Economics & Business Management
ISSN Print: 3079-5214
ISSN Online: 3079-5222
https://doi.org/10.63313/EBM.9187

Measurement and Influencing Factors of Green Logistics Efficiency in the Yangtze River Delta Region

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How to cite this paper: Guo, C. (2026). Measurement and influencing factors of green logistics efficiency in the Yangtze River Delta region. *Economics & Business Management*, *5*(3), 45–51. ISSN Print: 3079-5214; ISSN Online: 3079-5222.
https://doi.org/10.63313/EBM.9187
Published: 2026-05-14

Abstract

Under the dual-carbon target and regional integration strategy, green logistics has become a core path for high-quality development of the logistics industry. This paper takes the Yangtze River Delta (Shanghai, Jiangsu, Zhejiang) as the research object, and constructs an input-output index system including capital, labor, energy, expected outputs and undesirable outputs (CO_2 emissions). The Super-SBM model with undesirable outputs and the Global Malmquist-Luenberger (GML) index are used to measure static and dynamic green logistics efficiency from 2006 to 2023. Furthermore, a fixed-effects model and fuzzy-set qualitative comparative analysis (fsQCA) are adopted to explore influencing factors. The results show that: 1) The overall green logistics efficiency of the region is on the rise with obvious inter-provincial differences, and Shanghai ranks first; 2) Technological progress is the main driving force for efficiency growth; 3) Economic development, logistics scale and environmental governance positively affect efficiency, while energy intensity has a negative impact. Finally, targeted strategies are proposed from the perspectives of resource allocation, energy structure and policy coordination.

Keywords

Green Logistics Efficiency; Super-SBM Model; GML Index; Yangtze River Delta; Influencing Factors

1. Introduction

With the global promotion of low-carbon development and China's dual-carbon goals, green logistics has become a key support for sustainable economic and social development. The Yangtze River Delta region, as a core economic zone with dense logistics networks and strong industrial agglomeration, faces prominent contradictions between logistics expansion, energy consumption and carbon emissions. Existing studies mostly focus on national or single provincial levels, lacking systematic measurement and comparative analysis of the Yangtze River

Delta as a whole[1-3].

This paper aims to: 1) Build a green logistics efficiency measurement system suitable for the Yangtze River Delta; 2) Measure static efficiency and dynamic evolution via Super-SBM and GML models; 3) Identify key influencing factors through panel regression and fsQCA; 4) Propose differentiated and coordinated promotion strategies. This study supplements regional green logistics research and provides a decision-making basis for green transformation of the logistics industry.

2. Theoretical Basis and Related Models

2.1. Related Concepts of Green Logistics Efficiency

2.1.1. Logistics and Logistics Industry

Logistics refers to the physical flow of goods from suppliers to receivers through transportation, storage, loading and unloading, etc. The logistics industry is a comprehensive service industry integrating multiple links, which promotes the integration of industrial chains and supply chains.

2.1.2. Green Logistics

Green logistics aims to reduce environmental pollution and resource consumption in the whole logistics process, including green transportation, green packaging, reverse logistics and low-carbon operation.

2.1.3. Green Logistics Efficiency

Green logistics efficiency is a comprehensive efficiency index that considers economic outputs, resource inputs and environmental constraints (undesirable outputs such as carbon emissions), reflecting the ability to maximize economic benefits and minimize environmental impacts under given inputs.

2.2. Sustainable Development Theory

Sustainable development emphasizes the coordination of economy, society and environment. Green logistics is the concrete practice of this theory in the logistics industry, requiring balanced growth of economic benefits and ecological protection.

2.3. Related Models of Green Logistics Efficiency

2.3.1. Static Efficiency Measurement Model

Data Envelopment Analysis (DEA) is suitable for multi-input and multi-output systems[4]. The Super-SBM model with undesirable outputs can distinguish effective decision-making units (DMUs) and handle carbon emissions[5], which is adopted for static efficiency measurement in this paper.

2.3.2. Dynamic Efficiency Measurement Model

The Global Malmquist-Luenberger (GML) index takes the global production frontier as the reference, avoids unsolvable linear programming problems, and can decompose efficiency changes into technical efficiency change (EC) and technological progress (TC)[6].

2.3.3. Influencing Factor Analysis Model

This paper uses a fixed-effects model to test single-factor net effects and fsQCA to explore multi-factor combination effects, so as to comprehensively reveal the formation mechanism of green logistics efficiency.

3. Current Situation and Problems of Green Logistics in the Yangtze River Delta

3.1. Overview of Logistics Industry Scale

3.1.1. Input Scale

Fixed-asset investment: The total investment in the Yangtze River Delta increased from 209.81 billion yuan in 2006 to 933.43 billion yuan in 2023, with obvious provincial differences.
Logistics employees: The total number rose from 2.5777 million in 2006 to 4.0515 million in 2023, showing a fluctuating upward trend.

3.1.2. Output Scale

Logistics value added: Increased from 221.19 billion yuan to 930.40 billion yuan, with Jiangsu ranking first.
Freight turnover: Rose from 2184.55 billion ton-kilometers to 6186.36 billion ton-kilometers, with Shanghai in a leading position.

3.2. Current Situation of Green Logistics

3.2.1. Energy Consumption Status

Energy consumption increased from 33.1212 million tons of standard coal in 2006 to 65.7246 million tons in 2023[7]. The energy structure is dominated by diesel, gasoline and kerosene, while clean energy such as electricity and natural gas is growing slowly[8].

