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Evaluation of Green Logistics Efficiency in Northwest China

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Abstract: This paper develops an index system for assessing green logistics efficiency in Northwest China with the goal of "double carbon" (peak carbon dioxide emissions and carbon neutrality). The study employs a three-stage data envelopment analysis model of super efficiency to assess the spatial and temporal efficiency of the green logistics industry in Northwest China from 2010 to 2019. Our findings reveal that the overall logistics efficiency in Northwest China fluctuates. Each province has a high pure technical efficiency, but significant regional differences in comprehensive technical efficiency and scale efficiency are apparent. In Northwest China, government support and science and technology levels have a greater impact on green logistics efficiency. Based on the implementation of the "double carbon" strategy, this study offers pertinent insights and suggestions for the high-quality development of the green logistics industry in Northwest China.

Keywords: double carbon; Northwest China; green logistics; super-efficiency three-stage DEA

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1. Introduction

China has proposed a "double carbon" target based on the Paris Agreement declaration, i.e., to achieve carbon peaking by 2030 and carbon neutrality by 2060 [1]. The "double carbon" target is a requirement to meet the global trend of green and sustainable development and to promote China's high-quality economic development [2]. As one of the key industries for energy saving and carbon reduction, the logistics industry must make joint efforts both externally and internally to realize its green, low-carbon, and high-quality development in China.

Northwest China is an inland region, including Qinghai, Gansu, Shaanxi, Xinjiang, and Ningxia, that is lagging behind in the development of the logistics industry. Under the "One Belt and One Road" initiative, China has proposed a new pattern of transport corridors, a linkage between land and sea, and a two-way corridor between the east and west [1]. Northwest China, connected to Central Asia, West Asia, Southeast Asia, South Asia, and parts of Europe, will become an important hub and strategic channel for national logistics development [3]. Qinghai Golmud, Xinjiang Urumqi and Alashankou, Gansu Lanzhou, and Shaanxi Yan'an have been included in the national logistics hub key construction list.

Because of its geographical location, Northwest China has become an important hub and strategic channel for national logistics development under the Belt and Road Initiative, ushering in unprecedented development opportunities. However, the development of the logistics industry in Northwest China is still uneven, as evidenced by its low logistics efficiency [4]. There is still a scarcity of empirical research on the efficiency of the green logistics industry in Northwest China. Green development and the "double carbon" target have been adopted as national policies. Rapid logistics industry development cannot come at the expense of environmental pollution and resource waste. It is important to investigate the efficiency of green logistics in the context of “double carbon” [5]. The three-stage super-efficiency DEA process model combined with the SFA (stochastic frontier approach) model eliminates the influence of environmental and random variables, resulting in more realistic and effective research results.

This study builds on existing research on green logistics efficiency to create a green logistics efficiency evaluation index system in Northwest China. Then, using a three-stage super-efficiency DEA model, panel data from the previous ten years (2009–2018) are chosen to assess green logistics efficiency in Northwest China. Finally, by integrating the “double carbon” target, we propose a path for the high-quality development of the green logistics industry in Northwest China.

The logistics industry in Northwest China is inadequate in terms of infrastructure, logistics network construction, regional logistics synergy, space for logistics market development, logistics efficiency, and energy consumption by logistics transportation [2]. This paper evaluates the green logistics efficiency in Northwest China. By analyzing input–output indexes and influencing factors, we propose a path to improve the quality development of green logistics in Northwest China. This study is of great practical significance for helping Northwest China achieve the “double carbon” target, accelerate the green and low-carbon transformation of the logistics industry, and realize its sustainable and high-quality development.

2. Theoretical Lenses

The logistics industry has now become a huge driver of international economic growth, playing an important role in promoting economic globalization [6]. At the same time, economic growth and high demand have placed new pressures on logistics, i.e., the need for supply chain management [7,8]. An efficient, green, and low-carbon operation is the future direction of China’s logistics industry [9], which is developing rapidly. The logistics industry plays an increasingly important role in supporting the development of China’s national economy and the transformation of its development model [10]. The modern logistics industry is a complex service industry combining transport, warehousing, and information industries; as the third most profitable industry in the world, it has become a global economic development hot spot [10]. However, a low level of specialization, high costs, and inefficiency are prevalent in China’s logistics industry. This inefficiency has resulted in increased energy consumption and waste, and the negative impact of logistics processes on the environment continues to grow [11]. Current research on low-carbon logistics in China focuses on development strategies and policy analysis from a macro perspective, while quantitative research on low-carbon logistics is insufficient [12].

