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Research on the Measurement of Ecological Performance Levels and Influencing Factors in the Yangtze River Delta Region

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Abstract

Based on the perspective of the circular economy, this paper uses the DEA model to measure the ecological performance levels of nine central cities in the Yangtze River Delta urban cluster from 2011 to 2021, as determined by the government. The panel Tobit model and random effects model (RE) are employed to analyze the influencing factors of ecological performance. The results indicate the following: ①Shanghai has the highest ecological performance level, with comprehensive efficiency, pure technical efficiency, and scale efficiency values of 1 according to the DEA model calculations, placing it on the efficiency frontier. ②The average ecological performance levels in the Yangtze River Delta region follow the regional pattern of "Shanghai > cities in Zhejiang Province > cities in Anhui Province > cities in Jiangsu Province." ③Results of the regression analysis on influencing factors show that low carbon potential, air quality, and regional economic development have a positive impact on the ecological performance level. The estimated coefficients for the level of openness to the outside world and population pressure are negative and significant. The estimated coefficient for government execution is positive but not significant, indicating that its endogenous influence on ecological performance requires further research.

Keywords

Ecological Performance; Circular Economy; DEA Model; Panel Tobit Model.

1. Research Background and Significance

1.1 Research Background

The Yangtze River Delta region holds immense significance for China in various aspects, ranging from economic development to cultural heritage and environmental conservation. This vast and dynamic region, located in eastern China, encompasses Shanghai, Jiangsu Province, Zhejiang Province, and Anhui Province. With a population of over 230 million people and a land area of approximately 358,000 square kilometers, the Yangtze River Delta region is a crucial hub of economic growth and innovation.

Economically, the Yangtze River Delta region is considered the powerhouse of China[1]. It serves as a vital engine for the country's economic development, contributing significantly to China's GDP. Moreover, the Yangtze River Delta region is known for its advanced manufacturing industries and technological innovation. It hosts numerous industrial zones and high-tech parks, attracting domestic and foreign companies to establish their operations there. The region has a well-developed transportation infrastructure, including ports, railways, and highways, facilitating the efficient movement of goods and services[2]. This connectivity, coupled with a skilled labor force and a

 Volume 9 Issue 7, 2023
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vibrant entrepreneurial ecosystem, has fostered rapid industrialization and economic growth in the area.

In terms of environmental significance, the Yangtze River Delta region faces both challenges and opportunities. The region is situated along the Yangtze River, the longest river in Asia and a vital water resource for China. The delta area is prone to flooding, and managing water resources and mitigating the impacts of climate change are critical for sustainable development in the region. Efforts are being made to balance economic growth with environmental protection, including the restoration of wetlands, the promotion of green technologies, and the implementation of ecological conservation projects. The successful conservation of the region's natural resources not only benefits the local ecosystem but also has a broader impact on the overall ecological balance of China.

1.2 Research Significance

Measuring ecological performance levels in the Yangtze River Delta region holds significant research significance due to several compelling reasons. This region, characterized by rapid urbanization, industrialization, and population growth, faces numerous environmental challenges that necessitate a comprehensive evaluation of its ecological performance. By examining and assessing the region's ecological performance, researchers can provide valuable insights into the state of the environment, guide policy-making processes, promote sustainable development, and contribute to the overall well-being of the region and its inhabitants.

By quantifying and analyzing ecological indicators, researchers can generate a baseline assessment of the region's environmental condition, enabling the formulation of effective strategies for ecological restoration and conservation. Moreover, measuring ecological performance levels provides a framework for monitoring and evaluating the effectiveness of environmental policies and interventions in the Yangtze River Delta region. As governments and organizations implement various environmental measures, it is crucial to assess their impact and effectiveness. By establishing ecological performance indicators, researchers can track changes in the region's ecological condition over time, assess the success or shortcomings of implemented policies, and identify areas where adjustments or additional interventions are required. This feedback loop between research and policy enables evidence-based decision-making and facilitates adaptive management approaches that improve the region's ecological resilience and sustainability.

