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Original Research

Research on Comprehensive Performance Evaluation of High-Quality Development of China Provincial Manufacturing Industry Based on Low-Carbon Constraints

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Abstract

In order to explore an effective way to evaluate the comprehensive performance of high-quality development of China's manufacturing industry based on low-carbon constraints, this paper, based on the analysis of research background, drew on the latest domestic and international research results and experience, and fully considered the actual situation of high-quality development of China's manufacturing industry based on low-carbon constraints. Among the five criteria-layer evaluation index of economic development, energy consumption, technological innovation, environmental pressure and environmental pollution governance, 30 representative operating-layer evaluation indicators were selected, and a fuzzy matter-element extension evaluation model for the comprehensive performance evaluation of China's provincial high-quality development based on low-carbon constraints was constructed. By using the relevant statistical data in China Statistical Yearbook, China Energy Statistical Yearbook and China Environmental Status Bulletin, this paper conducted an evaluation study on the comprehensive performance of high-quality development of China's manufacturing industry based on low-carbon constraints in 31 provinces, verified the effectiveness of the fuzzy matter-element extension evaluation model, and provided an effective quantitative analysis method for the comprehensive performance evaluation of high-quality development of China's manufacturing industry based on low-carbon constraints.

Keywords: performance evaluation, high-quality development, fuzzy matter-element extension model, low-carbon, manufacturing industry

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Introduction

With the rapid growth of China's economy, China's manufacturing industry is constantly increasing its industrial added value, and at the same time, it is also constantly creating and deepening China's environmental pollution due to large-scale energy consumption [1]. According to the statistics of the China Statistical Yearbook, China's GDP in 2021 reached 114.37 trillion CNY (Chinese yuan), ranking second in the world, of which the industrial added value was 37.26 trillion CNY, ranking first in the world. In the same year, China's total energy consumption was 5.24 billion tons of standard coal, an increase of 5.2% over the previous year; China's CO_2 emissions were 10.52 billion tons, ranking first in the world, and its per capita CO_2 emissions were 8.4 tons, also ranking first in the world. It is estimated that by the end of 2022, China's CO_2 emissions will reach 12.80 billion tons, and its per capita CO_2 emissions will reach 9.10 tons, still ranking first in the world [2, 3]. Therefore, the task of the Chinese government to achieve the "double carbon" goal (peak CO_2 emissions and carbon neutrality) is still very difficult. According to the relevant statistics of the World Environment Organization and the Chinese government, China's CO_2 emissions account for about 47% of the world's CO_2 emissions, and China's industrial CO_2 emissions account for about 40% of China's total CO_2 emissions. It can be seen that industry is also a major contributor to China's CO_2 emissions [4, 5]. Therefore, in this case, studying the effective method of comprehensive performance evaluation of high-quality development of China's manufacturing industry based on low-carbon constraints is an important means to promote energy conservation and emission reduction of China's manufacturing industry. It is particularly important and urgent to study the comprehensive evaluation method and its application of high-quality development performance of manufacturing industry based on low-carbon constraints suitable for China's national conditions.

The research on the evaluation of high-quality development started in developed countries at the earliest. American scholars began to study the evaluation technology of urban residential environment quality in the mid-forties of the last century to explore effective ways for high-quality urban development [6, 7]. However, the performance evaluation of high-quality development of provincial manufacturing industry based on low-carbon constraints is a research topic with Chinese characteristics. The research of other countries outside China is not deep enough and the scope is relatively small. Many countries have only done some exploratory research on the evaluation of sustainable development at the urban level and below [8, 9]. In terms of research on evaluation of high-quality urban development: Dae-Sik took Seoul, South Korea as an example to conduct evaluation methods and simulation research on the effect of urban green space policy [10]; Taking two cities in Iran as examples, Bikdeli studied the evaluation method of urban sustainable development and its application by combining AHP analysis with compaction index [11]; Zinia and McShane studied the evaluation of green ecological service effect of urban development in Dhaka, Bangladesh [12]; Pablo et al. studied the urban green space quality evaluation tool and evaluated the quality of 149 urban green spaces in Barcelona, Spain; Moazzen et al. studied the effect of energy consumption on urban sustainable development in the urban planning of Tehran [13]; Prasad et al. used modern evaluation techniques to evaluate the effect of sustainable development in urban areas of India [14]. The research on high-quality development in China began in the 1970s, and the early research was mainly to solve the problem of high-quality development evaluation of projects, enterprises and local areas [15-17]. The 19th Congress of the Communist Party of China in 2017 formally raised the issue of high-quality development, which opened the prelude to the research on comprehensive performance evaluation of high-quality development of China's manufacturing industry based on low-carbon constraints [18]. In 2020, the Chinese government promised the world to achieve the "double carbon" goal, and Chinese scholars began to conduct in-depth research on the low-carbon development of manufacturing industry [19, 20], the research of Chinese scholars on the high-quality development of China's manufacturing industry began in 2018 [21], they began to study the performance evaluation of high-quality development of manufacturing industry in 2019 [22, 23], and they were gradually conducting extended research, adding low-carbon constraints on the basis of the research on the high-quality development of China's manufacturing industry [24, 25], Chinese scholars have not yet conducted research on the comprehensive performance evaluation of high-quality development of China's manufacturing industry based on low-carbon constraints.