2.1. Logistics Development and Carbon Emissions

Recently, the development of logistics in the context of carbon emissions has become popular for research. Logistics activities are important sources of carbon emissions, and low-carbon logistics is a strategic choice and necessary condition for the transformation of logistics enterprises [3,4]. China’s logistics industry should solve the problem of its unreasonable transportation structure to achieve the “double carbon” goal, and the application of digital technology in the logistics industry will become a core driving force for enterprises to achieve the “double carbon” goal [5]. The construction of an ecological civilization, involving carbon emissions rights and an emission trading mechanism, etc., will provide technical support for the green transformation of the logistics industry and promote its structural upgrading and high-quality development; meanwhile, the development of green logistics will promote the construction of an ecological civilization [13,14].

The authors of [15] investigated the green logistics efficiency of China’s three major bay area city clusters under carbon emission constraints by developing an unexpected-output green logistics efficiency input–output index system and a super-efficiency slacks-based measure model (S-BM). According to their findings, while transportation structure and urbanization level have a negative impact on green logistics efficiency, technological innovation and logistics industry labor productivity have a positive impact. The influence of different carbon emission policies on logistics distribution modes was investigated using a model. The results revealed that the structures of enterprises under different emission policies were different. Thus, the government could guide enterprises to reduce emissions through strategies involving different carbon emission policies, with carbon trading policies providing the best reduction effect [16]. Zhao et al. studied logistics center location by developing a dual-objective integer planning model that incorporated carbon emissions and logistics costs and concluded that local governments can achieve low-carbon logistics through urban logistics management strategies such as reasonable logistics center location selection, the standardization of urban logistics and distribution vehicle selection, and staggered peak hours [17].

2.2. Green Logistics

Many studies have considered green logistics methods for achieving high-quality logistics development [18–20] driven by a green supply chain. Such development would contribute to closing the logistics development gap between regions and improving logistics management across the board [21]. Jiang [22] examined high-quality rural green logistics development from the perspective of urban–rural integration and concluded that the bottleneck of rural green logistics development is the lack of green awareness and professional talent. Competitive cooperation, knowledge spillover, and policies are three mechanisms that can reduce resource waste and thus further green development [23].

There is much to learn from Japan's approach to green logistics [24]. The Japanese government has taken the lead in developing and implementing programmatic policies to plan the overall development of green logistics. Japan's logistics policy and legal framework are flawless and functional. Ultimately, Japan has adapted its policies and legislation to economic and social changes, maintaining a high level of stability and continuity. Key green logistics development strategies include the implementation of a green logistics industry planning and evaluation system, the technological transformation of infrastructure and product design, and human resource team training [25]. Green logistics development strategies also include a unified green logistics consensus, the creation of unified standards for logistics services, the strengthening of information system construction, and the deepening of talent training [26,27]. Green logistics is progressing through the strengthening of cooperation and exchange mechanisms, improving green supply chains, and encouraging information sharing and exchange [28].

2.3. Logistics Efficiency and Data Envelopment Analysis Model

Several scholars have studied green logistics efficiency. For instance, Zhang [29] used the slacks-based measure model (S-BM) to analyze the green logistics efficiency of Chinese provinces. He concluded that the level of science and technology, infrastructure, and the economic basis are the factors that promote the development of green logistics. Meanwhile, Zhang et al. [30] used a three-stage data envelopment analysis (DEA) model to analyze the green logistics efficiency of 19 provinces in China's Yangtze River protection region and proposed a development strategy of vigorously implementing a low-carbon economy, applying government support, and encouraging regional synergistic development. Liu et al. [31] used the super S-BM and Malmquist index models to analyze the total factor productivity of China's logistics industry, demonstrating large fluctuations along the coastal rivers and stable inland areas; they found demand, policy, and market technology to be the main drivers. Additionally, scholars have used DEA models to construct a logistics efficiency index system for relevant regions [32–34].

