Analysis of development efficiency and spatio-temporal evolution of logistics industry in East China under carbon constraints

Ningning Chen[a], Shiyuan Song[*a], Liwei Qiu[b]
[a]School of Management Science and Engineering, University of Jinan, Jinan 250022, Shandong, China; [b]Jinan Techfin Information Technology Co., Ltd., Jinan 250100, Shandong, China

ABSTRACT

This study employs a non-expected output super-efficiency slacks-based measure (SBM) model to construct an input-output index system under the condition of carbon constraints. The objective of this study is to provide a comprehensive analysis of the static efficiency of the development of the logistics industry in East China between the years 2012 and 2021. The decomposition of the Global-Malmquist-Luenberger (GML) index permitted a comprehensive analysis of the evolution of the logistics industry in the region over time. In addition, the efficiency data for specific years were employed to investigate the alterations in the spatial distribution of the development of the logistics industry. The findings of the study indicate that the efficiency of logistics industry development under carbon constraints in East China is generally low. In terms of temporality, the efficiency value of the logistics industry in the region has undergone a process of change, initially exhibiting a decline and subsequently an increase. In the spatial dimension, the region exhibiting the highest efficiency in logistics, centered on Shanghai, gradually shows a trend of moving northward. This results in the formation of a phenomenon of polarization between the north and the south. The findings of the research have led to the formulation of a series of recommendations for the environmentally conscious and coordinated development of the logistics industry in the East China region. These recommendations are designed to facilitate the advancement of a more environmentally conscious, efficient, and coordinated logistics industry in this region.

Keywords: Carbon constraint, green logistics, logistics efficiency, spatial and temporal characteristics, Eastern China

1. INTRODUCTION

As the most populous developing country in the world, China has responded positively to global initiatives and proposed the "dual carbon" goals, namely carbon peaking and carbon neutrality, to promote a green economic transformation. In the context of the modern economic system, it is of paramount importance to enhance the efficacy of green development within the logistics industry. As the core region of China's economy, the green development of East China's logistics industry has an important impact on the sustainable growth of the regional economy and the green transformation of the national economy.

In terms of research methodology, scholars commonly utilize the Data Envelopment Analysis (DEA) model to construct an input-output measurement system. Yang[1] empirically analyzed the quality and efficiency level using the super-efficiency DEA model. Deng et al.[2] employed a combination of BCC-DEA, bilateral DEA, and Malmquist index methodologies to analyze the logistics efficiency of China-Mongolia road ports. They identified the slow application of technology as an important factor contributing to lower logistics efficiency. Yang et al.[3] employed a three-stage DEA model and a Malmquist model, which accounted for environmental constraints, to assess efficiency. The findings indicated that technological progress and technical efficiency interact to enhance efficiency. Yue[4] utilized DEA and TOPSIS methods to evaluate the efficiency of China's regional smart logistics industry, emphasizing There is a significant disparity in smart logistics efficiency between Chinese provinces and regions, with a clear spatial correlation. Long et al.[5] employed the DEA three-phase model to identify innovation and development indicators from a scientific and technological perspective, and evaluated the effectiveness of the green logistics industry in Hunan Province. Currently, measuring and analyzing the efficiency value of green logistics is aligned with the prevailing economic circumstances and simultaneously addresses the imperative of green development within the logistics industry. In related studies, the majority of scholars have focused on carbon emissions. Yao et al.[6] selected the key provinces of the "Belt and Road" initiative as their research object. They employed the three-phase Data Envelopment Analysis (DEA) and

[*]598568506@qq.com; phone 1 555 474 8063

Fifth International Conference on Green Energy, Environment, and Sustainable Development (GEESD 2024), edited by M. Aghaei, X. Zhang, H. Ren, Proc. of SPIE Vol. 13279, 132793R · © 2024 SPIE · 0277-786X

Malmquist model to assess the low-carbon efficiency of the logistics industry from both a static and dynamic perspective. Li et al.[7] developed a comprehensive evaluation index system that considered carbon emissions. They then utilized the Slacks-Based Measure (SBM) Data Envelopment Analysis (DEA) model to evaluate the overall efficiency level of China's logistics industry. The overall efficiency of China's logistics industry has been evaluated. Ma et al.[8] quantified the carbon emissions of China's provincial logistics industry and identified the factors influencing its performance. The study revealed that the performance is generally at a medium level, and that the impact of energy structure on carbon emission performance is significantly negative. He et al.[9] employed the Malmquist Index to analyze the total factor productivity of low-carbon logistics. Their findings indicate that the efficiency of low-carbon logistics is influenced by a multitude of external variables, including regional economic level, intensity of logistics input, level of innovation, degree of openness, and level of urbanization, among other external environmental factors.

