Comprehensive Measurement and Spatial and Temporal Evolution Analysis of China's Green Logistics

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Abstract. Enhancing the level of green logistics development is of great significance to the high-quality development of the logistics industry.This paper adopts the entropy weight-TOPSIS method to measure the level of green logistics development in 31 provinces and cities in China from 2015 to 2021, and analyzes the characteristics of the evolution of its spatio-temporal pattern by comprehensively applying kernel density estimation.The study shows that: ① From the point of view of temporal evolution, the overall green logistics development level of the country is on an upward trend, but there are large differences in the level of green logistics development among regions, presenting a certain hierarchical pattern.②From the point of view of spatial evolution, the spatial distribution of the level of green logistics development is characterized by significant differences, showing a spatial pattern of "East>Central>West".③In terms of dynamic evolution, the level of green logistics development was well distributed during the sample period, with no polarization and large intra-regional disparities.

Keywords: green logistics; composite measure; spatio-temporal evolution; kernel density estimation.

1 INTRODUCTION

With the increasingly serious problems of global climate change and environmental degradation, green logistics, as an important way to realize sustainable development, has become a key trend in the development of the global logistics industry.China, as the world's largest producer and consumer of goods, the green transformation of its logistics industry has important implications for global sustainable development.Studying the spatial and temporal evolution characteristics of green logistics in China is of great value in understanding how the logistics industry can adapt to the needs of environmental protection, improve resource utilization efficiency and reduce environmental pollution. Research on the spatial and temporal evolution of green logistics can reveal the development differences and characteristics of each region, while reflecting the impact of factors such as policy changes, market demand and technological innovation, and provide a basis for policy makers and enterprises to make decisions. Evaluating policy effects and predicting future trends can help formulate scientific and reasonable

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green logistics policies and strategies. In this paper, the period from 2015 to 2021 is chosen as the time period for the study, which has not only witnessed the implementation of China's 13th Five-Year Plan and 14th Five-Year Plan, but also experienced major events such as the increase in uncertainty in the global economy and the outbreak of the New Crown Epidemic, which have had a significant impact on the operation mode and green practices of the logistics industry. These factors have had a significant impact on the operation mode and green practices of the logistics industry. The adaptability and development dynamics of green logistics in different economic and social environments can be revealed.

Green logistics as a global concern, from the existing related research progress, most of the research in recent years from the spatial and temporal evolution characteristics, influencing factors and diversified measurement methods and other aspects. First, regarding the spatial and temporal evolution characteristics, the studies of Huang Ailing et al. [1] and Lin Qiuping et al. [2] focused on the regional differences in carbon emission intensity and the spatial and temporal changes in the green and low-carbon logistics efficiency of the western land and sea corridor, respectively. The study by Ma Yuping et al.[3], on the other hand, reveals the dynamics of the coupled coordination degree of digital trade and green logistics in the spatio-temporal dimension. The studies of Jin Xin et al.[4] and He Guangjun et al.[5], on the other hand, focus on the impact of the Yangtze River Economic Belt and logistics industry agglomeration on green logistics, revealing the spatio-temporal dynamics of green logistics resilience and total factor productivity. Second, in terms of influencing factors, the studies of Jia Xianmin et al.[6] and Chen Shuguang et al.[7] focus on the green logistics efficiency of the provinces along the "Belt and Road" and its driving factors, such as the economic level, resource utilization rate and industrial structure. The studies by Zhang Xu et al.[8]and He Jingshi et al.[9] focused on the three Bay Area city clusters, emphasizing the decisive role of scientific and technological innovation and economic level on green logistics efficiency. In terms of diversified measurement methods, Huang C et al.[10] analyzed the entropy value of green logistics development resilience, but also Zhang Peng et al.[11] evaluated the multidimensionality of green logistics in the express industry, as well as Cheng C et al.[12]comprehensively evaluated the level of regional green logistics. These studies demonstrate the diversity of quantitative assessment methods for green logistics.