The DEA method is a non-parametric method for evaluating the relative efficiency of multi-indicator inputs and multi-indicator outputs by applying mathematical planning models [35]. In recent years, the DEA method has been widely used to evaluate the efficiency of logistics [36]. For example, Liu et al. (2011) analyzed the efficiency of logistics inputs and outputs in 31 provinces, cities, and autonomous regions across China based on the DEA method [37]. Xu (2010) used the fixed-scale payoff model (C2R) and the variable-scale payoff model (BE2) to evaluate the efficiency of the logistics industry in 31 provinces, cities, and autonomous regions in China over five years and calculated the relative total technical efficiency, pure technical efficiency, and scale efficiency of the logistics industry in China [38]. Scholars have also used the DEA method to analyze and evaluate the operational efficiency of third-party logistics enterprises to study the efficiency of regional logistics development [39]. In addition, Guo et al. (2018) used a DEA model to analyze the efficiency of the logistics industry in the Beijing–Tianjin–Hebei region and conducted input redundancy analysis for non-effective regions [40]. Yu and Qian (2018) used the super-efficiency DEA–Malmquist productivity index to analyze the technical efficiency of logistics and the total factor productivity in various provinces and cities on the Yangtze River Economic Belt and studied the influencing factors of logistics technical efficiency [41]. Chen and Pan (2016) took carbon emissions as the input index and studied the logistics efficiency of 30 provinces and regions in China by using the non-parametric DEA–Malmquist index [42]. Cao et al. (2016) used the DEA method to analyze the efficiency level of the logistics industry in JiuJiang city by taking CO_2 emissions as the input index [43]. However, the research on the efficiency of green and low-carbon logistics in Northwest China is still very limited.

Low-carbon green logistics has now become a trend in the development of the logistics industry. As a high-energy-consumption industry, the logistics industry has clearly failed to keep up with the times by continuing its previous business development model [44], and so it must take the low-carbon road [11].

3. Research Methodology

The super-efficiency three-stage model, combining the super-efficiency DEA model and the three-stage DEA model [34,45], shows the following advantages: The traditional DEA model cannot distinguish efficiency values and cannot effectively rank efficiency, whereas the super-efficiency model can resolve this defect. The super-efficiency three-stage DEA model eliminates external influences and provides more realistic and effective efficiency level evaluations. Finally, the introduction of carbon emission input indicators in the logistics industry can provide more accurate evaluations of green logistics efficiency under the "double carbon" objective.

3.1. Super-Efficiency DEA Analysis

In the first stage, we used a super-efficiency DEA model to calculate green logistics efficiency values in Northwest China without accounting for environmental factors or random disturbances. Because the logistics industry has a variable-scale payoff, we analyzed it using the variable-scale payoff model.

The input variables are expressed as,

$$x_i = (x_{1i}, x_{12i}, \ldots, x_{ti})^T > 0 \tag{1}$$

The decision unit with the same s outputs for each input variable corresponds to the output variable expressed as,

$$y_i = (y_{1i}, y_{12i}, \ldots, y_{si})^T > 0 \tag{2}$$

The linear programming equation is expressed as,

$$\min[\theta - \varepsilon(\hat{e}^T s^- + e^T s^+)] \tag{3}$$

$$s.t. \sum_{i=1}^{n} \lambda_i x_i + s^- = \theta x_0 \tag{4}$$

$$\sum_{i=1}^{n} \lambda_i y_i + s^+ = y_0 \tag{5}$$

In these equations, θ is the technical efficiency of the decision unit; λ is the multiplier; x_0, y_0 denote the input and output values of DMU_0; x_i, y_i are the input and output variables, respectively; s^-, s^+ are the slack and residual variables, respectively; s^-, s^+, λ are greater than or equal to 0; and $i = 1, 2, \ldots, n$. Note that the equation is premised on variable-scale payoffs.

3.2. SFA Regression Analysis

The second stage examined the impact of environmental variables on input slack variables using the SFA regression method, with the dependent variable being the slack values of each input variable in each province and the independent variables being regional GDP, government support, science and technology level, and regional consumer spending. We adjusted the values of the input variables based on the regression analysis results to eliminate the effect of environmental variables. The model was constructed as,

$$LnS_{ij} = \beta_0 + Ln\beta_1(\text{gdp}) + Ln\beta_2(gov) + Ln\beta_3(tec) + Ln\beta_4(\exp) + \nu_{ij} + \mu_{ij} \quad (6)$$

In this formula, S_{ij} denotes the slack value of the ith input indicator of the jth decision unit; gdp, gov, tec, and exp are environmental variables gross regional product, government support, science and technology level, and regional consumer spending variables, respectively; β is the coefficient to be estimated; and $v_{ij} + u_{ij}$ is the error term.