In conclusion, scholars have extensively employed DEA-related models to assess the efficiency. However, the efficiency values derived from the underlying DEA models exhibit considerable error and lack broad applicability. The majority of existing studies have concentrated on the exploration of static and dynamic efficiency values, with a notable absence of in-depth analysis of inter-regional spatial states. With regard to the selection of research objects, current studies tend to focus on China as a whole, the Yangtze River Delta, the Pearl River Delta Economic Belt, or the provinces along the "One Belt, One Road," among other regions. In contrast, relatively few studies have been conducted on East China. In light of the aforementioned considerations, this paper selects the input-output data of the logistics industry in East China from 2012 to 2021 as the core research object. A super-efficiency SBM-DEA model, which was developed without intention, was utilized as a foundation for the input-output system that considered carbon emissions. This system was constructed with reference to previous studies. The GML index model is introduced, which effectively addresses the shortcomings of the traditional DEA model in time-varying measurement. Furthermore, the efficiency values were analyzed in depth at the spatial level using ArcGIS. By comparing the efficiency differences and links between provinces, we aimed to provide targeted suggestions for the future development of the logistics industry in East China, in order to promote the progress of China's logistics industry towards a greener and more coordinated direction.

2. RESEARCH METHODOLOGY AND SELECTION OF INDICATORS

2.1 Research methodology

This paper examines the technical efficiency and technology gap of decision-making units, employing the GML index to decompose the decision-making units. Building upon existing studies, this paper utilizes the undesirable output super-efficiency SBM model and the GML index to assess the development efficiency, technical efficiency, and technology gap of the logistics industry in East China.

Undesired output super-efficiency SBM model. Reducing carbon emissions is a crucial objective. The optimal strategy for the logistics industry is to achieve a greater number of desired outputs with a smaller number of inputs, while simultaneously reducing the number of undesired outputs. As Tone[10] did not construct the formula of non-desired output super-efficiency SBM model on the original non-desired output SBM model, the study refers to the formula introduced by Cheng[11] to evaluate the decision-making unit using the super-efficiency SBM model with non-desired output.

The GML index overcomes the disadvantage of the traditional ML index, which lacks transferability. Accordingly, this paper selects the GML index to represent the efficiency change of logistics industry development in East China under carbon constraints. The GML index and decomposition refer to the research of Pastor et al.[12] GML is the efficiency index of logistics industry development. The GML index is used to represent the efficiency change of logistics industry development in East China under carbon constraints. The EC index is used to represent the technological efficiency change, while the BPC index is used to represent the technological gap change. The value of the BPC index is greater than 1 when there is an improvement in efficiency and advancement in technology, while the value is less than 1 when there is a reduction in efficiency and regression in technology.

2.2 Selection of indicators and data sources

This paper presents an analysis of the evolution and transformation of the logistics industry in the six provinces and one city of East China between 2012 and 2021. The transportation industry, warehousing industry, and postal industry have been identified as the main indicators of the logistics industry in previous literature. As illustrated in Table 1, an evaluation index system for the development efficiency of the logistics industry under carbon constraints is subsequently constructed. The necessary data were acquired from the China Statistical Yearbook, the China Energy Statistical Yearbook, the provincial statistical yearbooks, and the official website of the National Bureau of Statistics.

Table 1. Evaluation index system of logistics industry development efficiency under carbon constraints.

Index classification	Primary indicator	Secondary indicator	Units
Input indicator	Labor input	Number of employees in the logistics industry	Person/year
	Capital investment	Investment in fixed assets in the logistics industry	Billions
	Energy input	Total consumption of energy	10,000 tons of standard coal
Output indicator	Economic output	GDP	Billions
	Scale output	Cargo turnover	100 milliontons/km
	Undesired output	CO_2 emissions	10,000 tons

3. EMPIRICAL RESULTS AND ANALYSIS

3.1 Measuring and analyzing the development efficiency of the logistics industry under carbon constraints

In accordance with the established metrics system, this paper uses MatLabR2021b commercial math software for evaluation.This is achieved by utilising the non-expected output super-efficiency SBM model with constant returns to scale in conjunction with the GML index. The results of the data analysis are then analysed and the trend of changes in the efficiency of the logistics development of the logistics industry in East China is plotted, as shown in Figure 1.