2. Literature Review

In China, there is relatively limited research on ecological performance, with similar studies focusing mainly on environmental performance and ecological efficiency. He Pinglin[3] et al. (2012) conducted a case study on China's thermal power generation enterprises, constructing an implementation process for environmental performance evaluation based on data envelopment analysis (DEA) method. Fang Shijiao[4] et al. (2019) utilized super-efficiency DEA and spatial econometric methods to investigate the regional ecological welfare performance levels and their spatial effects in China from 2005 to 2016, revealing an East-West disparity with higher performance in the eastern region. Long Liangjun[5] (2019) employed a two-stage Super-NSBM model considering undesirable outputs and DEA window analysis to measure the ecological welfare performance of 35 major cities in China from 2011 to 2015, finding an overall low performance level. Xiao Deyun[6] et al. (2021) constructed a theoretical framework based on the interaction of urban political-business environment, enterprise innovation strategy, and innovation resources, and used NCA and fsQCA methods to analyze the influence path of internal and external characteristics of enterprises on innovation ecological performance from a configurational perspective. Ji Ming[7] et al. (2022) focused on 42 major prefecture-level cities in ethnic regions and employed the random frontier analysis method to measure the ecological performance of new urbanization from 2003 to 2020.

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3. Research Methods and Indicators

3.1 DEA Model

Data Envelopment Analysis (DEA) is a systematic analysis method for evaluating the relative efficiency between multiple inputs and outputs, representing a multi-input multi-output analysis method[8]. In this study, input-output data is utilized, and the input-oriented BCC (Variable Returns to Scale) model is selected to evaluate the ecological performance levels in the Yangtze River Delta region. For any decision-making unit, the dual form of the input-oriented BCC model can be expressed as:

$$\min\theta - \varepsilon(\hat{e}^T S^- + e^T S^+)$$
$$\text{s.t.}\begin{cases} \sum_{j=1}^{n} X_j \lambda_j + S^- = \theta X_\theta \\ \sum_{j=1}^{n} Y_j \lambda_j - S^+ = Y_\theta \\ \lambda_j \geq 0, S^-, S^+ \geq 0 \end{cases}$$

Here, $\mathrm{j} = 1, 2, \cdots\cdots, \mathrm{n}$ represents the decision−making unit, X represents the input vector, and Y represents the output vector.

If $\theta = 1$, $S^- = S^+ = 0$, then the decision-making unit is DEA efficient. If $\theta = 1$ and either $S^- \neq 0$ or $S^+ \neq 0$, then the decision-making unit is weakly DEA efficient. If $\theta < 1$, then the decision-making unit is not DEA efficient. The efficiency value calculated by the BCC model is the comprehensive technical efficiency (TE), which can be further decomposed into scale efficiency (SE) and pure technical efficiency (PTE), and $\mathrm{TE} = \mathrm{SE} \times \mathrm{PTE}$.

3.2 Influence Factor Model

The Tobit model, also known as the sample selection model or censored dependent variable model, is a model in which the dependent variable is subject to certain constraints. The formula expression is as follows:

$$\mathrm{Y} = \begin{cases} Y_{it}^* = \beta_j X_{it} + u_i + \varepsilon_{it}, Y_{it}^* > 0 \\ 0, Y_{it}^* \leq 0 \end{cases}$$

Here, Y represents the dependent variable, X_{it} represents the independent variable, u_i represents individual effects, β_j represents the estimated parameters ($\mathrm{j} = 1, 2, \cdots$), and ε is the random disturbance term, with $\varepsilon_{it} \sim N(0, \sigma_\varepsilon^2)$. To avoid data loss and biased estimation caused by using truncated data models, this study utilizes the panel random Tobit model regression analysis with maximum likelihood estimation. When u_i is uncorrelated with the independent variable X_{it}, it is a random effects model (RE).