3.3. Adjusted Super-Efficiency DEA Analysis

Using the original output data and the adjusted input index data, the first-stage super-efficiency model was used to remeasure the green logistics efficiency in Northwest China and obtain a more realistic and effective efficiency evaluation.

4. Indicator Selection and Data Sources

4.1. Indicator Selection

The logistics industry is a comprehensive service industry integrated into various sectors, such as transportation and freight forwarding; warehousing and distribution; and communication, post, and telecommunications. It is the supply guaranty of social production and life. Based on the results of existing studies, this study included data from the transportation, warehousing, and post and telecommunications industries. Focusing on the principles of the representativeness, relevance, accuracy, and accessibility of indicators, this study drew on the existing research results [26,30–32] and took into consideration the "double carbon" goal.

We introduced the carbon emissions of the logistics industry as an input index to build an index system for evaluating green logistics efficiency in Northwest China.

4.1.1. Input Indicators

The selection of input indicators was based primarily on four factors: human, financial, material, and low-carbon. The indicators chosen were as follows: First, the total investment in fixed assets in the transportation, storage, postal, and telecommunications industries. Second, the density of the transportation network (the number of public transport kilometers per unit area). Third, the number of people employed in the transportation, storage, postal, and telecommunications industries. Fourth, the carbon footprint of the logistics industry. Among these, the total fixed-asset investment and the transportation network density indicate investment in logistics and transportation infrastructure, as well as the importance of the logistics industry in Northwest China. The number of employees is determined by the size of the logistics enterprise, which can intuitively reflect the current state of production and development in the logistics industry in Northwest China. The growth of the logistics industry is inextricably linked to energy consumption and carbon emissions. We used the energy consumption of gasoline and diesel in the logistics industry and multiplied it by the carbon emission coefficient of fuels in the IPCC National Greenhouse Gas Inventory Guidelines to obtain the carbon emissions, which are an important sign of the green and sustainable development of logistics enterprises, according to the IPPC calculation method.

4.1.2. Output Indicators

The output indicators were determined according to the volume of output and the development space. The three selected output indicators were the volume of freight (billion tons); the volume of cargo turnover (billion tons); and the gross output of the transportation, storage, post, and telecommunications industries (billion Yuan).

4.1.3. Environment Variables

Environmental variables were primarily evaluated in terms of regional economic level, government support, level of science and technology, and consumption capacity. Regional economic development, national and local government support, scientific and technological investment and popularization, and regional consumption capacity all play a role in the development of the logistics industry. Our study's four environmental variables were as follows: First, the gross product (billion Yuan) of each province in the northwest region, which indicates the capacity for regional economic development. Second, the ratio of fixed-asset investment in the logistics industry to total social fixed-asset investment, which indicates the government's estimation of and support for the logistics industry. Third, the ratio of information transmission, software, and information technology service industry fixed-asset investment to total society fixed-asset investment, indicating the impact of science and technology on the logistics industry. Fourth, residents' per capita consumption expenditure (in billion Yuan), indicating the impact of the regional consumption capacity.

4.2. Sources of Data

The data in this paper were obtained from the National and Provincial Statistical Yearbooks, and the time period ranged from 2010 to 2019. The year 2010 was chosen because, in the decade of development following the adoption of the Western Development policy in 2000, Northwest China's economic growth, logistics infrastructure, and freight volume had achieved some remarkable results. Meanwhile, under the "One Belt, One Road" initiative, the northwest region's international exchange and cooperation, foreign investment, international logistics corridor construction, and freight volume improved further in 2015. As a result, the time period 2010–2019 was chosen to reflect the rapid development of the logistics industry in Northwest China following the Western Development program and the Belt and Road Initiative.