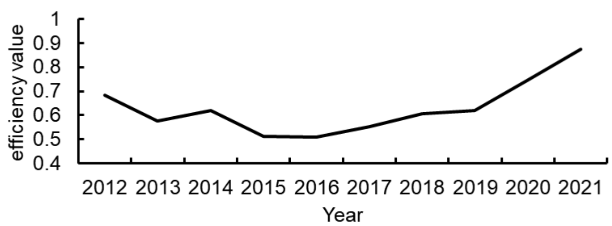

Figure 1. East China logistics industry development efficiency value line chart.

As illustrated in Figure 1, the mean value of the development efficiency of the logistics industry in East China under carbon constraints from 2012 to 2021 is 0.631. Overall, there has been a notable increase in efficiency in this area, with a significant rise from 0.682 in 2012 to 0.874 in 2021. This evidence indicates that the efficiency of the logistics industry in this region has been gradually improving in recent years. In examining the evolution of the logistics industry in East China, it becomes evident that the sector's growth can be delineated into two discernible phases. In the initial period (2012 to 2016), the overall efficiency exhibited a fluctuating downward trend, gradually decreasing from 0.682 to 0.511. This change can be attributed to the fact that China’s logistics industry was in its nascent stages of development during this period. Despite the state’s successive launch of medium- and long-term development plans for the logistics industry, which has led to sustained industry-wide attention, the issue of carbon dioxide emissions had not yet become a primary focus of the industry during this stage. This has led to a decline in the efficiency value to a certain extent. However, in the second stage (2016-2021), the situation has changed significantly, with the overall efficiency demonstrating a consistent and notable upward trend, increasing from 0.511 to 0.874. This improvement can be attributed to the implementation of a series of policies and programs by the Chinese government since 2016. These include the “Cost Reduction and Efficiency Improvement for Large Logistics Countries” program. The active promotion of these policies has led to profound technological innovation within the logistics industry, which has significantly improved the development efficiency of the logistics industry in East China. This change not only demonstrates the efficacy of the policy guidance but also reflects the growing emphasis on environmental protection and sustainable development in the logistics industry in East China.

In order to illustrate the efficiency of the in East China in detail and accurately, Table 2 presents the values of the efficiency in this region from 2012 to 2021. Figure 2 depicts the trend of the development efficiency in this region.

Table 2. East China logistics industry logistics development efficiency value.

Year	**Shanghai**	**Jiangsu**	**Zhejiang**	**Anhui**	**Fujian**	**Jiangxi**	**Shandong**	**Eastern China**
2012	1.029	0.749	0.554	0.750	0.472	0.647	0.575	0.682
2013	0.531	0.680	0.540	0.719	0.447	0.527	0.580	0.575
2014	1.018	0.600	0.532	0.719	0.485	0.494	0.502	0.621
2015	0.563	0.522	0.472	0.560	0.522	0.450	0.489	0.511
2016	0.523	0.497	0.478	0.561	0.554	0.456	0.507	0.511
2017	0.615	0.550	0.482	0.557	0.593	0.556	0.525	0.554
2018	0.725	0.526	0.528	0.876	0.457	0.590	0.550	0.621
2019	0.785	0.551	0.571	0.848	0.502	0.536	0.557	0.621
2020	1.034	0.841	0.490	0.961	0.538	0.651	0.724	0.748
2021	1.034	1.051	0.521	1.042	0.631	0.792	4.046	0.847
Mean	0.786	0.657	0.517	0.759	0.520	0.570	0.606	0.631

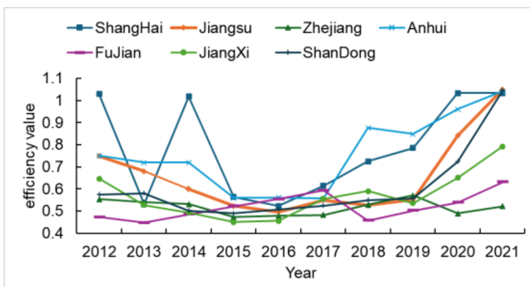

Figure 2. East China provinces logistics industry development efficiency value line chart.