3.3 Selection of Indicators and Data Sources

This study constructs an indicator system for evaluating ecological performance in the Yangtze River Delta urban cluster from the perspective of input-output and in combination with the circular economy perspective (Table.1). In the construction of the indicator system, inputs include capital consumption, land consumption, labor consumption, water resource consumption, energy consumption, and technology (information) consumption. Outputs include economic benefit output

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and circular utilization output. The calculation of capital stock is estimated using the perpetual inventory method:

$$K_{it} = K_{it-1}(1-\partial) + I_{it}$$

Here, K_{it} represents the capital stock in region i in year t, ∂ denotes the fixed asset depreciation rate, and I_{it} represents the total capital formation in region i in year t (using 2010 as the base year). Regarding the original data in monetary units, numerical adjustment is required to eliminate the influence of price factors. However, due to the lack of specific city-level economic data for price adjustment indices, the GDP deflator indices of various provinces and cities are commonly used for numerical adjustment. The selection of circular utilization output refers to the "Evaluation Index System for Circular Economy Development (2017 Edition)" jointly published by the National Development and Reform Commission, Ministry of Finance, Ministry of Ecology and Environment, and National Bureau of Statistics. Representative indicators for solid and water resource circular utilization rates are chosen. In this study, the ecological performance levels are tested using nine central cities in the Yangtze River Delta urban cluster, which were selected by the central government, namely Shanghai, Nanjing, Hangzhou, Hefei, Ningbo, Nantong, Suzhou, Wuxi, and Changzhou, for the period 2011-2021. The sample data is sourced from various publications such as "China City Statistical Yearbook," "China Statistical Yearbook," "China Urban Construction Statistical Yearbook," "China Regional Economic Statistical Yearbook," as well as statistical yearbooks and websites of provinces and cities.

Table 1. The index system of urban ecological performance

Types of Indicators	Categories of Indicators	Indicators
Input Indicators	Capital Consumption	Fixed Capital Stock (100 million yuan)
	Labor Consumption	Number of Employees at the End of the Year (10,000 people)
	Water Resource Consumption	Total Water Supply (100,000 cubic meters)
	Land Resource Consumption	Built-up Area (hectares)
	Energy Resource Consumption	Total Energy Consumption (10,000 tons of standard coal)
	Technology (Information) Consumption	Scientific Expenditure of Public Finance (yuan)
		Number of International Internet Users (households)
		Number of Fixed Telephone Users (10,000 households)
		Number of Mobile Phone Users (10,000 households)
Output Indicators	Economic Benefit Output	Gross Domestic Product (100 million yuan)
	Circular Utilization Output	Urban Water Reuse Rate (%)
		Comprehensive Utilization Rate of General Industrial Solid Waste (%)

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4. Empirical Analysis

4.1 Empirical Analysis of the DEA Model

In this stage, this study utilized DEAP2.1 to calculate the comprehensive efficiency (TE), pure technical efficiency (PTE), and scale efficiency (SE) of 9 central cities in the Yangtze River Delta region from 2011 to 2021, as shown in Table.2.

Table 2. Average ecological performance of 9 central cities in the Yangtze River Delta region from 2011 to 2021

City	TE	PTE	SE
Shanghai	1.0000	1.0000	1.0000
Nanjing	0.8630	1.0000	0.8630
Hangzhou	0.9976	1.0000	0.9976
Hefei	0.7870	0.9234	0.8542
Ningbo	0.8328	0.8518	0.9782
Nantong	0.5638	0.5936	0.9496
Suzhou	0.8884	0.9962	0.8918
Wuxi	0.9642	1.0000	0.9642
Changzhou	0.7856	0.9320	0.8436
Average Value of Cities in Zhejiang Province	0.9152	0.9259	0.9879
Average Value of Cities in Jiangsu Province	0.8140	0.9040	0.9020
Average Value	0.8536	0.9219	0.9269

According to Table.2, among the 9 central cities in the Yangtze River Delta region, only Shanghai has achieved a comprehensive efficiency, pure technical efficiency, and scale efficiency value of 1, placing it at the efficiency frontier. This indicates that Shanghai has achieved overall effectiveness, technical effectiveness, and scale effectiveness in terms of input and output. The other 8 central cities in the Yangtze River Delta region have not achieved overall effectiveness, indicating the presence of input redundancy and resource wastage. This suggests that there is still room for improvement in the ecological performance of these cities.