5. Results of Empirical Analysis

5.1. Isotropy Test

The input and output indicators selected in this paper had to satisfy the requirement of homoscedasticity, that is, an increase in input necessarily increases the output. This study used SPSS20.0 software to test for homoscedasticity with Pearson correlation coefficient. The results showed that the input and output variables were positively correlated, with 1 or 5% significance. Therefore, the selected indicators are reasonable, as shown in Table 1.

Table 1. Pearson correlation coefficients of green logistics evaluation indicators in Northwest China.

Input Variables / Output Variables	Total Fixed-Asset Investment	Number of Employees	Transportation Network Density	Carbon Emissions
Cargo volume	0.979 * (0.021)	0.951 * (0.049)	0.594 * (0.406)	0.985 * (0.015)
Cargo turnover	0.896 * (0.0104)	0.928 (0.072)	0.296 (0.704)	0.955 * (0.045)
Gross value of logistics	0.992 ** (0.008)	1.000 ** (0.001)	0.332 (0.668)	0.979 * (0.021)

* Significant at 5% level; ** significant at 1% level.

5.2. Green Logistics Efficiency Measurement in Northwest China

5.2.1. Phase I of Super-Efficiency DEA Empirical Results Analysis

Using DEAP 2.1 software, the green logistics efficiency in Northwest China from 2010 to 2019 was evaluated without eliminating the effects of random errors and environmental factors, and the results are shown in Table 2.

Table 2. Efficiency values of the first phase of green logistics analysis in Northwest China by province, 2010–2019.

Province	Efficiency Value	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Average
Shaanxi	TE	0.832	0.900	1.100	0.945	1.233	0.925	0.944	0.971	1.092	1.025	0.997
	PE	0.838	0.903	1.269	0.957	1.519	0.929	0.946	0.971	1.000	1.000	1.033
	SE	0.992	0.996	0.867	0.988	0.812	0.996	0.998	1.000	1.092	1.025	0.977
Gansu	TE	1.036	1.035	1.150	0.988	0.957	0.907	0.909	0.978	1.052	0.957	0.997
	PE	1.063	1.045	1.334	0.990	1.025	0.915	0.920	0.981	1.070	0.958	1.030
	SE	0.975	0.990	0.862	0.998	0.934	0.991	0.988	0.996	0.984	0.999	0.972
Qinghai	TE	0.793	0.822	0.828	0.724	0.758	0.689	0.680	0.672	0.717	0.561	0.724
	PE	1.111	1.113	1.049	0.935	0.941	0.914	0.902	0.863	0.925	0.802	0.955
	SE	0.713	0.738	0.790	0.774	0.806	0.754	0.754	0.779	0.775	0.700	0.758
Ningxia	TE	0.970	1.012	1.104	0.919	1.014	1.023	1.045	0.947	0.857	0.953	0.984
	PE	1.098	1.088	1.233	0.926	1.033	1.024	1.063	0.951	0.859	0.962	1.024
	SE	0.883	0.931	0.895	0.992	0.982	0.998	0.983	0.995	0.998	0.992	0.965
Xinjiang	TE	0.911	1.017	1.052	0.973	0.961	0.805	0.800	0.911	1.026	0.997	0.945
	PE	1.011	1.049	1.053	0.977	0.983	0.959	0.948	0.982	1.158	1.191	1.031
	SE	0.901	0.970	0.999	0.996	0.978	0.840	0.844	0.928	0.886	0.837	0.918
Mean value	TE	0.908	0.957	1.047	0.910	0.985	0.870	0.876	0.896	0.949	0.899	0.930
	PE	1.024	1.040	1.188	0.957	1.100	0.948	0.956	0.950	1.002	0.983	1.015
	SE	0.893	0.925	0.883	0.950	0.902	0.916	0.913	0.940	0.947	0.910	0.918

During the 10-year period of 2010–2019, the mean value of the comprehensive technical efficiency of the logistics industry in Northwest China was between 0.870 and 1.047, and the scale efficiency was between 0.883 and 0.950. The overall levels of comprehensive technical efficiency and scale efficiency were high and showed a fluctuating upward trend, but the pure technical efficiency showed a decreasing trend. Overall, the average value of the pure technical efficiency of the logistics industry in Northwest China from 2010–2019 was 1.015. In terms of individual years, the pure technical efficiency in 2011, 2012, 2014, and 2018 was greater than 1. The average value of the scale efficiency of the logistics industry in Northwest China from 2010–2019 was smaller than the comprehensive technical efficiency. Although the scale efficiency has been improving, it is still the main constraint for improving comprehensive technical efficiency.