From the above literature review, it can be clearly seen that the comprehensive performance evaluation of high-quality development of China's manufacturing industry based on low-carbon constraints is an important research topic with Chinese characteristics, which can be used for reference by countries around the world. At present, the academic research on this topic is not deep enough, especially the current research of scholars divides the low-carbon development and high-quality development of China's manufacturing industry into two parts for research. In fact, the low-carbon development and the high-quality development of China's manufacturing industry are inseparable whole. If there is no emission of energy consumption, there will be no concept of high-quality development, and the implementation of high-quality development performance evaluation of China's manufacturing industry will certainly promote energy conservation and emission reduction of China's manufacturing industry. Therefore, the topic of this paper is very important, solving this topic is of great significance for China to save energy and reduce emissions, to achieve the "double carbon" goal and to promote the overall high-quality development of China's manufacturing industry.

Materials and Methods

Material Source and Data Collection

The manufacturing industry refers to the industry that converts manufacturing resources, including materials, energy, equipment, tools, capital, technology, information and human resources, into industrial products and consumer goods that can be used and utilized by people through the manufacturing process according to market requirements. It is the sum of the remaining sub-industries after deducting the extractive industries and public utilities from industry. Manufacturing industry is the main body of industry, with the characteristics of high energy consumption and high emissions. It is also a key industry of energy conservation and emission reduction in China [26]. In order to effectively evaluate the comprehensive performance of high-quality development of China's manufacturing industry based on low-carbon constraints, the data are derived from China Statistical Yearbook, China Energy Statistical Yearbook, China Environmental Status Bulletin and the corresponding yearbooks and bulletins of provinces, municipalities and autonomous regions in China. Since the Chinese government began to compile and publish data on environmental pollution in 2013 [27], considering the comparability and effectiveness of the statistics data, the data period selected in this paper is from 2013 to 2020; Considering that the statistics of Taiwan, Hong Kong and Macao in the Chinese government statistics are incomplete, the research object of this paper selected 31 provincial manufacturing industries with comparable statistics. In order to improve the accuracy of research data, the authors not only obtained statistical data from the government, but also collected comprehensive information in various ways through questionnaire, interview, online search, email and WeChat. On the basis of the data obtained, the authors comprehensively analyzed the data using statistical analysis methods and financial analysis methods, which not only clarified the rules of the data, but also, more importantly, clarified the influencing factors and future trends of the data, making a good preparation for the research of this topic.

Selection of Evaluation Index and Construction of Evaluation Indicator System

In order to improve the effectiveness of the comprehensive performance evaluation of high-quality development of China's provincial manufacturing industry based on low-carbon constraints, this paper, based on the characteristics and actual situation of China's provincial manufacturing industry, comprehensively considered the comprehensive performance evaluation indicators of high-quality development in five aspects of economic development, energy consumption, technological innovation, environmental pressure and environmental pollution governance of the manufacturing industry, 30 specific evaluation indicators were selected to build a comprehensive performance evaluation indicator system for high-quality development of China's provincial manufacturing industry based on low-carbon constraints. See Table 1 for details.