As illustrated in Table 2, the comprehensive logistics efficiency in East China has not yet attained the efficacy threshold established by the Data Envelopment Analysis (DEA) methodology. This suggests that the input indicators of green logistics have not been fully utilized. Consequently, East China must adjust the input indicators in a timely manner and prioritize the green and low-carbon development of the logistics industry. This will enhance the efficacy of green logistics in East China. Among the provinces and cities, Shanghai and Anhui Province have relatively high green logistics efficiency, yet have not yet reached the DEA effective level. This indicates that the utilization of input indicators is relatively high compared to other provinces. Zhejiang Province exhibits the lowest green logistics efficiency, and thus it is recommended that the province adjust and fully utilize the input indicators in a timely manner, with the objective of focusing on the green and low-carbon development of the logistics industry. Figure 2 illustrates that Shanghai's green logistics efficiency exhibited considerable fluctuations during the initial stage prior to 2016. The green logistics efficiency of Anhui, Jiangsu, and Shandong provinces all exhibited varying degrees of decline. Nevertheless, the green logistics efficiencies of Shanghai, Anhui, Jiangsu, and Shandong provinces have since commenced a period of accelerated growth. Since 2016, these provinces and cities have begun to develop at a high level, and by 2021, all four provinces and cities are at the DEA effective production frontier. This indicates that the four provinces and cities have responded to the national policy and attached great importance to the green development of the logistics industry. Prior to 2016, the logistics industry in Jiangxi province exhibited a declining trend; however, after that, it began to demonstrate a continuous growth trajectory. This indicates that Jiangxi Province has significant potential for enhancing the efficiency of its green logistics operations. In contrast, the overall green logistics efficiency in Fujian and Zhejiang provinces has remained relatively stable, though it has not shown any improvement in recent years. This is less efficient in comparison to other provinces. It is recommended that the provinces of Jiangxi, Fujian, and Zhejiang, situated in the downstream position, promptly adjust their input indicators and align themselves with national policies to enhance the efficiency of green logistics development.

3.2 Analysis of the temporal evolution of logistics development

Following the measurement and analysis of the static efficiency of logistics industry development in East China, this section employs the GML index model to determine the technical efficiency and technology gap within the region. The results of this decomposition are presented in Table 3, while the corresponding trend is illustrated in Figure 3.

Table 3. Efficiency index and decomposition of logistics industry development in East China in different time periods.

Year	GML	EC	BPC
2012-2012	0.8754	1.0585	0.8310
2013-2014	1.0961	1.0941	1.0038
2014-2015	0.8646	1.0002	0.8585
2015-2016	1.0009	1.0178	0.9832
2016-2017	1.0866	1.0100	1.0789
2017-2018	1.0979	0.8042	1.4136
2018-2019	1.0282	1.0636	0.9675
2019-2020	1.2032	1.0750	1.1964
2020-2021	1.1760	1.0231	1.1497
Geometric mean	1.0414	1.0127	1.0405

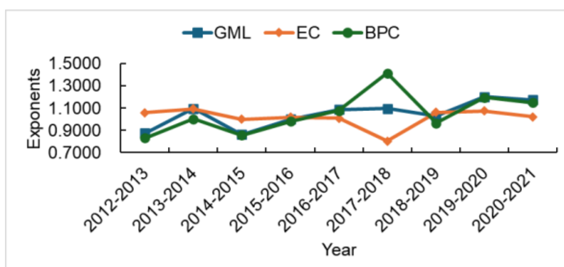

Figure 3. Trend of development efficiency index and decomposition of logistics industry in East China, 2012-2021.

Table 3 presents the efficiency index and decomposition of logistics industry development in East China under carbon constraints from 2012 to 2021. The GML index is greater than 1, indicating that the GML index increased at an average annual rate of 4.14% during the period 2012-2021. From a technical perspective, the technical efficiency has increased by 1.26%, indicating that East China is gradually improving its technical efficiency in the development of the logistics industry. From a technology gap perspective, the technology gap index has increased by 4.04%, which indicates that East China is experiencing improved efficiency and technological progress in the development of the logistics industry.

Figure 3 visually shows the fluctuations and trends of the three indices. It can be seen that the GML Index and the Technology Gap Index show a similar trend, indicating that the efficiency index of the development of the logistics industry is mainly influenced by the Technology Gap Index. It is therefore of the utmost importance to prioritize the advancement of green technology within the logistics industry in East China, with the ultimate aim of enhancing its efficiency.