Shaanxi and Gansu both had an overall technical efficiency of 0.997, placing them first in the northwest region. Ningxia and Xinjiang were in the second tier, with 0.984 and 0.945, respectively, whereas Qinghai had a comprehensive technical efficiency of 0.724, which is relatively low in terms of overall efficiency. The pure technical efficiencies of Shaanxi, Gansu, Ningxia, and Xinjiang all exceeded one. Qinghai's was 0.955, which is very close to 1, indicating that all five provinces in the northwest region had high pure technical efficiency. Shaanxi and Gansu had high scale efficiency, while Ningxia and Xinjiang had medium and Qinghai's was 0.758, indicating that scale efficiency is the main constraint limiting the logistics industry's overall technical efficiency in Northwest China.

Qinghai province has a complex topography and diverse landscapes, with an average altitude of more than 3000 m and 80% of its area more than 3000 m above sea level. The transportation infrastructure network system is imperfect, the industrial and economic development is relatively weak, and the GDP for the relevant 10 consecutive years was the lowest in the northwest region. However, Qinghai is rich in natural resources such as minerals and land and has a lot of room for future development. Qinghai should seize the opportunities of "One Belt and One Road" construction, strengthen its logistics infrastructure investment and interconnection, optimize the industrial layout, actively integrate into the construction of the "Silk Road Economic Belt" core area, and improve the efficiency of its logistics scale to further enhance its comprehensive logistics efficiency.

Over time, the overall technical efficiency, pure technical efficiency, and scale efficiency of the logistics industry in each province all increased. Among them, Shaanxi's efficiency increased the most, owing primarily to Shaanxi's significant location advantages, which actively promote the "Belt and Road" core area; the construction of a comprehensive transportation hub; and the construction of a green, efficient, and convenient modern logistics service system. The year 2015 was noteworthy for the northwest region as a whole; the overall and provincial logistics industry pure technical efficiency and scale efficiency significantly decreased, reaching the lowest point in ten years. The three major efficiency measures showed a gradual upward trend in 2017 with the integration of provinces into the "Silk Road Economic Belt" and the effects of synergistic development.

5.2.2. Phase II SFA Regression Results

The results of the second-stage SFA regression are shown in Table 3.

Table 3. SFA regression of logistics efficiency in Northwest China, 2010–2019.

Item	Total Fixed-Asset Investment in Logistics Industry Slack Variable	Slack Variable for the Number of Employees in the Logistics Industry	Traffic Network Density Slack Variable	Carbon Emission Slack Variable
Constant term	360.000 ***	1.700 *	0.0397	17.900
	(4.340)	(1.680)	(1.230)	(0.166)
Regional GDP	0.003	0.001	0.001 ***	0.007 **
	(−0.793)	(−0.370)	(2.930)	(2.350)
Government support	−4830.000 ***	−8.050 ***	−0.003	−1280.00 ***
	(−494.000)	(−8.050)	(−0.013)	(−178.000)
Technology level	13.200 ***	4.150 ***	0.0529	449.000 ***
	(10.800)	(4.150)	(0.0359)	(328.000)
Regional consumer expenditures	−0.001	−0.001 *	−0.001 **	−0.001
	(−0.004)	(1.570)	(−2.080)	(−2.130)
δ^2	313.00 ***	3.522 ***	0.016 ***	460.600 ***
	(232.000)	(4.330)	(4.160)	(390.000)
γ	0.801 *	0.701 ***	0.614 *	0.501 **
	(0.802)	(0.712)	(0.697)	(0.551)
LR	75.402	19.005	2.18	2.18

***, **, and * denote significance at the 1%, 5%, and 10% level, respectively.

As seen in Table 3, the overall γ value of the input index was close to 1 and significantly valid at 10%, indicating that the external environmental variables had a significant effect on the input slack variables of the efficiency of the logistics industry in the northwest region; thus, it was necessary to adopt the SFA method. The regression coefficients of the gross regional product and the science and technology level on the input slack variables were positive, that is, an improvement in the economic and science and technology level would increase the investment in fixed assets in the logistics industry, the density of the transportation network, the scale and capacity of logistics operations, the number of logistics employees, and the energy consumption and carbon emissions.

