Industrial Engineering and Innovation Management (2025)
Clausius Scientific Press, Canada

DOI: 10.23977/ieim.2025.080113
ISSN 2522-6924 Vol. 8 Num. 1

Measurement of Green Logistics Efficiency in the Chengdu-Chongqing Twin-City Economic Circle of China

Tian Tian[1,a], Hongbin Yuan[1,b,*]

[1]School of China, Chongqing University of Posts and Telecommunications, Nanan District 400000, Chongqing Municipality, China
[a]1515200897@qq.com, [b]yang505866726@yu.ac.kr
**Corresponding author*

Keywords: Chengdu-Chongqing Twin-City Economic Circle; Green Logistics Efficiency; Super-SBM Model; ML Index

Abstract: The logistics industry is a key sector supporting the national economy and plays a crucial role in the development of the Chengdu-Chongqing Twin-City Economic Circle. With the intensification of global environmental issues, the "dual carbon" goals have set higher requirements for the green development of the logistics industry, making the traditional high-investment, high-output logistics model increasingly incompatible with sustainable development objectives. Therefore, a scientific assessment of the current state and efficiency of regional green logistics is of great theoretical and practical significance for policymaking. This study focuses on the Chengdu-Chongqing Twin-City Economic Circle, measuring and analyzing green logistics efficiency from 2013 to 2022. Firstly, the current development of logistics within the region is analyzed, with an emphasis on energy consumption and carbon emissions; secondly, a green logistics efficiency evaluation index system is constructed, and static analysis is performed using the Super-SBM model; thirdly, the ML index is applied to analyze the dynamic changes from both temporal and spatial perspectives; finally, the regional heterogeneity of green logistics efficiency is explored. The results show that: (1) The green logistics efficiency of the Chengdu-Chongqing Twin-City Economic Circle has generally increased, with higher efficiency observed in the Chongqing region compared to the Sichuan region; (2) Temporal and spatial analysis indicates a growth in green total factor productivity, with technological progress being the primary driving factor; (3) Targeted improvement suggestions are proposed for different regions to promote overall green development in logistics and reduce regional disparities.

1. Introduction

In the context of global green development, achieving maximum economic and social benefits with the minimum resource consumption has become a consensus. The green transformation of the logistics industry plays a significant role in promoting the green and sustainable development of regional economies [1]. In the face of increasing global greenhouse gas emissions and climate change challenges, the low-carbon economy has become a key path to global sustainable development [2]. The International Transport Forum predicts that global transport activity will more than double by 2050, but policy guidance could reduce carbon emissions by nearly 70% [3]. China has set the goal of "carbon peaking by 2030 and carbon neutrality by 2060" and has integrated green and low-carbon concepts into its national development strategy [4]. As a demonstration area for regional coordinated development, the Chengdu-Chongqing Twin-City Economic Circle plays an important role in promoting green development and achieving the "dual carbon" goals, and its logistics industry's green transformation is crucial for the high-quality development of the regional economy [5].

As an important node in the national strategy, the logistics industry in the Chengdu-Chongqing Twin-City Economic Circle plays a key role in promoting regional connectivity and industrial chain coordination [6]. However, while the logistics industry drives economic development, it faces issues of high energy consumption and emissions, particularly in underdeveloped regions, where problems such as imbalanced infrastructure, a shortage of talent, and inefficient resource allocation are prominent [7]. Therefore, improving green logistics efficiency, especially in underdeveloped areas, is crucial for achieving the green and high-quality development of the economic circle [2]. This study aims to evaluate the green efficiency of the logistics industry in the Chengdu-Chongqing Twin-City Economic Circle and explore the key factors influencing its green efficiency [8]. Through analysis using the Super-Efficiency SBM static efficiency and ML dynamic efficiency measurement, the study reveals the current status and potential improvements of green logistics efficiency, providing theoretical support for policy formulation and promoting the green transformation and coordinated development of the regional economy [9].