As the manufacturing industry is spread all over China, it is impossible to separate specific areas of manufacturing industry. Therefore, the average value of each prefecture-level city within provinces was used for each evaluation indicator, and the statistical data of the province was used where all prefecture-level cities cannot be obtained for calculation. The meaning and calculation requirements of each indicator in the above table are: X_{11} is the gross output value per capita of the manufacturing industry of each province, X_{12} is the proportion of the total output value of the manufacturing industry to the provincial GDP, X_{13} is the ratio of the total fixed assets of the manufacturing industry to the number of people registered at the end of the period with the same caliber, X_{14} is the ratio of the total operating income of the provincial manufacturing industry to the corresponding total net profit, X_{15} is the ratio of the sum of the annual taxes and profits of the manufacturing industry to the number of people registered at the end of the period with the same caliber, X_{16} is the ratio of the total net profit of the manufacturing industry in the accounting year to the total investment in the same period, X_{17} is the average disposable income of the number of registered people at the end of the period, and X_{18} is the ratio of the added value created by foreign-funded enterprises in the manufacturing industry to the total output value of the provincial manufacturing industry; X_{21} is the ratio of the total CO_2 emissions of energy consumption in manufacturing industry to the number of registered people at the end of the period with the same caliber, X_{22} is the ratio of the total annual energy consumption of the manufacturing industry to the number of people registered at the end of the period, X_{23} is the ratio of the total annual coal consumption to the total energy consumption in manufacturing industry, X_{24} is the ratio of the annual total energy consumption of the manufacturing industry to the provincial GDP, and X_{25} is the reduction rate of the annual energy consumption intensity of the manufacturing industry; X_{31} is the ratio of total technology R&D investment amount in the manufacturing industry to the total output value, X_{32} is the number of technicians (including R&D personnel) invested in the manufacturing industry per 10000 CNY to total output value, X_{33} is the ratio of investment amount in technological transformation in manufacturing industry to total output value, X_{34} is the ratio of the output value of relevant technologies

Table 1. Comprehensive performance evaluation indicator system for high-quality development of China's provincial manufacturing industry based on low-carbon constraints.

Target	Criteria-Layer	Operating-Layer	Unit	Properties
Research on comprehensive performance evaluation of high-quality development of Chinese provincial MI based on low-carbon constraints	Comprehensive performance indicators of economic development for high-quality development of MI (X_1)	Per capita gross output value of MI (X_{11})	10000CNY/person	Forward indicator
		Proportion of total output value in provincial GDP (X_{12})	%	Forward indicator
		Investment amount in fixed assets per capita (X_{13})	10000CNY/person	Forward indicator
		Profit margin of total revenue of MI (X_{14})	%	Forward indicator
		Net profit and tax per capita of MI (X_{15})	10000CNY/person	Forward indicator
		Total investment profit rate of MI (X_{16})	%	Forward indicator
		Per capita disposable income of MI (X_{17})	10000CNY	Forward indicator
		The openness degree to outside world of MI (X_{18})	%	Forward indicator
	Comprehensive performance indicators of energy consumption for high-quality development of MI (X_2)	Number of CO_2 emissions per capita for MI EC (X_{21})	Tons SC/ person	Contrary indicator
		Per capita energy consumption of MI (X_{22})	Tons/ person	Contrary indicator
		Proportion of coal energy consumption in MI (X_{23})	%	Contrary indicator
		Energy consumption intensity of MI (X_{24})	Ton/ 10000CNY	Contrary indicator
		Energy consumption intensity reduction rate (X_{25})	%	Forward indicator
	Comprehensive performance indicators of technological innovation for high-quality development of MI (X_3)	Input intensity of MI technology R&D (X_{31})	CNY/ / 10000CNY	Forward indicator
		Input intensity of MI researchers (X_{32})	Person / 110000CNY	Forward indicator
		Investment density of MI technological transformation (X_{33})	%	Forward indicator
		CR of MI's technological innovation output value (X_{34})	%	Forward indicator
		Growth rate of technology R&D investment of MI (X_{35})	%	Forward indicator
	Comprehensive performance indicators of environmental pressure for high-quality development of MI (X_4)	Exhaust emission intensity of MI (X_{41})	M^3/10000 CNY	Contrary indicator
		Effluent discharge intensity of MI (X_{42})	Tons/10000 CNY	Contrary indicator
		Waste residue discharge intensity of MI (X_{43})	Tons/10000 CNY	Contrary indicator
		Average pollution index of three waste of MI (X_{44})	Index	Contrary indicator
		Noise pollution index of MI (X_{45})	Index	Contrary indicator
		Comprehensive pollution index of MI (X_{46})	Index	Contrary indicator
	Comprehensive performance indicators of EPG for high-quality development of MI (X_5)	Per capita investment amount in EPG of MI (X_{51})	CNY / person	Forward indicator
		Investment intensity of MI in EPG (X_{52})	%	Forward indicator
		Air pollution governance compliance rate of MI (X_{53})	%	Forward indicator
		Water pollution governance compliance rate of MI (X_{54})	%	Forward indicator
		Land pollution governance compliance rate of MI (X_{55})	%	Forward indicator
		Ecological environment index of MI (X_{56})	Index	Forward indicator