Thus, as regional GDP and technology levels rise, the logistics industry expands rapidly, resulting in input redundancy, but the regression coefficient of the regional GDP slack variable approaches zero, indicating a limited impact. The regression coefficients of government support and consumption level on the input slack variables were less than zero, and the effects of government support on total investment in fixed assets, the number of logistics industry employees, and carbon emissions were significant at the 1% level, indicating that an increase in government support will reduce input waste or increase output. Government participation can reduce excessive carbon emissions in the logistics industry and provide support for development. An increase in the regional consumption level does not result in input redundancy in Northwest China's logistics industry, but the regression coefficient is close to zero, indicating that it has little effect on the efficiency of the industry.

5.2.3. Phase III Adjusted Super-Efficiency DEA Analysis

The original output data and the adjusted input data were compiled, and after removing the influence of environmental factors and random variables, the super-efficiency DEA model was used to remeasure the efficiency of the logistics industry in Northwest China under the "double carbon" target.

As Table 4 shows, the differences between the results from before and after adjustment were large, and the three major efficiency values for the logistics industry in the northwest region and in each province and city were reduced to varying degrees. Overall, the comprehensive technical efficiency was reduced by 20%, the pure technical efficiency by 5.6%, and the scale efficiency by 15.8%; the decrease ratio of the scale efficiency was higher than that of the pure technical efficiency, which indicates that the efficiency of the logistics industry in the northwest is indeed affected by the environment. Therefore, the SFA method must be used to eliminate environmental factors and random interference.

Table 4. Comparison of the average value of efficiency before and after adjustment in Northwest China, 2010–2019.

Province	Efficiency Value	First-Stage Mean Value	Third-Stage Mean Value	Difference
Shaanxi	TE	0.997	0.946	−0.051
	PE	1.033	0.981	−0.052
	SE	0.977	0.972	−0.005
Gansu	TE	0.997	0.897	−0.100
	PE	1.030	0.944	−0.086
	SE	0.972	0.950	−0.022
Qinghai	TE	0.724	0.320	−0.404
	PE	0.955	0.929	−0.026
	SE	0.758	0.345	−0.413
Ningxia	TE	0.984	0.708	−0.276
	PE	1.024	0.987	−0.037
	SE	0.965	0.718	−0.247
Xinjiang	TE	0.945	0.775	−0.170
	PE	1.031	0.950	−0.081
	SE	0.918	0.816	−0.102
Mean value	TE	0.929	0.729	−0.200
	PE	1.015	0.958	−0.056
	SE	0.918	0.760	−0.158

From a spatial standpoint, the adjusted decline in the pure technical efficiency of the five provinces in Northwest China was small and remained at a high level before and after adjustment, indicating that logistics enterprises in Northwest China have a high management level. In terms of overall technical efficiency, the decline was greater in Qinghai and Ningxia, which were down by 0.404 and 0.276 points, respectively; followed by Xinjiang and Gansu, which were down by 0.170 and 0.100 points, respectively; and Shaanxi, which was down by only 0.05 points. In terms of scale efficiency, Qinghai fell the most (−0.413), followed by Ningxia (−0.247), Gansu (−0.022), Xinjiang (−0.0102), and Shaanxi (−0.005).

Environmental variables had a certain impact on all three logistics efficiency measures in Northwest China (affecting scale efficiency the most). The exclusion of these variables would make the logistics efficiency measurements more realistic and effective; otherwise, the values of the logistics efficiency in Northwest China would be overestimated. Moreover, there is still room for improvement regarding logistics efficiency, and increasing scale efficiency is the focus.

6. Discussion

Our study used the SFA method to adjust the input variables, eliminating environmental factors and random interference, making the efficiency evaluation more realistic and effective.

First, in terms of logistics efficiency, the comprehensive technical efficiency of the green logistics industry in Northwest China showed a fluctuating upward trend from 2010 to 2019, and the low scale efficiency was the main reason for the low comprehensive technical efficiency. From a spatial viewpoint, the pure technical efficiency of the northwest region was high, but the comprehensive technical efficiency was highest in Shaanxi and Gansu, followed by Ningxia and Xinjiang, and lower in Qinghai. This phenomenon is due to Qinghai's complex topography and diverse landscapes, with more than 80% of its area over 3000 m above sea level, as well as its imperfect transportation infrastructure network system. To solve this shortcoming, Qinghai province needs to strengthen its internal connectivity and external expansion, fully integrate into the construction of the "Silk Road Economic Belt", and optimize its industrial layout. Qinghai province had the lowest GDP in Northwest China for the 10-year study period, and there is much room for future development.

