecological red line. The comprehensive utilization rate of general industrial solid waste remained stable at over 95%, and the resource recovery and utilization capacity for hazardous waste remained at a high level. The capacity for harmless treatment of garbage reached 5,565 tons per day, achieving full coverage across urban and rural areas. However, environmental issues in Lianyungang remain prominent. Nitrogen and phosphorus pollution in nearshore waters has not been fundamentally resolved, VOCs management in some areas still needs to be strengthened, and the balance of environmental infrastructure requires improvement. Overall, the city exhibits the characteristics of “significant emission reduction achievements, excellent ecological foundation, improved governance levels, and prominent local pollution.”

3.2. Current State of Economic Development

Lianyungang has achieved steady progress in high-quality economic development. In 2024, the city's gross domestic product (GDP) reached 466.3 billion yuan, representing a year-on-year increase of approximately 5.8%, with a growth rate exceeding the provincial average. The industrial structure continued to optimize, with the tertiary industry structure adjusted to 9.86:44.15:45:99. The tertiary industry's share increased by 2.09 percentage points year-on-year, with modern services and port-related industries becoming the main drivers of growth. Residents' income steadily increased, with the per capita disposable income of all residents reaching 38,100 yuan, up 5.83%. However, the urban-rural income gap remains significant, with urban residents' income approximately 2.2 times that of rural residents. The port economy performed strongly, with the cargo throughput of Lianyungang Port exceeding 346 million tons and container throughput reaching 6.6907 million TEUs, representing a year-on-year increase of 7.65% in cargo throughput. The port plays an important role in the “Belt and Road” initiative. However, compared with the southern region of Jiangsu Province, the economic output of Lianyungang remains insufficient, and its scientific and technological innovation capabilities and the concentration of high-end industries need to be enhanced, posing challenges to regional coordinated development. Overall, Lianyungang is leveraging its port advantages and industrial upgrading to drive high-quality economic development, but efforts to strengthen regional balanced development and industrial transformation remain necessary.

4. Coupling Coordination Model

4.1. Overview of Coupling Coordination

The Coupling Coordination Degree Model is an assessment method used to quantify the level of interaction and coordinated development among multiple systems. It is widely applied in fields such as economic-social-environmental systems, urbanization and ecological coordination, and industrial synergy development. Its core concept involves calculating the Coupling Degree and Coordination Degree to determine whether systems promote or constrain one another, thereby evaluating their state of coordination.

4.2. Determining Indicator Weights Using Entropy Values

The entropy method can measure the impact of the dispersion of indicators on comprehensive evaluation. The greater the dispersion of indicators, the greater the impact of that indicator on comprehensive evaluation. The specific process of the entropy method is as follows: in the constructed indicator system, for the data matrix $A = \begin{bmatrix} X_{11} & \cdots & X_{1m} \\ \vdots & \vdots & \vdots \\ X_{n1} & \cdots & X_{nm} \end{bmatrix}_{n\times m}$,before calculating indicator weights using the entropy method, it is necessary to eliminate indicator heterogeneity. The original indicator X_{ij} needs to be standardized, i = 1, 2, ..., n; j = 1, 2, ..., m (in the following text, i and j have the same range of values); calculate the proportion of the i-th plan under the j-th indicator $P_{ij} = X_{ij}/\sum_{i=1}^{n} X_{ij}$. Then, calculate the entropy value of this indicator $e_j = -k \times \sum_{i=1}^{n} P_{ij}\log(P_{ij})$ .The smaller the entropy value, the smaller the evaluation effect on the plan; furthermore, the difference coefficient of the j-th indicator can be calculated as $1-e_j$, thereby obtaining the weights of each indicator $W_j = g_j/\sum_{j=1}^{m} g_j$.

4.3. Coupling Coordination Category

According to the integrated method, the comprehensive evaluation scores for the ecological environment subsystem and the high-quality economic development subsystem are calculated separately using the following formulas: $S_i = \sum_{j=1}^{m} W_j \times P_{ij}$,i = 1, 2, ..., n; j = 1, 2, ..., m, S_1,S_2 represent the comprehensive evaluation scores for the ecological environment subsystem and the high-quality economic development subsystem, respectively. The degree of coupling between the ecological environment and high-quality economic development subsystems in Lianyungang is calculated using the following formula: $C = 2\sqrt{\frac{S_1 \times S_2}{(S_1+S_2)^2}}$,in order to reflect the degree of coupling between ecological environment and high-quality economic development, the coupling degree is divided into six levels according to the median segmentation method. The specific classification results are shown in Table 1:

Table 1. Coupling Degree Classification

Serial	Coupling Degree	Coupling Level
1	C=0	Irrelevant
2	0<C≤0.3	Low Coupling
3	0.3<C≤0.5	Antagonism
4	0.5<C≤0.8	Running Coupling
5	0.8<C<1	Highly Coupled
6	C=1	Benign Resonance