4.2 Empirical Analysis of the Tobit Model

Due to the wide range of factors influencing urban ecological performance and considering data availability, this study draws on existing relevant research[9][10] to construct a regression model using a panel Tobit model to select potential factors that may affect urban ecological performance. The ecological performance of the Yangtze River Delta cities is used as the dependent variable, while independent variables are selected from six aspects: population pressure, low-carbon potential, government execution, level of openness, air quality, and regional economic development. Specific representative indicators for each aspect are shown in Table.3. The regression analysis incorporates year random effects, and the results (Table.3) are obtained. The Likelihood-ratio test's Chibar 2(1) statistic is -32.257, with a P-value of 0.000, and it passes the Hausman test. Additionally, the random effects model (RE) is tested by incorporating the model to further explore the reliability of the influencing factors. The Tobit model with year random effects is used to identify the factors influencing the ecological performance of the Yangtze River Delta cities, and the model is constructed as follows:

$$EP_i^t = \beta_0 + \beta_1 Y_{1i}^t + \beta_2 Y_{2i}^t + \beta_3 Y_{3i}^t + \beta_4 Y_{4i}^t + \beta_5 Y_{5i}^t + \beta_6 Y_{6i}^t + u_i^t + \delta + \varepsilon$$

Here, the dependent variable EP represents the urban ecological performance, where i denotes different regions and t represents the year. β_0 represents the intercept, while β_1, β_2, β_3, β_4, β_5, β_6 are the estimated parameters for the independent variables. δ represents the error term, and ε represents the time random effects. The parameter estimation results for each variable using Stata 16.0 are shown in Table.3. The estimation results for the influencing factors (Table.3) indicate a consistent pattern between the Tobit model and the random effects model. The direction of the impact of each independent variable on the ecological performance is the same. The results of the Tobit model regression are more significant, and therefore, the interpretation of the results mainly focuses on the Tobit model regression results, with the other estimation results provided for reference. The interpretation of the results is as follows.

Table 3. The regression results of the influential factors of ecological performance in Yangtze River Delta Region

Explanatory Variables	Representative Indicators	Model	
		Tobit	RE
Population Pressure (Y_1)	Population Density (people/km²)	-0.057*	-0.085*
Low-carbon Potential (Y_2)	Proportion of Total Public Bus (Electric Bus) Passenger Volume to Total Regional Population (trips/person)	0.213*	0.148*
Government Execution Capacity (Y_3)	Proportion of Government Fiscal Expenditure to GDP (%)	0.020	0.008
Level of Openness to the Outside World (Y_4)	Proportion of Foreign Direct Investment to GDP (%)	-0.092*	-0.031**
Air Quality (Y_5)	Percentage of Days with Air Quality Reaching or Exceeding Level II Standard Throughout the Year (%)	1.872***	0.704***
Regional Economic Development Status (Y_6)	Per Capita GDP (yuan/person)	0.693***	0.465***
Regional Random Factor		YES	YES
Year Random Factor		YES	YES

Note: ***, **, * represent the significance levels of 1%, 5%, and 10%, respectively.

According to Table.3, the estimated coefficient for population pressure is negative and significant at the 10% level, indicating that an increase in population density is detrimental to the improvement of urban ecological performance. It leads to increased resource consumption and greater demand for land, water, energy, and other natural resources. This puts additional pressure on the environment and ecosystems, leading to their degradation and depletion. The finite nature of natural resources necessitates considering ecological limits, while urban development requires a sense of sustainable

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development[11], enhancing the compactness in urban planning and fostering awareness of the recyclability of production and consumption needs.

The estimated coefficients for low-carbon potential are positive and significant at the 10% level, indicating that green transportation methods are beneficial for improving the level of urban ecological performance. They help reduce greenhouse gas emissions and air pollution, which are major contributors to environmental degradation and climate change. Relevant studies have shown that as consumers' environmental attitudes increase, their intention to engage in green transportation also strengthens[12]. Therefore, advocating consumers' environmental attitudes towards green transportation is of significant importance for urban sustainable development.