Research on logistics efficiency mainly focuses on evaluation and evaluation methods, with green logistics efficiency gradually becoming an academic hotspot [10,11]. This paper takes the Chengdu-Chongqing Twin-City Economic Circle as an example to explore the measurement and development trends of green logistics efficiency in the region [12]. Logistics efficiency research is mostly concentrated at the national and provincial levels, particularly using DEA and Super-DEA models for evaluation [13,14]. Although existing studies have covered regions such as the Yangtze River Economic Belt, there is still a lack of green logistics efficiency analysis in the Chengdu-Chongqing Twin-City Economic Circle, especially at the district and county levels [15]. Studying green logistics efficiency in this region is of great significance for promoting green transformation and high-quality development [16]. The measurement methods for logistics efficiency mainly include parametric and non-parametric approaches [17]. Although the SFA method has certain advantages, the DEA model performs better in multi-input and multi-output systems [18]. With the introduction of green development goals, scholars have incorporated non-expected outputs, such as carbon emissions and energy consumption, into the DEA model, proposing a green logistics efficiency evaluation framework [19], and enhancing evaluation accuracy through super-efficiency DEA, SBM, and Malmquist indices [20]. As attention to green development increases, the evaluation system for green logistics efficiency has gradually formed, with traditional models focusing on input and output indicators, while the intensifying environmental issues have prompted scholars to incorporate non-expected outputs such as carbon emissions and energy consumption into the evaluation [1]. Research shows that there is still significant room for improvement in green transformation in some regions, and long-term green logistics development requires reducing carbon emissions and energy consumption [19,21].

Although existing studies provide support for logistics efficiency evaluation, there are still three main shortcomings: 1) Most studies focus on the national or provincial level, with insufficient measurement and heterogeneity analysis of green logistics efficiency at the district and county levels in the Chengdu-Chongqing Twin-City Economic Circle; 2) There is a lack of sufficient consideration of green development factors such as carbon emissions and energy consumption; 3) Most studies rely on static DEA models, which fail to effectively reflect the spatiotemporal variations and long-term evolution of logistics efficiency.

This paper addresses the shortcomings of existing research through the following innovations: 1) Focusing on the district and county levels of the Chengdu-Chongqing Twin-City Economic Circle, analyzing the spatial heterogeneity of regional logistics efficiency; 2) Incorporating energy consumption and carbon emissions into the green logistics efficiency evaluation, and constructing a comprehensive measurement system; 3) Combining the super-efficiency SBM model and ML dynamic efficiency measurement to comprehensively analyze green logistics efficiency and development trends, providing references for regional high-quality development.

2. Empirical research design

2.1. Model selection

2.1.1. Super efficiency SBM Model

Data Envelopment Analysis (DEA) is used for efficiency evaluation in multi-input and multi-output systems. To address the slackness issue and radial errors, Tone proposed the non-radial, non-oriented SBM model and further introduced the Super Efficiency SBM model to distinguish multiple efficient units [22]. In this study, the Super-SBM model based on undesirable outputs is used to evaluate the green logistics efficiency of the Chengdu-Chongqing Twin-City Economic Circle [23].

$$\min \rho = \frac{\frac{1}{n}\sum_{i=1}^{n}\frac{\bar{x}}{x_{ik}}}{\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{\bar{y}}{y_{rk}}+\sum_{l=1}^{s_2}\frac{\bar{q}}{q_{lk}}\right)} \tag{1}$$

$$s.t.\begin{cases} \bar{x} \geq \sum_{j=1,j\neq k}^{m}\lambda_j x_{ij}, & i=1,2,\dots,n \\ \bar{y} \leq \sum_{j=1,j\neq k}^{m}\lambda_j y_{rj}, & r=1,2,\dots,s_1 \\ \bar{q} \geq \sum_{j=1,j\neq k}^{m}\lambda_j q_{lj}, & l=1,2,\dots,s_2 \\ \bar{x}\geq x_k,\quad \bar{y}\leq y_k,\quad \bar{q}\geq q_k,\quad \lambda_j\geq 0, & j=1,2,\dots,m \end{cases}$$

In Equation (1), ρ represents the efficiency value of carbon emissions in the logistics industry; n denotes the number of input indicators; s_1,s_2 represent the number of desirable and undesirable output indicators, respectively; m is the number of decision-making units (DMUs); x_{ik} denotes the k input indicator of the i DMU, while y_{rk} and q_{lk} represent the k desirable output indicator and the r undesirable output indicator of the l DMU, respectively. When $\rho \geq 1$, the DMU is considered relatively efficient, and a higher ρ value indicates greater carbon emission efficiency. Conversely, when $\rho < 1$, the DMU is considered relatively inefficient.