MI: manufacturing industry; SC: standard coal; CR: contribution rate; EPG: environmental pollution governance

increased by new products, new processes and new technologies to the total output value of the manufacturing industry, X_{35} is the annual growth rate of total investment related to technological progress and innovation in the manufacturing industry; X_{41} is the ratio of total waste gas emissions from manufacturing industry to total output value, X_{42} is the ratio of total waste water discharge from manufacturing industry to total output value, X_{43} is the ratio of total waste residue discharge from manufacturing industry to total output value, X_{44} is the average value of pollution index of waste gas, waste water and soil, X_{45} is the average value of the noise pollution index of the manufacturing industry, which is the average value of the prefecture-level cities in this paper, X_{46} is the provincial comprehensive pollution index; X_{51} is the ratio of the total annual investment amount in environmental pollution governance of the manufacturing industry to the number of people registered at the end of the period, X_{52} is the ratio of the annual total investment amount in environmental pollution governance to the total output value of the manufacturing industry, X_{53}, X_{54} and X_{55} are ratios of reaching the standard of environmental pollution governance of "Three wastes" (waste gas, waste water and waste residue) in the manufacturing industry, which is the average value of prefecture-level cities in this paper, X_{56} is the ecological environment index, which is calculated by the government statistics department.

Construction of Comprehensive Performance Evaluation Model for High-Quality Development of Manufacturing Industry

Because the membership of the above 30 evaluation indicators for the comprehensive performance of high-quality development of China's manufacturing industry, as well as the multi-indicator evaluation results of the comprehensive performance of high-quality development of manufacturing industry in 31 provinces, all have obvious fuzzy attribute characteristics. Therefore, this paper chose the fuzzy matter-element extension model for evaluation research [28]. According to the extension evaluation theory of fuzzy matter-element, if the comprehensive performance evaluation indicators of high-quality development of provincial manufacturing industry are X_i, the evaluation indicators' value is V_{ij}, then the fuzzy extension matter-element can be recorded as: $R = (n, X, Y)$. If the evaluation indicators' value constitutes an n-dimensional fuzzy matter-element matrix, the comprehensive performance evaluation result of high-quality development of China's provincial manufacturing industry can be expressed as follows:

$$R_{\mathrm{ij}} = \begin{pmatrix} & \mathrm{N}_1 & \mathrm{N}_2 & \cdots & N_{\mathrm{m}} \\ X_1 & V_{11} & V_{21} & \cdots & V_{m1} \\ X_2 & V_{12} & V_{22} & \cdots & V_{m2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ X_{\mathrm{j}} & V_{1n} & V_{2n} & \cdots & V_{mn} \end{pmatrix} \tag{1}$$

In formula (1): N_i (i = 1, 2,..., m) are evaluation objects, X_j (j = 1, 2,..., n) are evaluation indicators, V_{ij} is the quantity value of the i_{th} evaluation item and the j_{th} evaluation indicator, S_{ik} is the boundary value of the k_{th} evaluation level where the maximum value of the i_{th} evaluation indicator located. When the maximum value of the evaluation standard tends to infinity, the maximum value is selected as a certain multiple of the boundary value of the maximum value of the evaluation indicator of the evaluation standard level. If u_{ij} represents the dimensionless result of the i_{th} evaluation item and the j_{th} contrary evaluation indicator, u'_{ij} represents the dimensionless result of the i_{th} evaluation item and j_{th} forward evaluation indicator, the dimensionless calculation formula of the evaluation indicators is as follows:

$$\begin{cases} u_{ij} = \left(\max\left(S_{ik}\right) - V_{ij}\right)\cdot\left(\max\left(S_{ik}\right) - \min\left(S_{ik}\right)\right)^{-1} \\ u'_{ij} = 1 - \left(\max\left(S_{ik}\right) - V_{ij}\right)\cdot\left(\max\left(S_{ik}\right) - \min\left(S_{ik}\right)\right)^{-1} \end{cases} \tag{2}$$