Despite the progress made by existing studies on several aspects of green logistics, the existing studies on the spatio-temporal evolution perspective have not yet considered the impacts of different regions, logistics modes, and digital transformation on the dynamics of green logistics, which are crucial for revealing the overall picture and development trend of green logistics, as they are directly related to the formulation, implementation, and evaluation of the effects of green logistics policies. Against this background, this paper conducts an in-depth study on the comprehensive measurement and spatial and temporal evolution of green logistics in China, in order to comprehensively understand the status quo and characteristics of China's green logistics development, as well as its spatial and temporal patterns of change. Firstly, we construct a comprehensive measurement index system of China's green logistics, which covers multiple dimensions such as infrastructure, environment, economy, policy, innovation and development potential to ensure a more comprehensive and accurate assessment of the development level of green logistics. Secondly, this paper innovates the research methodology by adopting a combination of entropy weight-TOPSIS method and kernel density analysis, in order to measure and analyze the spatio-temporal evolution of green logistics more accurately. and analyze the spatial and temporal evolution characteristics of green logistics, and finally, based on the previous analysis, conclusions and recommendations are drawn.

2 EVALUATION INDEX SYSTEM CONSTRUCTION AND DATA METHODOLOGY

2.1 Construction of the Indicator System of China's Green Logistics Development Level

For the construction of the indicator system for the level of green logistics development in China, the aim is to create an assessment framework that can comprehensively reflect the practice and effectiveness of green logistics. The system is based on an in-depth understanding of the core elements of green logistics, including the greening of logistics operations and the environmental impact of logistics activities, as well as the support of economic, social and technological innovation for green logistics. The indicator system begins by considering infrastructure, such as digitalization of the logistics industry, road and network construction, which directly affect transport efficiency and the environment. Environmental impacts are measured through energy consumption and waste recycling rates, aiming to reduce the burden of the logistics industry on the environment. Economic indicators reflect the logistics industry's contribution to economic growth, such as logistics output and cargo turnover, showing market demand for green services. Policy support involves policies to build logistics nodes, parks and hubs, and these help the industry make the transition to green. Innovative capacity is measured through technology investment and the number of green inventions, reflecting the logistics industry's technological innovation efforts. Finally, development potential predicts the degree of regional support for future green logistics development through indicators such as education funding and fixed asset investment, which not only relate to current green logistics practices, but also critically determine whether the logistics industry can sustain the transition to green.Therefore, digitalization construction of logistics industry, road construction of logistics industry and logistics network construction are selected as green logistics infrastructure support indicators, energy consumption of green logistics industry, recycling rate of waste in logistics industry, greening of logistics warehousing, greening of logistics transportation, greening of logistics transport and green logistics governance are selected as green logistics environment support indicators, industrial scale support and technology market support are selected as green logistics Environmental support, select whether to build logistics nodes? Whether to build a model logistics park? Whether to build logistics hubs? As green logistics policy support? (These three policies in the policy implementation year and after the value of

1, the rest of the value of 0) selected science and technology support, R & D support as green logistics innovation support, selected education potential support, investment potential support as green logistics development potential support. By constructing the indicator system in this way, it is possible to comprehensively assess the development level of China's green logistics from multiple perspectives, and to identify the advantages and shortcomings.

Based on the above analysis, this paper establishes the indicator system of China's green logistics development level (see Table 1).