2.1.2. Malmquist index

The Malmquist index was proposed by Sten Malmquist, and scholars such as Caves applied it to measure dynamic efficiency changes [24]. Fare and others, based on Caves' model, constructed the Total Factor Productivity (TFP) index [25,26].

$$M^{t+1}(x^{t+1},y^{t+1},X^t,y^t) = \left[\frac{E^{t+1}(x^{t+1},y^{t+1})}{E^t(x^t,y^t)} \times \frac{E^{t+1}(x^{t+1},y^{t+1})}{E^{t+1}(x^{t+1},y^{t+1})}\right]^{\frac{1}{2}} \tag{2}$$

In the equation, M^{t+1} represents the efficiency value under constant returns to scale, (x^t,y^t) represents the input and output of period t, and (x^{t+1},y^{t+1}), $t+1$ represents the input and output of period $t+1$. $E^t(x^t,y^t)$ and $E^{t+1}(x^{t+1},y^{t+1})$ represent the distance functions for periods t and $t+1$, respectively. If $M^{t+1}(x^{t+1}, y^{t+1}, X^t, y^t) > 1$, it indicates an improvement in total factor productivity from period t to period $t+1$; if $M^{t+1}(x^{t+1}, y^{t+1}, X^t, y^t) < 1$, it indicates a deterioration in total factor productivity from period t to period $t+1$. Fare et al. decomposed the Malmquist index into the technical efficiency change index (EC) and the technical progress change index (TC), with the decomposition shown as follows:

$$M^{t+1}(x^{t+1}, y^{t+1}, X^t, y^t) = EC \times TC \tag{3}$$

$$EC = \frac{E^{t+1}(x^{t+1}, y^{t+1})}{E^t(x^t, y^t)} \tag{4}$$

$$TC = \left[\frac{E^{t+1}(x^{t+1}, y^{t+1})}{E^{t+1}(x^{t+1}, y^{t+1})} \times \frac{E^t(x^t, y^t)}{E^t(x^t, y^t)}\right]^{\frac{1}{2}} \tag{5}$$

2.2. Research approach and indicator selection

2.2.1. Research approach

According to the "Planning Outline for the Construction of the Chengdu-Chongqing Twin-City Economic Circle," the regional division and strategic positioning of the Chengdu-Chongqing Twin-City Economic Circle have been clearly defined [27]. This study takes 27 districts and counties in Chongqing and 15 cities in Sichuan within the Chengdu-Chongqing Twin-City Economic Circle as the research subjects. It employs the super-efficiency SBM-DEA model to conduct a static measurement of green logistics efficiency, and combines the Malmquist index to analyze the dynamic evolution characteristics and total factor productivity changes of regional green logistics efficiency. The study aims to explore the key factors affecting green logistics efficiency and propose policy recommendations to enhance green logistics efficiency in the region, providing theoretical support for the coordinated development of green logistics in the Chengdu-Chongqing Twin-City Economic Circle.

2.2.2. Indicator selection

According to the studies in references [17-21], the evaluation of carbon emission efficiency in the logistics industry typically includes input indicators such as labor, capital, and energy consumption, and output indicators such as scale output, economic output, and undesirable output. The green logistics efficiency evaluation index system is constructed as shown in Table 1.

Table 1: Input and Output Index System for the Logistics Industry in the Chengdu-Chongqing Twin-City Economic Circle.

Indicator Type	First-Level Indicator	Second-Level Indicator	Unit
Input Indicators	Fixed Asset Investment	Fixed asset investment in the logistics industry	Ten thousand yuan
	Labor Input	Employment	Ten thousand people
	Energy Consumption	Energy consumption of the logistics industry	Ten thousand tons of standard coal
Output Indicators	Expected Output	Gross output of the logistics industry	Ten thousand yuan
		Freight turnover volume	Ten thousand ton-kilometers
	Unexpected Output	Carbon emissions in the logistics industry	Ten thousand tons

The research data mainly comes from the *China Statistical Yearbook* (2013–2022), statistical yearbooks of various cities and counties (2013–2022), the *China Energy Statistical Yearbook* (2013–

2022), and the *China Environmental Statistical Yearbook* (2013–2022). For handling missing data, machine learning algorithms are employed for prediction and imputation, specifically utilizing Random Forest, Gradient Boosting, Lasso regression, and Support Vector Regression (SVR).

3. Regional logistics efficiency evaluation

3.1. Static analysis of regional logistics efficiency based on the Super-SBM-DEA Model

This study selects logistics data from 27 districts and counties in Chongqing and 15 cities in Sichuan Province within the Chengdu-Chongqing Twin-City Economic Circle from 2013 to 2022. The Super-SBM-DEA model, based on the variable returns to scale (VRS) assumption, is used to measure the green logistics efficiency of each city. To enhance computational efficiency, this study utilizes MaxDEA 8.0 software to first analyze the overall trend of the Chengdu-Chongqing Twin-City Economic Circle and compare the Sichuan and Chongqing regions. The analysis focuses on the years 2013, 2016, 2019, 2022, and the 10-year average. The specific analysis results are presented in Figure 1 and Table 2.