Use formula (2) to normalize the evaluation indicators value of the evaluation indicators matrix in formula (1), u_{ij} represents the dimensionless membership of the evaluation indicators, exist: $0 \leq u_{ij} \leq 1$; If R^u_{min} is used to represent the dimensionless preferential membership fuzzy matter element, then there is:

$$R^u_{mn} = \begin{pmatrix} & N_1 & N_2 & \cdots & N_m \\ X_1 & u_{11} & u_{21} & \cdots & u_{m1} \\ X_2 & u_{12} & u_{22} & \cdots & u_{m2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ X_n & u_{1n} & u_{2n} & \cdots & u_{mn} \end{pmatrix} \tag{3}$$

The relative weight value of the evaluation indicators reflects the important degree of the evaluation indicators in the evaluation indicator system. A variety of methods can be used to determine the relative weight value of the evaluation indicators, common methods are: analytic hierarchy process, entropy weight method, expert survey, etc. This paper used the importance degree proportion method to determine the relative weight value of the evaluation indicators. The meanings of the letters are the same as that set above, the formula for calculating the relative weight of the evaluation indicators can be expressed as follows:

$$\xi_{ij} = \left(u_{ij}/\max S_{ik}\right)\cdot\left(\sum_{j=1}^{n}\left(u_{ij}/\max S_{ik}\right)\right)^{-1} \tag{4}$$

According to the requirements of non-negativity and normalization of indicators' relative weights of comprehensive performance evaluation for high-quality development of China's provincial manufacturing industry, the relative weight value of the evaluation indicators has the following properties: $0 \leq \xi_{ij} \leq 1$, $\Sigma^n_{j=1} \xi_{ij} = 1$. If R_ξ is used to represent the weighted composite matter-element, then the relative weight matrix of the evaluation indicators can be expressed as follows:

$$R_\xi = \begin{pmatrix} & N_1 & N_2 & \cdots & N_m \\ X_1 & \xi_{11} & \xi_{21} & \cdots & \xi_{m1} \\ X_2 & \xi_{12} & \xi_{22} & \cdots & \xi_{m2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ X_n & \xi_{1n} & \xi_{2n} & \cdots & \xi_{mn} \end{pmatrix} \tag{5}$$

When the expert survey method is used to determine the relative weight value of the evaluation indicators, the column vector matrix of the evaluation indicators weight value is usually determined as: $(w_1, w_2, ..., w_n)^{-1}$, which can reduce the calculation workload of the relative weight value. If R_{0n} represents standard fuzzy matter-element, $u_{0j} = max\ (u_{1j}, u_{2j}, ..., u_{mj})$, u_{0j} is the maximum value of each line in formula (3) or the maximum value of evaluation criteria, then the fuzzy matter-element of comprehensive performance evaluation of high-quality development of China's manufacturing industry can be expressed as:

$$R_{0n} = \begin{pmatrix} & X_1 & X_2 & \cdots & X_N \\ N_0 & u_{01} & u_{02} & \cdots & u_{0n} \end{pmatrix}^T \tag{6}$$

The difference exponentiation is performed on the above preferential membership fuzzy matter-element R^u_{mn} and the corresponding items of standard fuzzy matter-element R_{0n}, the result of the difference exponentiation calculation is expressed by Δ_{ij}. The basic calculation formula is as follows:

$$\Delta_{ij} = \left| u_{oj} - u_{ij} \right|^P \tag{7}$$

Where P is an exponentiation sign, the result of the difference exponentiation is composed of Δ_{ij} to form the composite fuzzy matter-element R_Δ, the basic expression of the composite fuzzy matter-element model is as follows:

$$R_\Delta = \begin{pmatrix} & N_1 & N_2 & \cdots & N_m \\ X_1 & \Delta_{11} & \Delta_{21} & \cdots & \Delta_{m1} \\ X_2 & \Delta_{12} & \Delta_{22} & \cdots & \Delta_{m2} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ X_n & \Delta_{1n} & \Delta_{2n} & \cdots & \Delta_{mn} \end{pmatrix} \tag{8}$$

The Nearness Degree of the comprehensive performance evaluation indicators for the high-quality development of manufacturing industry in the j_{th} province is defined as ND_j. The closeness of the evaluation indicators to the evaluation object can be easily determined by using the difference exponentiation composite fuzzy matter-element R_Δ and the weighted composite matter-element R_ξ constructed above, then:

$$ND_j\ \Re\Re\Re\left(R_\xi \quad R_\Delta\right)^{1/P} \quad 1 \quad \left(\sum\nolimits_{j=1}^{n} \xi_{ij} \quad {}_{ij}\right)^{1/P} \tag{9}$$

In the above formula, selecting different P values, and the corresponding ND_j has different meanings. When P = 1, ND_j is called Hamming closeness. In this paper, P = 1 was selected, and the comprehensive performance of high-quality development of China's manufacturing industry is evaluated by the Hamming closeness of fuzzy matter-element extension method [29].