Coupling degree is an indicator used to measure the degree of static coupling coordination in composite systems, reflecting the closeness of the relationship between systems. However, this metric has obvious limitations. It can only reflect the strength of the interrelationship between systems and cannot characterize the overall level of coordinated development of the systems. It is also difficult to accurately assess the coordination status and coupling degree of the systems. Therefore, a weighted method is introduced based on the coupling degree model to construct a dynamic coupling coordination degree model. This model can effectively reflect the long-term symbiotic development trend between systems and characterize the relative levels of development of the two systems. The comprehensive evaluation calculation formula is: $D = C \times S$, Where C represents the coupling degree, $S = \alpha S_1 + \beta S_2$, α and β represent the weights of the two subsystems of ecological environment and high-quality economic development. Since the two systems are considered equally important, both are set to 0.5. To more intuitively reflect the coupling and coordination between the ecological environment system and the high-quality economic development system, the coupling coordination degree is divided into 10 intervals based on the uniform distribution function method, as shown in Table 2:

Table 2. Coordination Level Classification

Serial	Coupling Coordination Degree	Type
1	0≤D≤0.1	Extreme Imbalance
2	0.1<D≤0.2	Severe Imbalance
3	0.2<D≤0.3	Moderate Imbalance
4	0.3<D≤0.4	Mild Imbalance
5	0.4<D≤0.5	On the Verge of Imbalance
6	0.5<D≤0.6	Reluctant Coordination
7	0.6<D≤0.7	Junior Coordinator
8	0.7<D≤0.8	Moderate Coordination
9	0.8<D≤0.9	Good Coordination
10	0.9<D≤1	Highly Coordinated

5. Empirical Analysis

5.1. Construction of an Indicator System

The selection of scientific and effective indicators has a significant impact on research outcomes, so establishing a reasonable evaluation system is the foundational guarantee for analyzing the coordination between ecological environment and high-quality economic development in Lianyungang. During the indicator selection process, the principles of scientific rigor, comparability, and relevance were strictly adhered to, while also considering data availability and referencing relevant research findings. Ultimately, eight indicators reflecting ecological and environmental conditions were selected: population density, energy consumption per unit of GDP, industrial wastewater discharge volume, per capita public green space area, arable land area, comprehensive utilization rate of general industrial waste, green coverage rate in built-up areas, and waste harmless treatment capacity. Additionally, the following indicators were selected: per capita GDP, the proportion of general public budget revenue to GDP, the proportion of tertiary industry output to GDP, the proportion of fixed-asset investment to GDP, high-tech industry output, the proportion of R&D expenditure to GDP, the number of doctors per 10,000 people, the student-teacher ratio, per capita general public budget expenditure, the Engel coefficient for all residents, the per capita urban-rural income gap, the urban registered unemployment rate, the urbanization rate, the foreign trade dependency ratio, and the total actual utilization of foreign capital.

5.2. Data processing

The data processing steps are as follows: Firstly, based on the 2017-2024 Lianyungang Statistical Yearbook, collect and summarize the indicator data from the ecological environment system and the high-quality economic development system; Secondly, for individual missing data points, the moving average method is used to fill in the gaps. Finally, the original data is preprocessed using the deviation standardization method to eliminate the impact of unit and magnitude differences on data analysis. The weights for each indicator are determined using the entropy method.

5.3. Empirical analysis results

5.3.1. Analysis of the Level of High-Quality Development of the Ecological Environment and Economy

Based on the relevant data from the evaluation indicators for ecological environment and high-quality economic development in Lianyungang, the comprehensive evaluation scores for the two subsystems were calculated using the entropy method. As shown in the Table 3, both the ecological environment and high-quality economic development in Lianyungang have seen significant improvements from 2017 to 2024. During these eight years, the ecological environment development of Lianyungang remained at an intermediate level and exhibited a fluctuating upward trend, reaching its peak in 2024 with a comprehensive evaluation index of 0.596230. The comprehensive evaluation index for economic development has shown a steady upward trend year by year, rising from 0.263956 initially to 0.503791 in 2024, with a significant increase of 90.86% year-on-year.

Table 3. Economic and Environmental Index

Year	Economic Index	Environmental Index
2017	0.263956	0.468206
2018	0.267114	0.534652
2019	0.321196	0.523403
2020	0.373057	0.533889
2021	0.359854	0.456456
2022	0.376466	0.546488
2023	0.394669	0.576575
2024	0.503791	0.596230

5.3.2. Analysis of the Coupling Level between Ecological Environment and High-Quality Economic Development

Table 4. Coupling Degree Analysis

Year	Coupling Degree	Coupling Level
2017	0.960300	Highly Coupled
2018	0.942684	Highly Coupled
2019	0.970918	Highly Coupled
2020	0.984151	Highly Coupled
2021	0.992973	Highly Coupled
2022	0.982886	Highly Coupled
2023	0.982304	Highly Coupled
2024	0.996463	Highly Coupled

Table 4 shows that during the period from 2017 to 2024, the coupling degree between the ecological environment and high-quality economic development in Lianyungang remained at a relatively high level overall. Except for 2018, the coupling degree values for the remaining years remained stable between 0.95 and 1, with relatively small fluctuations. In 2024, the coupling degree reached its peak at 0.996463.