3.3 Logistics development space analysis

In order to investigate the spatial agglomeration effects of logistics industry development efficiency in East China, efficiency values from seven provinces and cities for the years 2012, 2016, and 2021 were chosen as observational data points. These data points were then subjected to a spatial analysis utilizing ArcGIS 10.8 software. The natural breaks method was employed to categorize the observed logistics efficiency values into high, medium, and low levels for each province across different time periods. A gradient color scheme was utilized to visualize the spatial distribution map, where the color intensity progressively intensifies from light to dark. Table 4 provides an overview of the efficiency values corresponding to each interval and time period.

Table 4. Distribution of different efficiency intervals.

Efficiency level	2012	2016	2021
Low level of logistics efficiency	0.4720-0.5750	0.4560-0.4781	0.5211-0.6315
Medium level of logistics efficiency	0.5750-0.7500	0.4781-0.5230	0.6315-0.7923
High level of logistics efficiency	0.7500-1.0290	0.5230-0.5610	0.7923-1.0510

In order to illustrate the temporal evolution of efficiency distribution across provinces more clearly, ArcGIS was employed to generate a map of the temporal evolution of efficiency distribution in East China, as depicted in Figure 4.

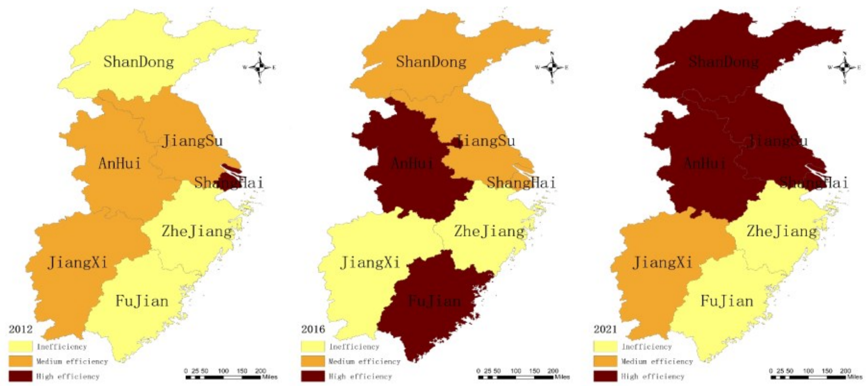

Figure 4. Distribution of efficiency in East China over different periods of time.

A longitudinal analysis of the efficiency distribution of the logistics industry in East China reveals a gradual transition from a high-efficiency zone centered on Shanghai to a high-efficiency zone including Anhui and Fujian provinces during the period from 2012 to 2016. Concurrently, the medium efficiency zone expanded from Shanghai to the north and south. This suggests that, as China's economic, financial, and trade center, Shanghai has exerted a pervasive influence on neighboring regions due to its robust economic influence and robust logistics demand. With the accelerated development of Shanghai's logistics industry, Anhui Province and Fujian Province have begun to form an efficient logistics development system. Furthermore, the implementation of policies such as the Special Action Program for Reducing Costs and Increasing Efficiency in the Logistics Industry has contributed to the rapid development and increased efficiency in and around Shanghai. Provinces north of Shanghai, including Shandong, Jiangsu, and Anhui, have demonstrated higher efficiencies during the period from 2016 to 2021. During this period, East China has demonstrated sustained economic growth, which has increased demand for logistics services and contributed to improved logistics efficiency. With the advancement of regional economic integration, the frequency of inter-provincial cooperation in East China has increased significantly. This also indicates that environmental sustainability and low-carbon practices have been prioritized. The relatively low efficiency of logistics development in Jiangxi and Zhejiang provinces may be related to their respective logistics resource allocation and industrial structure.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Research proposal

(1) In order to establish a low-carbon and efficient logistics network, it is necessary to strengthen regional synergies. This can be achieved by fostering collaboration between cities to construct a low-carbon and efficient regional logistics network, which facilitates resource sharing and optimal allocation. Efficient logistics centers, exemplified by Shanghai, should assume a pioneering role in the advancement of green logistics in neighboring regions. Furthermore, it is

recommended that the improvement of green logistics in less efficient regions be facilitated through the sharing of technology and the exchange of experience. This approach can facilitate the greening of the logistics industry in East China and promote inter-regional coordination and stability.

(2) The promotion of research and development, as well as the application of green logistics technology, is essential for enhancing low-carbon efficiency. It is imperative that the research and development, as well as the application, of green logistics technologies be actively promoted, with a particular focus on those that can significantly enhance low-carbon efficiency. The development and promotion of clean energy means of transportation is essential for reducing the consumption of fossil fuels. Furthermore, the implementation of intelligent scheduling systems can optimize transportation plans and reduce ineffective transportation and waiting time, thereby improving low-carbon efficiency.