Table 2: The calculation results of logistics efficiency for some cities and counties in the Chengdu-Chongqing Twin-City Economic Circle region.

City (District)	Year				Average	City (District)	Year				Average
	2013	2016	2019	2022			2013	2016	2019	2022	
Yuzhong	0.605	0.818	0.811	1.009	0.811	Qijiang	0.644	0.568	0.555	0.419	0.547
Jiangbei	0.465	0.540	0.545	0.640	0.548	Bishan	0.514	0.646	0.772	0.559	0.622
Shapingba	0.577	0.601	0.670	0.702	0.637	Wanzhou	0.495	0.731	1.012	1.006	0.811
Jiulongpo	0.637	0.722	0.807	1.023	0.798	Fengdu	0.363	0.324	0.789	1.011	0.622
Yubei	0.634	0.830	0.937	0.793	0.799	Chengdu	0.982	0.743	1.021	0.979	0.931
Fuling	0.460	0.812	1.018	0.927	0.804	Deyang	0.518	0.536	0.961	0.544	0.640
Changshou	0.435	0.458	0.590	0.519	0.500	Neijiang	1.013	0.861	0.817	0.628	0.830
Jiangjin	0.451	0.559	0.615	0.528	0.538	Leshan	0.622	0.607	0.837	0.641	0.677
Yongchuan	0.494	0.525	0.522	0.525	0.516	Meishan	0.476	0.446	0.812	0.501	0.559

3.1.1. Overall trend analysis of green logistics efficiency in the Chengdu-Chongqing Twin-City Economic Circle

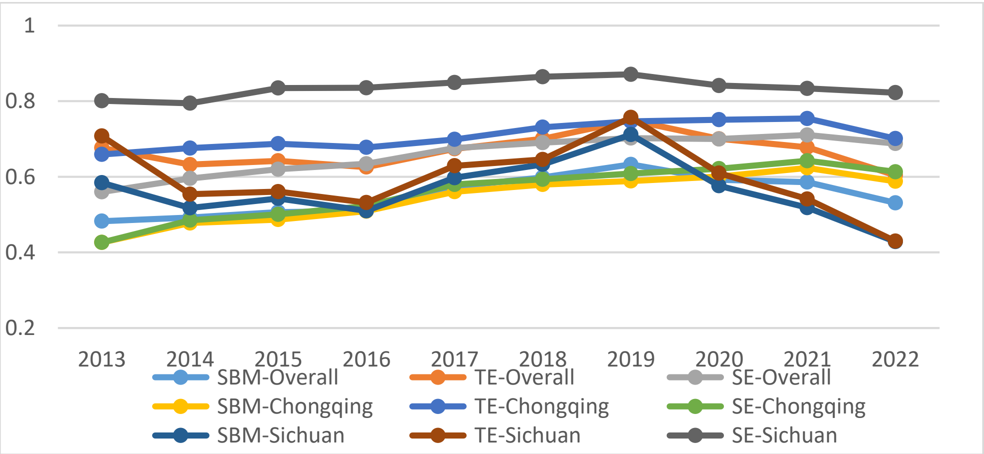

Figure 1: Trend of Green Logistics Efficiency in the Chengdu-Chongqing Twin-City Economic Circle (2013-2022).

Based on Figure 1, a detailed analysis of the green logistics efficiency data and trends in the Chengdu-Chongqing Twin-City Economic Circle reveals the following findings:

(1) Overall Green Logistics Efficiency Trend: From 2013 to 2020, the green logistics efficiency of the Chengdu-Chongqing Twin-City Economic Circle steadily increased, reflecting the positive impact of policy-driven green transformation in the regional logistics sector. This growth is primarily attributed to traditional logistics optimization, increased investment in energy-saving and emission reduction, and the promotion of new energy sources. Additionally, the continuous improvement of green logistics infrastructure and technological innovation played a key role. However, from 2021 to 2022, the green logistics efficiency slightly declined due to the impact of the COVID-19 pandemic, which caused disruptions in logistics operations, supply chain interruptions, and restrictions from pandemic control measures, leading to a slowdown in the progress of green development.