5.3.3. Analysis of the Coupling and Coordination Types between Ecological Environment and High-Quality Economic Development

Table 5 shows that between 2017 and 2024, the comprehensive evaluation index for ecological environment and economic development in Lianyungang exhibited a sustained upward trend, indicating a significant improvement in the overall development level of both systems. Meanwhile, the coupling coordination degree increased from 0.351548 in 2017 to 0.548065 in 2024, with a year-on-year growth rate of 55.9%, reflecting the continuous optimization of the coordination between the two systems. From the perspective of coordination level changes, the system was in a state of "mild imbalance—obstructing high-quality economic development" in 2017, transitioning to "near imbalance" in 2019. From 2019 to 2023, it remained at the "near imbalance" level, and since 2017, the coordination type has consistently been "economic development hindered." By 2024, the coordination level between the two systems further improved, reaching the "barely coordinated" state, indicating that Lianyungang has achieved certain effectiveness in the coordinated development of ecological environment and high-quality economic development.

Table 5. Coordination Analysis

Year	Coordination Degree	Type
2017	0.351548	Mild imbalance
2018	0.377907	Mild imbalance
2019	0.410018	the Verge of Imbalance
2020	0.446286	the Verge of Imbalance
2021	0.405287	the Verge of Imbalance
2022	0.453580	the Verge of Imbalance
2023	0.477029	the Verge of Imbalance
2024	0.548065	Reluctant Coordination

6. Conclusion and Recommendation

6.1. Conclusion

By establishing an indicator system for the two subsystems of ecological environment and economic development in Lianyungang, and conducting quantitative analysis using the coupling degree and coupling coordination degree models, the following conclusions were drawn: the overall quality of the ecological environment in Lianyungang has improved, and the trend toward high-quality economic development has steadily improved. Empirical results show that over the past eight years, the comprehensive evaluation value of the ecological environment subsystem in Lianyungang has shown a fluctuating upward trend, with overall improvement. The economic high-quality development subsystem has shown more significant improvements, with notable progress in economic scale, structure, and quality. In terms of coupling degree, the coupling relationship between the ecological environment and economic high-quality development subsystems in Lianyungang has consistently maintained a high level of coupling. Additionally, from 2017 to 2024, the coupling coordination between the two subsystems has continued to strengthen. In 2017 and 2018, the systems were in a state of mild imbalance, and from 2019 to 2023, they were in a state of basic imbalance. In 2024, the coupling coordination state of the two systems shifted to a state of barely coordinated, showing some improvement. Additionally, over the past 8 years, the main issue has been the constraints on economic development. Research indicates that over the past decade, the coordination between ecological environment and economic development of Lianyungang has continued to improve. Prior to 2024, the synergistic effects between the two systems were weak, and economic development was constrained. As regional economic levels improved and ecological-economic linkages strengthened, the coupling and interactive effects between the systems continued to enhance. Especially after 2023, under the impetus of the national regional coordinated development strategy, the coordination between the two systems significantly improved, indicating that coordinated development policies effectively promoted the positive interaction between the economy and ecology of Lianyungang.

6.2. Recommendation

Firstly, intensify efforts to protect and manage the ecological environment. Accelerate the construction of beautiful coastal areas and ecological corridors. Lianyungang should combine local conditions with precise policies to steadily advance ecological environmental protection work. It should improve the ecological environmental protection system, innovate environmental management mechanisms, focus on overall planning, and rigorously implement specific measures.

Secondly, promote high-quality economic development. We will deeply implement the innovation-driven development strategy, accelerate industrial transformation and upgrading, and promote the transition of new and old growth drivers. We will seize national strategic opportunities such as the construction of the "Belt and Road" intersection point, leverage important platforms like the Lianyungang National East-West Regional Cooperation Demonstration Zone, and focus on cultivating strategic emerging industries such as new pharmaceuticals, new materials, and new energy. In particular, the port industrial zone should accelerate the transformation of its development model, promote industrial development toward high-end and green directions, establish and improve an industrial collaborative innovation system, and achieve high-quality economic development.

Thirdly, promote the coordinated development of the ecological environment and the economy. Adhere to the principle of prioritizing ecology and green development, and properly balance protection and development. Resolutely reject extensive development models that sacrifice the environment, give full play to the synergistic effects of the ecological environment and economic development, promote the integrated development of ports, industries, and cities, and achieve a virtuous cycle of ecological environment improvement and economic growth.

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