Table 1. Indicator system of China's green logistics development level

Primary indicators	Secondary indicators	Segmentation indicators	Unit	attribute	weights
Green Logistics Infrastructure Support	Digitalization of the logistics industry	Internet penetration	%	+	0.004
	Road construction in the logistics industry	Road mileage	kilometer	+	0.008
		Area of urban roads at the end of the year	ten thousand square meters	+	0.012
	Logistics Networking	Land area for logistics and warehousing	square kilometer	+	0.008
		Post Office at year-end	place	+	0.013
Green Logistics Environmental Support	Green Logistics Energy Consumption	Petroleum emissions	ton	_	0.001
	Waste recycling rate in the logistics industry	Greening coverage in built-up areas	%	+	0.043
	Greening Logistics and Warehousing	Urban greening area	ten thousand hectares	+	0.026
	Greening of logistics and transportation	Nitrogen oxide emissions	ten thousand tons	_	0.013
	Green Logistics Governance	Investment in environmental pollution control	ten thousand tons	+	0.042
Green Logistics Economic Support	Industrial scale support	Output value of the logistics industry	billions	+	0.013
		Postal traffic	billions	+	0.040
		Cargo turnover in the logistics industry	Billion ton kilometers	+	0.014
	Technical market support	Technology market turnover	billions	+	0.040
Green Logistics Policy Support	Whether to build logistics nodes		_______	+	0.225
	Whether to build a model logistics park		_______	+	0.225
	Whether to build a logistics hub		_______	+	0.225
Green Logistics Innovation Support	technological support	Science and technology expenditures/fiscal expenditures	%	+	0.004
	Research and development support	Number of green inventions filed in the year	unit	+	0.030
Green Logistics Development Potential Support	Educational potential support	funding for education	billions	+	0.010
	Investment potential support	Investment in fixed assets in the logistics industry	billions	+	0.050

2.2 Research Methods

Entropy Weights - TOPSIS Method. Entropy weight method is an objective evaluation method which is assigned according to the information size of the index data, and can avoid the defects of subjective assignment method. TOPSIS method is ranked according to the comprehensive distance between the measurement object to the optimal solution and the worst solution, and get the relative advantages and disadvantages of

the evaluation target. Combining the two into a new entropy weight-TOPSIS method.[13] can make the measurement results more reasonable. The calculation steps are as follows:
Positive indicators:

$$x'_{ij}=\frac{x_{ij}-\min x_{ij}}{\max x_{ij}-\min x_{ij}}\times 0.99+0.01 \quad (1)$$

Negative indicators:

$$x'_{ij}=\frac{\max x_{ij}-x_{ij}}{\max x_{ij}-\min x_{ij}}\times 0.99+0.01 \quad (2)$$

Among them: x_{ij} represents the raw data under the j-th indicator for the i-th region, x'_{ij} is the corresponding normalized value.

Kernel Density Estimation Methods. Kernel density estimation is a nonparametric estimation method, which can help to characterize the distribution pattern of data samples, and is especially suitable for exploring the spatio-temporal evolution characteristics of logistics development level.[14] Through the kernel density estimation and exploratory spatial data analysis method, the spatial and temporal evolution characteristics of green logistics development level can be studied in depth, which provides powerful support for the comprehensive measurement and spatial and temporal evolution analysis of green logistics. Its calculation formula is as follows.

$$f(x)=\frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{X_i-x}{h}\right) \quad (3)$$

Where: n is the number of research units; X_i is the observation; x is the mean value; h is the bandwidth; K denotes the kernel function, this paper adopts Gaussian kernel function, expression is:

$$K(x)=\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{x^2}{2}\right) \quad (4)$$

2.3 Generalization of the Study Area and Data Sources

This paper focuses on the critical period of China's green logistics from 2015 to 2021, and, using panel data covering the logistics development situation in 31 provinces in China (excluding Hong Kong, Macao, and Taiwan), subdivided into three regions: East, Central, and West①, the purpose is to reveal the continuity and change in the implementation of green logistics policies, and to reveal the continuity of green logistics policies and the impact of technological advances on the industry through authoritative

① The specific definitions of the regions are as follows: in the eastern region, there are 11 provinces, including Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan, etc., in the central region, there are 8 provinces, including Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan, etc., and in the western region, there are 12 provinces, including Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. provinces data such as China Statistical Yearbook and China Environmental Statistics Yearbook, and by comprehensively taking into account the core indicators of fixed asset investment in the logistics industry and Internet penetration rate. The linear interpolation method is used to ensure data integrity, and the six-year data analysis reveals the dynamic evolution of green logistics, which provides a decision-making basis for the future sustainable development path and emphasizes the importance of policy innovation and resource optimization.