(2) Comparison of Overall Efficiency and DEA Efficient Values. The average green logistics efficiency in the Chengdu-Chongqing Twin-City Economic Circle does not reach the DEA efficient values, indicating that the input-output structure needs optimization and there is significant room for improvement. Both pure technical efficiency and scale efficiency fall short of the efficient standard, suggesting that further efforts are required to enhance the rational input of production factors and foster technological innovation in improving green logistics efficiency.

(3) Efficiency Comparison between Chongqing and Sichuan Regions: The Chongqing region has higher technical efficiency but lower scale efficiency, showing its strength in technological innovation. However, there is still room for improvement in scale expansion and resource allocation. In contrast, the Sichuan region has an advantage in scale efficiency but relatively low technical efficiency, suggesting that there is still substantial room for improvement in technological investment. This indicates that both Chongqing and Sichuan should strengthen regional collaboration and optimize resource allocation to further promote the overall improvement of green logistics efficiency.

3.1.2. Analysis of regional logistics efficiency in the Chengdu-Chongqing Twin-City Economic Circle

Table 2 shows significant differences in green logistics efficiency across cities and districts (counties) in the Chengdu-Chongqing Twin-City Economic Circle, reflecting disparities in resource allocation, technology application, and management levels.

Overall, logistics efficiency has shown a fluctuating upward trend, but regional development remains uneven. Core cities such as Yuzhong District, Jiulongpo District, and Chengdu have steadily improved logistics efficiency due to well-developed infrastructure, advanced supply chain management, and logistics technology, becoming key logistics hubs in the region. In contrast, regions such as Nanchong and Ziyang have remained at lower logistics efficiency levels for an extended period, with efficiency declines in certain years. These disparities may be attributed to factors such as weaker economic foundations, poor transportation access, and lagging logistics infrastructure, especially in areas farther from core cities where logistics networks lack effective integration.

From an average value perspective, core areas such as Yuzhong District, Jiulongpo District, and Chengdu have higher logistics efficiency averages, reflecting their long-term competitiveness. Conversely, regions such as Dazhou, Nanchong, and Ziyang have lower logistics efficiency averages, constrained by insufficient infrastructure, small-scale enterprises, and low supply chain integration, leading to higher overall logistics costs and hindering efficiency improvements.This indicates that while some regions have developed into high-efficiency logistics hubs, others require targeted policies and infrastructure investment to promote more balanced logistics efficiency.

3.2. Dynamic analysis of M Index in the Chengdu-Chongqing Twin-City Economic Circle

The decomposition analysis of pure technical efficiency, scale efficiency, and technological progress for selected cities in the Chengdu-Chongqing Twin-City Economic Circle from 2013 to 2022 further reveals the main driving factors behind the changes in regional logistics efficiency. For details, please refer to Table 3.

Table 3 Decomposition of M Index in the Chengdu-Chongqing Twin-City Economic Circle (Partial Cities and Districts)

Year	Indicator	City (District/County)						
		Jiangbei	Shapingba	Jiangjin	Tongliang	Mianyang	Yibin	Deyang
2013～2014	PTEC	1.186	0.998	1.137	1.230	1.266	1.375	0.907
	SEC	0.876	1.024	0.883	0.925	1.013	1.107	0.940
	TC	1.019	1.011	1.002	1.067	1.132	1.234	0.923
2014～2015	PTEC	1.008	1.305	1.021	1.021	1.257	1.071	1.335
	SEC	0.982	1.203	1.008	1.042	1.009	1.003	1.027
	TC	0.995	1.253	1.013	1.032	1.126	1.036	1.171
2015～2016	PTEC	0.950	1.009	0.894	1.103	0.886	1.062	1.140
	SEC	0.967	0.718	0.921	0.941	0.982	0.998	1.020
	TC	0.958	0.847	0.907	1.019	0.933	1.030	1.078
2016-2017	PTEC	0.961	0.766	1.048	1.035	1.033	1.003	1.028
	SEC	0.958	1.106	0.995	0.929	1.016	1.003	1.004
	TC	0.960	0.920	1.021	0.980	1.025	1.003	1.016
2017-2018	PTEC	1.357	0.975	1.067	1.000	1.093	0.885	1.050
	SEC	1.166	1.007	0.950	0.691	1.001	0.997	1.027
	TC	1.258	0.991	1.007	0.831	1.046	0.939	1.038
2018-2019	PTEC	0.854	1.089	0.892	0.971	0.755	1.085	1.012
	SEC	0.649	1.121	0.649	1.103	0.997	0.998	1.008
	TC	0.745	1.105	0.761	1.035	0.867	1.041	1.732
2019-2020	PTEC	1.170	0.986	0.933	0.976	0.673	0.577	0.665
	SEC	1.772	0.924	1.492	0.827	1.002	0.995	0.948
	TC	1.440	0.954	1.180	0.898	0.821	0.757	0.794
2020-2021	PTEC	0.890	1.037	1.049	1.057	0.871	0.904	1.020
	SEC	0.856	1.006	0.963	0.894	1.002	0.937	1.010
	TC	0.873	1.022	1.005	0.972	0.934	0.920	1.015
2021-2022	PTEC	0.921	1.034	0.982	1.094	0.993	1.057	1.183
	SEC	0.719	0.873	0.964	0.974	0.885	0.876	0.839
	TC	0.814	0.950	0.973	1.033	0.937	0.963	0.996