3.2.2. Carbon Emission Status

Calculated by the IPCC method, carbon emissions increased from 73.12 million tons in 2006 to 149.26 million tons in 2023, showing a synchronous growth trend with energy consumption.

3.2.3. Policy Environment

Policies have evolved from energy conservation to low-carbon governance, including the Yangtze River Delta Regional Integrated Development Plan and provincial logistics development plans, which provide institutional support for green logistics.

3.3. Existing Problems

Mismatch between input expansion and output growth: Investment growth is faster than output growth, resulting in resource redundancy.
High-carbon energy structure and emission pressure: Fossil energy accounts for more than 80%, and carbon emissions are under great pressure.
Mismatch between policy guidance and market response: Policy implementation lags behind industrial development, and market subjects' green transformation motivation is insufficient.

4. Construction and Analysis of Green Logistics Efficiency Measurement Model

4.1. Index Selection of Green Logistics Efficiency Measurement

Principles include scientificity, systematicness, feasibility, pertinence and dynamics.

Table 1. Evaluation index system of green logistics efficiency

Attribute	Category	Index
Input	Capital	Fixed-asset investment (100 million yuan)
	Labor	Logistics employees (10 thousand people)
	Energy	Energy consumption (10 thousand tons of standard coal)
Desirable Output	Economy	Logistics value added (100 million yuan)
	Scale	Freight turnover (100 million ton-kilometers)
Undesirable Output	Environment	CO_2 emissions (10 thousand tons)

4.2. Model Construction

4.2.1. Super-SBM Model with Undesirable Outputs

The model is constructed as follows:

$$\rho^* = min \frac{1 - \frac{1}{m}\sum_{i=1}^{m} \frac{s_i^-}{x_{i0}}}{1 + \frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1} \frac{s_r^g}{y_{r0}^g} + \sum_{q=1}^{s_2} \frac{s_q^b}{y_{q0}^b}\right)} \tag{1}$$

where s^-, s^g, s^b are slacks of inputs, desirable and undesirable outputs; λ is the weight vector.

4.2.2. GML Index Model

The GML index is decomposed into EC and TC:

$$GML^{t,t+1} = GMLEC^{t,t+1} \times GMLTC^{t,t+1}$$

$GML > 1$ means efficiency growth;
$EC > 1$ means efficiency improvement;
$TC > 1$ means technological progress[9].

4.3. Measurement Result Analysis

4.3.1. Overall Regional Efficiency Analysis

Static efficiency maintained an upward trend from 2006 to 2023, with the overall mean greater than 1. Dynamic efficiency fluctuated upward, and technological progress was the main driving force[10].

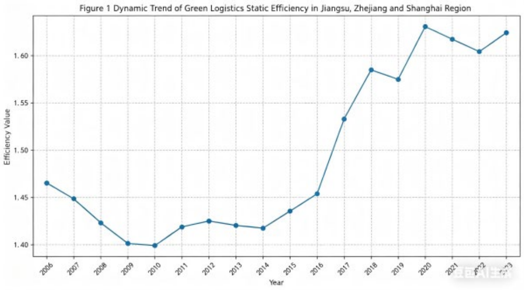

Figure 1. Trends in Static Green Logistics Efficiency of the Entire Yangtze River Delta Region(Resolution: 600 dpi, PNG format)

4.3.2. Inter-Provincial Comparative Analysis

Shanghai had the highest efficiency, followed by Jiangsu and Zhejiang. Shanghai's efficiency was driven by both technology and management; Jiangsu relied on technological progress; Zhejiang showed obvious fluctuations.

5. Influencing Factors and Promotion Strategies of Green Logistics Efficiency

5.1. Selection of Influencing Factors

Factors include economic development level (per capita GDP), logistics scale (proportion of logistics value added), energy intensity, clean energy structure, informatization level and environmental governance intensity.

5.2. Empirical Analysis

5.2.1. Model Construction

Fixed-effects model:

$$Y_{it}^{*} = \beta_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \beta_3 X_{3it} + \beta_4 X_{4it} + \beta_5 X_{5it} + \beta_6 X_{6it} + \mu_i + \varepsilon_{it}$$

fsQCA is used for configuration analysis[11].

5.2.2. Result Analysis

Regression results show that logistics scale and environmental governance have significant positive effects, while energy intensity has a negative effect. fsQCA reveals that high efficiency is driven by the combination of economic scale, logistics agglomeration and policy constraints.

5.3. Promotion Strategies

5.3.1. Optimize Resource Allocation

Establish an investment efficiency supervision mechanism, promote intermodal transportation, and build a shared capacity platform.

5.3.2. Promote Low-carbon Energy Structure

Layout new energy infrastructure, promote electric logistics vehicles, and optimize transportation structure.

5.3.3. Improve Policy Coordination and Incentive Mechanism

Build a regional policy coordination mechanism, set up a green logistics guidance fund, and promote digital empowerment[12].

6. Conclusion and Prospect

This paper measures the green logistics efficiency of the Yangtze River Delta from static and dynamic perspectives, identifies key influencing factors, and proposes targeted strategies. The limitations include short data span and single regional scope. Future research can expand to city-level samples and introduce spatial econometric models.

Acknowledgements

The author would like to thank the journal editors and anonymous reviewers for their constructive comments and suggestions. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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