3 ANALYSIS OF THE SPATIAL AND TEMPORAL EVOLUTION OF GREEN LOGISTICS IN CHINA

Through the comprehensive measurement and evaluation index system constructed in the previous section, the development of green logistics is comprehensively evaluated, and its evolutionary characteristics are analyzed in two dimensions: chronological and spatio-temporal.

3.1 Evolution of China's Green Logistics Chronology

According to the entropy method, the evaluation score of China's green logistics comprehensive measurement in 2015-2021 is calculated, and its value is between 0 and 1, and the larger value represents the better development of regional logistics, the results of the national and regional green logistics comprehensive measurement are shown in Fig. 1, and the results of the 31 provinces' green logistics comprehensive measurement are shown in Fig. 2. China's overall green logistics score increases from 0.22 to 0.43 from 2015 to 2021, showing two stages of growth: steady growth from 2015 to 2020, with an average annual growth rate of 4.55%, and slower growth from 2020 to 2021, with an average annual decline of 8.51%. This change is influenced by multiple factors: first, changes in the policy environment, especially the strengthening of environmental regulations during the 14th Five-Year Plan period, which raised carbon emissions and resource efficiency standards. Second, global economic uncertainty and the new crown epidemic have influenced companies' green logistics investment decisions. In addition, while technological advances offer long-term potential, large initial investments have affected short-term growth rates.

By region, China's overall green logistics measure is East > Central > West, with the East continuing to lead between 2015 and 2021, showing a good balance between economic development and environmental protection. The central region has made progress but still needs to find a balance between growth and green transformation. 2015-2020 saw significant growth in the eastern and central regions, followed by a downward trend in 2020-2021, reflecting the impact of policy adjustments. The western region, on the other hand, has always maintained stable growth, indicating that green development has been effectively promoted through measures such as industrial restructuring and green infrastructure construction. The above analysis not only reveals the temporal evolution of green logistics, but also provides a basis for the formulation of targeted policies to promote the balanced and sustainable development of green logistics across the country.

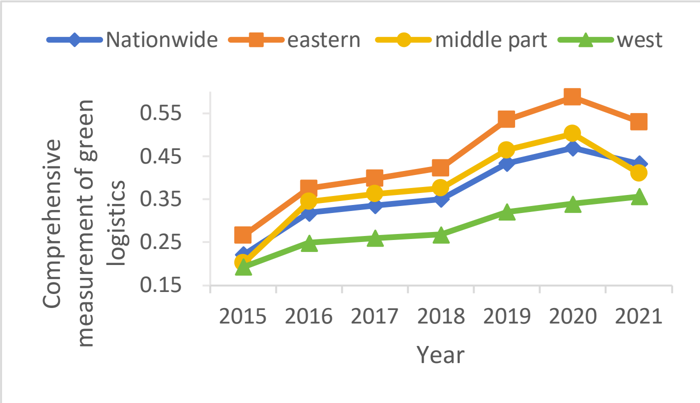

Fig. 1. Comprehensive Measurement of Green Logistics in the Country and Major Regions.

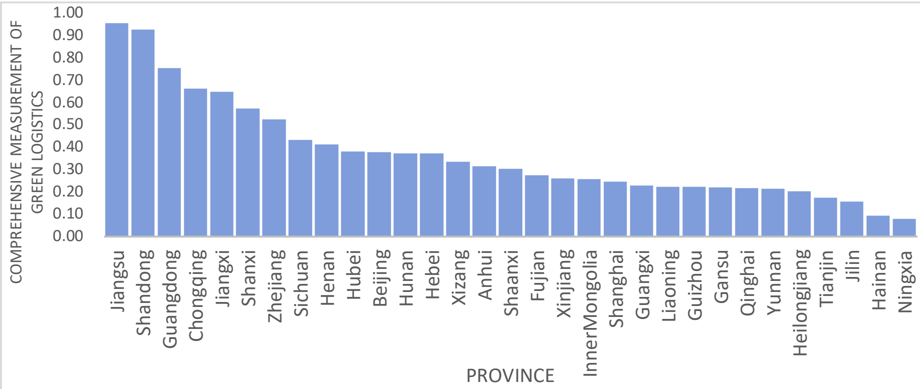

Fig. 2. Comprehensive Measurement of Green Logistics in 31 Provinces.