(3) A comprehensive green logistics evaluation system should be established, with low-carbon efficiency as a primary evaluation indicator. The system should include an evaluation of the carbon emissions, energy consumption, and resource utilization efficiency of logistics enterprises. By disseminating the evaluation results on a regular basis, enterprises will be encouraged to adopt low-carbon measures with the aim of enhancing the level of green logistics. Concurrently, the government may formulate targeted policies based on the evaluation results to guide the industry in the direction of low-carbon green development.

4.2 Findings

This paper examines the evolution of the logistics industry in East China in the context of carbon constraints. Two models are employed in the study: the unintended super-efficiency SBM model and the GML index model. The industry's static and dynamic efficiency values were measured and analyzed. A comprehensive spatial comparative analysis was conducted using the natural break method of ArcGIS 10.8 software. The development efficiency of the logistics industry in the region was analyzed from multiple perspectives. The findings of the study indicate that the efficiency value of the logistics industry in East China has undergone a process of initial decline and subsequent recovery. The average efficiency value is slightly below 1, indicating that the industry has not yet reached the DEA efficiency standard. In the initial stages of development, the disparity in efficiency between provinces is not pronounced. Nevertheless, this disparity gradually increased over time. Furthermore, the region is confronted with challenges such as redundant inputs, insufficient outputs, and unbalanced development. With regard to temporal evolution, the GML index exceeds 1, with the technology gap index exerting a significant influence. From the perspective of spatial evolution, the center of gravity is undergoing a gradual shift and strengthening, with an increasing concentration in the northern regions. While the disparity between regions is diminishing, the divergence between the North and South is becoming more evident.

ACKNOWLEDGEMENTS

This paper is supported by Shandong Province Key R&D Program (Soft Science) Project (Grant No: 2023RKY01004), China Society of Logistics, China Federation of Logistics & Purchasing Project plan (Grant No. 2024CSLKT3--572).

REFERENCES

[1] Yang, H., "Quality and efficiency improvement of logistics industry and its impact on regional economy-based on the analysis of Yangtze River economic belt and inter-provincial comparison," Journal of Commercial Economics 24, 91-94 (2020).

[2] Deng, H., Jargalsaikhan M. and Liu, M., "Analysis on logistics efficiency of highway ports between China-Mongolia based on DEA-Malmquist," Journal of Chongqing University of Technology (Natural Science) 35(04), 224-230 (2021).

[3] Yang, C., Zhang L. and Zhou, D., "Analysis on the spatial and temporal evolution of logistics industry efficiency in the Yangtze River economic belt under environmental constraints," Modernization of Management 41(03), 16-19 (2021).

[4] Yue, Y., "Study on the measurement and spatial differentiation of smart logistics industry combination efficiency in the context of digitization," Journal of Commercial Economics 21, 93-96 (2023).

[5] Long, T. and He, Z., "Efficiency evaluation of green logistics industry based on DEA three stage model," Journal of Natural Science of Hunan Normal University 47(01), 134-142 (2024).
[6] Yao, S., Ma, L. and Lai, Y., "Low-Carbon logistics efficiency measurement of provinces and cities along "the Belt and Road," Ecological Economy 36(11), 18-24 (2020).
[7] Li, Y. and Sun, Z., "Measurement of operational efficiency of China's logistics industry and analysis of its influencing factors under carbon emission constraints," Journal of Commercial Economics 8, 75-78 (2021).
[8] Ma, F., Hu, J., Sun, Q., et al., "Carbon emission performance measurement and it's driving factors of China's provincial logistics industry," Ecological Economy 37(09), 27-33+39 (2021).
[9] He, J., Zhang, Z. and Ye, S., "Research on efficiency of low-carbon logistics in China's five coastal urban groups based on three-stage super-efficiency SBM-DEA model," Journal of Shanghai Maritime University 44(03), 55-63 (2023).
[10] Tone, K., "Dealing with undesirable outputs in DEA: A slacks-based measure (SBM) approach," North American productivity workshop, 44-45(2004).
[11] Cheng, G., [Data Envelopment Analysis and MaxDEA Softwear], Intellectual property Publishing House, Beijing, 2014.
[12] Pastor, J, T. and Lovell, C. A. K., "A global Malmquist productivity index," Economics Letters 88(2), 266-271 (2005).