The estimated coefficients for government execution are positive but not significant. Some studies have indicated that unreasonable behavior of local governments can lead to environmental pollution[13]. A higher proportion of public service expenditure by local governments is advantageous for reducing environmental pollution, while increased investment in economic development can lead to higher levels of environmental pollution[14]. Therefore, further research is needed to explore the endogenous impact of government macro-regulation on ecological performance.

The estimated coefficients for the level of openness to the outside world are negative and statistically significant. This result is consistent with the "pollution haven" hypothesis.

The estimated coefficients for air quality are all positive and statistically significant at the 1% level. Clean air reduces pollution and the release of harmful substances into the environment, preventing damage to natural resources, wildlife, and ecosystems. Improved air quality contributes to a healthier and more sustainable environment, enhancing the overall ecological performance of urban areas.

The estimated coefficients for regional economic development are positive and significant at the 1% level, indicating that the growth of per capita GDP is beneficial for improving urban ecological performance. Higher per capita GDP indicates a higher standard of living, which often leads to increased environmental awareness and demand for a cleaner and healthier environment. This can drive individuals, businesses, and governments to adopt more sustainable practices and policies, such as reducing pollution, conserving resources, and promoting eco-friendly transportation options.

5. Conclusion and Recommendations

5.1 Conclusion

Based on the perspective of circular economy and the concept of performance, this paper constructs an input-output evaluation index system and uses the DEA model to measure the ecological performance of 9 central cities in the Yangtze River Delta region from 2011 to 2021, as follows:

During the study period, the average ecological performance of the Yangtze River Delta region was 0.8536. Shanghai had the highest level of ecological performance, with all three efficiency values (comprehensive efficiency, pure technical efficiency, and scale efficiency) calculated by the DEA model being 1, indicating that it is on the efficiency frontier. Overall, the ecological performance in Zhejiang Province was relatively high, with the DEA model's calculated values consistently higher than the overall average. Jiangsu Province, on the other hand, had lower average values for all three efficiency measures compared to the overall average. Anhui Province (Hefei City) had lower average values for comprehensive efficiency and scale efficiency compared to the overall average, but higher average value for pure technical efficiency. Therefore, the regional pattern of ecological performance in the Yangtze River Delta region can be summarized as "Shanghai > cities in Zhejiang Province > cities in Anhui Province > cities in Jiangsu Province".

The regression analysis of influencing factors shows that the estimated coefficient for government execution is positive but not significant, suggesting that further research is needed to understand the endogenous impact of government macroeconomic regulation on ecological performance. The estimated coefficients for low-carbon potential, air quality, and regional economic development are

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all positive and significant. The estimated coefficients for population pressure and level of openness are negative and highly significant.

5.2 Recommendations

5.2.1 Enhance Resource Efficiency

The cities should focus on optimizing resource allocation and minimizing waste. This can be achieved through better planning and management of inputs such as capital, labor, water resources, and energy consumption.

5.2.2 Promote Technology Adoption

Emphasize the importance of innovation and technology adoption to improve ecological performance. Encourage the development and implementation of sustainable technologies that reduce environmental impact and enhance resource efficiency.

5.2.3 Strengthen Policy Implementation

Ensure effective implementation of environmental policies and regulations at the local level. Enhance monitoring and enforcement mechanisms to ensure compliance and address any violations or shortcomings in ecological performance.

5.2.4 Foster Collaboration and Knowledge Sharing

Facilitate collaboration among the central cities in the Yangtze River Delta region to share best practices and experiences in improving ecological performance. Establish platforms for knowledge exchange, where successful strategies and initiatives can be shared and replicated.

5.2.5 Monitor and Evaluate Progress

Regularly assess and monitor the ecological performance of the central cities. This will help track progress, identify areas for improvement, and evaluate the effectiveness of implemented measures. Use the findings to refine strategies and policies for continuous enhancement of ecological performance.

By implementing these recommendations, the central cities in the Yangtze River Delta region can work towards achieving higher ecological performance and contribute to the overall sustainable development of the region.

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