3.2 Spatial and Temporal Evolution of Green Logistics in China

In order to explore the dynamic evolution and internal differences of green logistics in different regions of China, on the basis of the results of the comprehensive measurement of green logistics in China, this paper draws a kernel density estimation map of the development level of green logistics of the whole country and the eastern, central and western regions in the period of 2015-2021 with the help of Matlab software. (See Figure 3 to Figure 6 on the next page). Table 2 summarizes the evolutionary characteristics of green logistics distribution dynamics in China.

Table 2. Characteristics of the dynamic evolution of the distribution of green logistics in China

region	distribution location	Main peak evolutionary dynamics	Distribution ductility	polarization trend
whole country	shift left	Peak decreases, width becomes larger	Right trailing, stretch contraction	The trend towards multipolarity
the eastern	shift left	Peak decreases, width becomes larger	Right trailing, stretch contraction	No - polarization trend
central	shift left	Peak decreases, width becomes larger	Right trailing, stretch contraction	No - polarization trend
western	shift left	The peak rises and then falls, and the width is small and then large	Right trailing, widened extension	The trend towards multipolarity

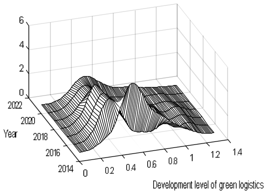

Fig. 3. Kernel density estimation of national green logistics development level.

Figure 3 shows the estimated kernel density of the national green logistics development level, in which the single-peak distribution of the data for 2015 and 2019 to 2021 reflects the general recognition and concentrated promotion of green logistics in the logistics industry. During this period, the level of green logistics increased significantly thanks to policy promotion, technological innovation and the growth of market demand for environmentally friendly services. However, between 2016 and 2018, the multi-peak distribution reveals the diversity and unevenness of the industry's development, with some companies making breakthroughs in green transformation while others are still exploring.The decrease of the main peak and the increase of the distribution width indicate the overall improvement of the green logistics level and the expansion of enterprise participation, and green logistics gradually becomes the new standard of the industry. The leftward shift of the distribution position shows the continuous progress of the level of green logistics and reflects the logistics industry's strong commitment to environmental protection and sustainable development. The right trailing of the distribution curve and the ductile contraction reflect the differences in the level of green logistics among enterprises and the continuous pursuit of higher standards, which foretells a multi-polarization trend in the development of green logistics.

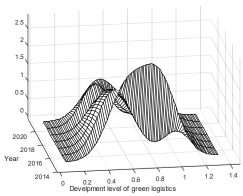

Fig. 4. Kernel density estimation of the level of green logistics development in the east.

Figure 4 shows the kernel density estimation of the level of green logistics development in the east, in which the single-peak distribution in 2015 shows the consistency of green logistics in that year, while the double-peak distribution from 2016 to 2021 shows a divergence in the level of green logistics, but no overall polarization. Declining peaks and increasing distribution widths reflect overall level improvement and expanding business participation. The left-shifted distribution position and contracted extensibility indicate a move toward higher standards and a narrowing of the gap within the industry, showing that the industry as a whole is moving toward equilibrium. These changes may be attributed to policies, technologies, market demand and rising environmental awareness. In the future, green logistics in the East is expected to continue to progress towards sustainability.

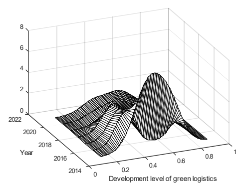

Fig. 5. Kernel density estimation of the level of green logistics development in central China.