(1) Pure Technical Efficiency : During the observation period, the pure technical efficiency of some cities showed a declining trend, such as Shapingba District (0.998 in 2013–2014 → 0.873 in 2021–2022), Jiangjin District (1.137 in 2013–2014 → 0.964 in 2021–2022), and Tongliang District (1.230 in 2013–2014 → 1.033 in 2021–2022). This indicates that these regions have room for improvement in logistics management, technology application, and resource allocation. In particular, Shapingba District experienced a significant decline in pure technical efficiency, reflecting a lack of technological innovation and refined management capabilities in the logistics industry, leading to a decrease in the utilization of production factors. A long-term reliance on traditional logistics models without effectively driving intelligent and digital transformation is the key factor influencing the efficiency decline.

(2) Scale Efficiency: Scale efficiency generally showed an upward trend, with significant increases in some cities, such as Jiangjin District (0.883 in 2013–2014 → 0.964 in 2021–2022) and Tongliang District (0.925 in 2013–2014 → 1.033 in 2021–2022). This indicates that these regions made positive progress in logistics infrastructure, industrial agglomeration, and scale expansion. Jiangjin District, as an important logistics node in the Chengdu-Chongqing Twin-City Economic Circle, improved its

logistics intensification level by optimizing its transportation network and enhancing industrial chain coordination. Additionally, the improvement in scale efficiency in Tongliang District demonstrates that the region has promoted the rational layout of the logistics industry through resource integration, industrial collaboration, and infrastructure investment.

(3) Technological Progress: Technological progress played an important role in improving regional logistics efficiency, as seen in cities like Yibin (1.137 in 2013–2014 → 1.033 in 2021–2022) and Deyang (0.907 in 2013–2014 → 1.024 in 2021–2022). This indicates that these cities strengthened logistics informationization and intelligent construction during the observation period, improved their technological innovation capabilities, and promoted the development of green logistics and digital logistics. However, some regions showed relatively fluctuating technological progress indices, such as Shapingba District (1.011 in 2013–2014 → 0.950 in 2021–2022), suggesting that there are still unstable factors in the technological upgrading of their logistics industries. Further acceleration of the application of smart logistics technologies is needed to improve logistics efficiency.

4. Conclusion and Policy Recommendations

4.1. Research Results

Based on data from 2013 to 2022 in the Chengdu-Chongqing Twin-City Economic Circle, this paper uses the Super-SBM-DEA model and M index for static and dynamic efficiency measurement to analyze the changes in regional green logistics efficiency. The results are as follows:

Static Efficiency Analysis: The Super-SBM-DEA model shows that the overall logistics efficiency of the Chengdu-Chongqing Twin-City Economic Circle is relatively high and continues to improve, especially in core cities such as Yuzhong District, Jiulongpo District, and Chengdu. However, some underdeveloped areas, such as Nanchong and Ziyang, have relatively low efficiency and room for improvement.

Dynamic Efficiency Analysis: According to the M index, the M index for the region follows a "decline-rise-decline" trend, with scale efficiency growing at an average annual rate of 12%, pure technical efficiency at 10%, and technological progress at 7%. The improvement in logistics efficiency is mainly driven by scale benefits, followed by technical efficiency, while technological progress has been slower.

Key Factor Analysis: The improvement in efficiency is mainly attributed to infrastructure development, technological innovation, and policy promotion. Underdeveloped areas need to strengthen technological innovation and resource optimization.