From a temporal perspective, the efficiency of Shaanxi increased significantly from 2010 to 2019, due to its significant location advantages, which actively promote the construction of the "Belt and Road" core area, accelerating the construction of a comprehensive transportation hub and the building of a green, efficient, and convenient modern logistics service system. The year 2015 was notable: the logistics efficiency and scale efficiency of the northwest region significantly decreased. This was the lowest inflection point over the 10 years and arose because the northwest region began building the Silk Road together. The provinces kept increasing their investment in transportation infrastructure construction, but the output of the logistics industry has a lag; therefore, the output values such as freight volume and gross product were not improved in that year, showing a temporary inefficiency. However, with the promotion of the construction of the Silk Road Economic Belt, the development of the logistics industry in the northwest region has demonstrated a synergistic effect, and the three major efficiency measures have shown a gradual increase since 2017.

Second, in terms of environmental factors, the regional economic level positively influences the efficiency of the logistics industry in Northwest China. However, the current impact is limited. Government support can increase the output with constant logistics inputs and reduce input redundancy with certain outputs, indicating that the government plays an important policy support and promotion role in the logistics industry in terms of regional synergistic development, infrastructure construction, and low-carbon green development. A high level of science and technology can promote the use and popularity of technological innovation in the logistics industry, increasing the output under the same input, thus improving the logistics efficiency. However, too much technology input will cause an input redundancy or energy waste. Regional consumer spending can reduce redundancy and enhance logistics output, thus improving logistics efficiency, but the impact is limited.

Third, the external environment has a significant impact on the northwest region's logistics efficiency. Because of the removal of environmental factors and random interference, the three major efficiency measures in Northwest China and its provinces decreased to varying degrees. The region's logistics efficiency is clearly influenced by the economic environment. The logistics efficiency was overestimated before the adjustment and was more realistic and effective after the adjustment, indicating that there is still more room to improve the logistics efficiency in Northwest China, and that enhancing the scale efficiency is the key.

7. Implications for Practice

The study makes the following recommendations based on an analysis of the empirical results.

First, provincial coordination should be strengthened, and a green logistics network system should be established in the northwest. According to the findings of the study, the development of the green logistics industry in the northwest region is uneven. Provinces should improve regional cooperation, speed up the optimization and upgrading of the transportation infrastructure network node layout, and build a green logistics network system. They should also increase the level of the green supply chain in Northwest China by deepening supply-side reforms and promoting the domestic and international cycle. In the construction and development of the "One Belt and One Road" logistics industry, each province should maximize its own advantages, find the right strategy, strengthen interconnection, build an efficient logistics network system, save energy, reduce emissions, and promote the achievement of the "double carbon" goal.

Second, to reduce costs and increase efficiency, government functions should be given full play based on the goal of reducing carbon emissions and achieving carbon neutrality. According to research, government support [46] is critical in guiding and promoting the efficiency of the northwest region's green logistics industry. Each province should develop policies and measures to guide and encourage green logistics development, regulate market order and business behavior, and continuously improve laws and regulations related to the green logistics industry; for example, by developing policies pertaining to carbon emission standards, emission reduction, vehicle emission regulation, and logistics route optimization for green logistics requirements. Furthermore, provincial governments should plan the construction of green logistics [47], green storage [48], and other transportation infrastructure and logistics parks; avoid duplicate construction; strengthen cooperation to allocate logistics resources more efficiently; reduce congestion and transportation waste [49]; and improve the efficiency of transportation and distribution services [50] with a limited amount of input.

8. Conclusions

This paper develops an index system for green logistics efficiency in Northwest China, employing a super-efficiency three-stage DEA model to assess the efficiency of China's green logistics industry after accounting for carbon emissions. Based on the general context of China's implementation of the "double carbon" strategy, the findings provide implications and suggestions for the high-quality development of a green logistics industry in Northwest China.

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