Figure 5 shows the kernel density estimation of the level of green logistics development in central China. during the period from 2015 to 2021, the level of green logistics development in central China has increased as a whole, and the kernel density map shows that the main peak shifts to the right, which indicates that the level of green logistics has increased. 2015 and 2019 to 2021 show a single-peak distribution, reflecting the progress of the industry's concentration. during the period from 2016 to 2018, the peak decreases and distribution width increased, showing inter-regional development differences. The peak decline and width increase in the main peak evolution trend indicate that more enterprises participate in green logistics and the overall level of distribution is broadened. The leftward shift of the distribution position and the trailing of the curve to the right show that the level of green logistics continues to improve. The ductile contraction indicates a balanced development with no polarization trend. This is due to the strategy of the rise of central China and the driving role of core cities, but the development of marginal cities needs to be strengthened. In the future, it is necessary to optimize resource allocation, strengthen infrastructure construction, promote policy innovation and facilitate balanced development to achieve a sustainable logistics system.

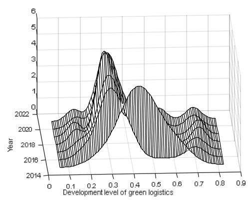

Fig. 6. Kernel density estimation of the level of green logistics development in western China.

Figure 6 shows the estimated kernel density of the level of green logistics development in the central region. The single-peaked distribution in 2015 indicates the consistency of the level of green logistics in that year, with enterprises generally at a similar stage of development. Subsequently, from 2016 to 2017, the distribution shows a double peak, indicating that green logistics in the western region is beginning to diverge, and a part of the enterprises may have begun to adopt more advanced green logistics measures, while the other part maintains the original level. Entering 2018 to 2021, the multi-peak distribution is revealed, and the main peak evolution pattern shows the peak rising first and then falling, while the distribution width changes from narrow to wide, which indicates that the overall level of green logistics in the western region improves, but the development speed and effectiveness show significant differences among different enterprises. The leftward shift of the distribution position and the trailing of the curve to the right further confirm the improvement of the level of green logistics and the increase of participation. The ductile broadening trend, on the other hand, reflects the multi-polarization of green logistics development in the western region, with varying achievements and challenges in green practices among enterprises. This multi-polarization trend may be due to differences in the level of economic development, infrastructure development, policy support, and enterprises' awareness of green logistics between regions.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

This paper constructs a green logistics index system in China, and applies entropy weight-TOPSIS method to comprehensively measure green logistics in China in 2015-2021. The conclusions are as follows.

First, from 2015 to 2021, the overall evaluation score of the comprehensive measure of green logistics in the country increased. This indicates that the level of green logistics in China has been significantly improved during the study period, reflecting the positive progress made by the country in promoting the green development of the logistics industry.

Secondly, the temporal evolution characteristics show that the development of green logistics has gone through two distinct phases: the growth period from 2015 to 2020 and the growth slowdown from 2020 to 2021. The stable growth in the first period reflects the positive impact of policy support and market demand on green logistics inputs, while the declining growth rate in the later period may be related to factors such as global economic fluctuations, policy adjustments, and environmental changes.

Third, the spatial and temporal evolution characteristics show that the spatial and temporal evolution of green logistics in China shows that the eastern region is leading, the central region has made some progress in catching up with the eastern region but still needs to find a balance between growth and green transformation, and the western region has a stable growth trend despite a lower starting point, showing the differences and dynamic changes in the development of green logistics in different regions.

4.2 Recommendations

Based on the above findings, the following policy recommendations are proposed in order to enhance the development of green logistics in China and promote the high-quality development of the logistics industry:

First, it is recommended that the Government and industry associations should strengthen the standardization of green logistics and promote a green logistics certification system, so as to enhance the environmental awareness and practice of the industry as a whole.

Secondly, the government should formulate and implement appropriate policy measures based on the stage of development of the logistics industry, including the provision of incentives such as tax breaks and green investment funds during the growth period, as well as the adjustment of policies during the slowdown period, so as to help enterprises cope with the challenges and to ensure the sustainable and healthy development of green logistics.

Third, in view of the differences in economic development, infrastructure and technological innovation capacity in different regions, policymakers should formulate differentiated strategies for the development of green logistics, with the eastern region staying ahead of the curve, the central region needing to balance growth and transformation, and the western region focusing on upgrading its infrastructure and technology in order to achieve stable growth in all regions.

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