4.2. Policy Recommendations

Based on the analysis of logistics efficiency in the Chengdu-Chongqing Twin-City Economic Circle, cities and districts within the region can take the following measures to further enhance logistics efficiency:

(1) Enhance the level of logistics industry agglomeration: The research results indicate that logistics industry agglomeration is positively correlated with logistics efficiency in the Chengdu-Chongqing Twin-City Economic Circle. Therefore, enhancing the agglomeration of the logistics industry is key to improving logistics efficiency. For regions with relatively weak logistics industry agglomeration, such as Nanchong and Ziyang, it is recommended to build high-quality logistics hubs, integrate dispersed logistics nodes within the region, promote industry agglomeration, and drive improvements in urban logistics efficiency, thereby injecting logistical momentum into regional economic growth.

(2) Optimize the utilization of logistics resources:The utilization of logistics resources is

significantly related to regional logistics efficiency. There are differences in logistics infrastructure development within the Chengdu-Chongqing Twin-City Economic Circle. Core cities such as Chongqing and Chengdu can further introduce green low-carbon technologies and intelligent logistics equipment to enhance resource utilization. For cities with weaker infrastructure, such as Ziyang and Yibin, increasing investment in logistics infrastructure, optimizing transportation networks, and improving the level of automation will enhance the overall utilization efficiency of logistics resources.

(3) Promote Low-Carbon Logistics Development: To achieve low-carbon logistics, a change in development concepts is required, integrating sustainable development and carbon emission control into the entire logistics process, achieving a win-win for economic and environmental benefits. Furthermore, the application of green logistics technologies, including new energy technologies, should be promoted to reduce carbon emissions. In addition, the Chengdu-Chongqing Twin-City Economic Circle should develop specific energy emission policies, improve energy conservation and emission reduction mechanisms, strengthen pollution control in logistics environments, and promote the sustainable development of low-carbon logistics.

(4) Enhance Logistics Informationization: The logistics industry in the Chengdu-Chongqing Twin-City Economic Circle needs to leverage high-tech innovations to promote industrial upgrading and improve informationization and intelligence levels. Especially in areas such as intelligent scheduling of logistics resources and the construction of information systems, core cities like Chongqing and Chengdu can take the lead in technological innovation, integrating the logistics industry with high-tech advancements. For other cities, strengthening the construction of logistics information infrastructure and utilizing advanced technologies such as big data and artificial intelligence will improve logistics management efficiency, reduce resource waste, and minimize environmental impact.

Acknowledgments

The authors sincerely thanks their supervisor for the valuable suggestions provided during the research process, which greatly helped improve the quality of this paper.

Author contributions

Tian Tian conceived the research idea, analyzed the data, and wrote the paper. Yuan Hongbin performed data processing in the study.

References

[1] Zhang, X., & Chen, S. (2020). Green logistics and sustainable development: A review and research agenda. Transportation Research Part D: Transport and Environment, 81, 102309. https://doi.org/10.1016/j.trd.2020.102309.
[2] Zhao, Y., & Liu, Z. (2018). The low-carbon economy and sustainable development in China: Evidence from the provincial panel data. Energy Economics, 72, 79-89. https://doi.org/10.1016/j.eneco.2018.03.009.
[3] International Transport Forum (2021). Decarbonising Transport: Pathways to a Low-carbon Transport System. International Transport Forum Report. OECD Publishing. https://doi.org/10.1787/6b93b28d-en.
[4] Liu, Z., & Li, J. (2020). China's carbon peaking and carbon neutrality goals: Implications and policy actions. Energy Policy, 145, 111624. https://doi.org/10.1016/j.enpol.2020.111624.
[5] Jiang, L., & Wang, X. (2019). The green transformation of logistics industry and its role in regional sustainable development: Evidence from the Chengdu-Chongqing economic zone. Journal of Cleaner Production, 231, 970-979. https://doi.org/10.1016/j.jclepro.2019.05.099.
[6] Zhang, X., & Zhang, Y. (2020). The impact of logistics infrastructure on regional economic integration: A study of the Chengdu-Chongqing economic zone. Transportation Research Part E: Logistics and Transportation Review, 138, 101909. https://doi.org/10.1016/j.tre.2020.101909.
[7] Liu, X., & Liu, Z. (2019). The challenges and opportunities for green logistics development in China's underdeveloped regions. Journal of Cleaner Production, 222, 747-755. https://doi.org/10.1016/j.jclepro.2019.03.053.

[8] Wang, H., & Li, J. (2021). Enhancing green logistics efficiency for sustainable development in western China. Sustainable Cities and Society, 65, 102598. https://doi.org/10.1016/j.scs.2020.102598.
[9] Wei, W., & Liu, Z. (2019). A dynamic efficiency evaluation of logistics systems using machine learning techniques: Evidence from China. Computers, Environment and Urban Systems, 74, 112-123. https://doi.org/10.1016/j.compenvurbsys.2019.01.005.
[10] Yang, H., & Zhang, L. (2020). A review of logistics efficiency measurement methods: A comparative study of parametric and non-parametric approaches. Transportation Research Part E: Logistics and Transportation Review, 141, 102036. https://doi.org/10.1016/j.tre.2020.102036.
[11] Gallo, M., & Pappas, A. (2019). Green logistics efficiency: A systematic literature review and future directions. Journal of Cleaner Production, 238, 117823. https://doi.org/10.1016/j.jclepro.2019.117823.
[12] Wang, S., & Xu, Y. (2021). Measuring and analyzing green logistics efficiency in the Chengdu-Chongqing economic zone. Sustainable Cities and Society, 66, 102667. https://doi.org/10.1016/j.scs.2020.102667.
[13] Kamran, M. (2002). Evaluating logistics efficiency in OECD countries using DEA model. International Journal of Physical Distribution & Logistics Management, 32(5), 349-360. https://doi.org/10.1108/09600030210434904.
[14] Xu, H., & Li, J. (2017). Evaluating sustainable innovation efficiency in China using Super-DEA: A provincial-level analysis. Technological Forecasting and Social Change, 120, 169-179. https://doi.org/10.1016/j.techfore.2017.02.020.
[15] Yang, B. (2018). Analyzing logistics efficiency in the Yangtze River Economic Belt using DEA. Sustainability, 10(5), 1575. https://doi.org/10.3390/su10051575.
[16] Zhang, W., & Liu, T. (2020). Green logistics efficiency evaluation in Western China: Evidence from the Chengdu-Chongqing economic zone. Journal of Cleaner Production, 246, 119030. https://doi.org/10.1016/j.jclepro.2019.119030.
[17] Coelli, T. J., & Rao, D. S. P. (2005). Application of parametric and non-parametric methods to measuring efficiency in the transport sector. Journal of Productivity Analysis, 23(1), 67-77. https://doi.org/10.1007/s11123-004-1584-3.
[18] Wang, H. F., Li, Y., & Shi, X. (2019). Evaluation of logistics efficiency in the Belt and Road Initiative using SFA: Evidence from provincial data. Transportation Research Part A: Policy and Practice, 130, 369-380. https://doi.org/10.1016/j.tra.2019.10.010.
[19] Jiang, Z., Wang, X., & Li, J. (2020). Green logistics efficiency and carbon emission performance in China: Evidence from the Super-SBM and Malmquist Index. Journal of Cleaner Production, 272, 122536. https://doi.org/10.1016/j.jclepro.2020.122536.
[20] Liu, J., & Xu, L. (2021). The application of Super-DEA, SBM, and Malmquist Index in evaluating green logistics efficiency. Sustainable Production and Consumption, 27, 176-185. https://doi.org/10.1016/j.spc.2020.11.009.
[21] Wei, S., & Zhu, J. (2021). Sustainable logistics and its efficiency: A review and a framework for green logistics. Sustainable Development, 29(6), 1283-1297. https://doi.org/10.1002/sd.2220.
[22] Tone, K. (2001). A slacks-based measure of efficiency in data envelopment analysis. European Journal of Operational Research, 130(3), 498-509. https://doi.org/10.1016/S0377-2217(00)00099-7.
[23] Jiang, W., Wang, L., & Zhao, L. (2020). Carbon emission efficiency of China's logistics industry: A Super-SBM model analysis. Journal of Cleaner Production, 258, 120682. https://doi.org/10.1016/j.jclepro.2020.120682.
[24] Malmquist, S. (1953). Index numbers and the measurement of input and output. Trabajos de Estadística, 4, 209-242.
[25] Caves, D. W., Christensen, L. R., & Diewert, W. E. (1982). The economic theory of index numbers and the measurement of productivity. Econometrica, 50(6), 1393-1414. https://doi.org/10.2307/1911154.
[26] Fare, R., Grosskopf, S., & Lindgren, B. (1994). Productivity change in Swedish pharmacies 1980-1989: A non-parametric approach. Journal of Productivity Analysis, 5(1), 85-101. https://doi.org/10.1007/BF01073977.
[27] National Development and Reform Commission (NDRC). The Outline of the Construction Plan for the Chengdu-Chongqing Twin-City Economic Circle [M]. Beijing: China Planning Press, 2020.