Determination of Comprehensive Performance Evaluation Criteria for High-Quality Development of Manufacturing Industry

In order to effectively evaluate the comprehensive performance of the high-quality development of China's manufacturing industry, after referring to relevant standards of the Chinese government and provincial governments on comprehensive performance evaluation of high-quality development, fully considering the actual situation of high-quality manufacturing in China, and learning from the latest research results in academia, the following two grades of evaluation criteria were determined:

(1) The standard of comprehensive performance evaluation indicators for high-quality development of China's manufacturing industry. Based on the analysis of the statistical data of the Chinese government and provincial governments, and in combination with the requirements of the comprehensive performance evaluation of the high-quality development of China's provincial manufacturing industry, the criteria for the 30 evaluation indicators were determined in Table 2.

(2) Evaluation criteria for comprehensive performance target-layer of high-quality development of China's manufacturing industry. This paper aims at the comprehensive performance evaluation of high-quality development of China's manufacturing industry based on low-carbon constraints, and uses the evaluation results calculated by the fuzzy matter-element extension model to determine the following comprehensive performance evaluation criteria for high-quality development of China's manufacturing industry: $ND_j \in [0.9, 1]$, the evaluation object is Level I, which belongs to the excellent grade of performance; $ND_j \in [0.8, 0.9)$, the evaluation object is Level II, which belongs to the good grade of performance; $ND_j \in [0.65, 0.8)$, the evaluation object is Level III, which belongs to the middle grade of performance; $ND_j \in [0.5, 0.65)$, the evaluation object is Level IV, which belongs to the lower grade of performance; $ND_j \in [0, 0.5)$, the evaluation object is Level V, which belongs to the inferior grade of performance [30].

Results and Discussion

Technical Processing of Basic Evaluation Data

The basic data for the comprehensive performance evaluation of the high-quality development of China's manufacturing industry are derived from the statistical yearbooks and relevant performance evaluation standards of the Chinese government and provincial governments. Due to the huge data scale, the basic data includes 31 evaluation objects and eight 31×30 dimensional matrices of 30 evaluation indicators. Data processing needs to be carried out by statistical software. The annual evaluation of the evaluation

Table 2. Five level criteria for comprehensive performance evaluation indicators of high-quality development of China's manufacturing industry.

Criteria-Layer	Operating-Layer	Comprehensive evaluation level criteria				
		Level I	Level II	Level III	Level IV	Level V
X_1	X_{11}	³20	16-20	12-16	8-12	<8
	X_{12}	³ 45	40-45	35-40	30-35	<30
	X_{13}	³12	9-12	7-9	5-7	<5
	X_{14}	³10	8-10	6-8	4-6	<4
	X_{15}	³2	1.5-2	1-1.5	0.5-1	< 0.5
	X_{16}	³8	6-8	4-6	2-4	<2
	X_{17}	³15	11-15	8-11	5-8	< 5
	X_{18}	³10	8-10	5-8	2-5	< 2
X_2	X_{21}	0-5	5-6	6-8	8-10	³10
	X_{22}	0-1	1-1.2	1.2-1.4	1.4-1.6	³ 1.6
	X_{23}	0-50	50-60	60-70	70-80	³80
	X_{24}	0-1.1	1.1-1.4	1.4-1.7	1.7-2.0	³2.0
	X_{25}	³5	3-5	1-3	0-1	< 0
X_3	X_{31}	³ 1	0.8-1	0.6-0.8	0.4-0.6	0-0.4
	X_{32}	³ 0.55	0.40-0.55	0.25-0.40	0.1-0.25	0-1
	X_{33}	³ 0.20	0.15-0.20	0.10-0.15	0.08-0.1	0-08
	X_{34}	³20	15-20	10-15	5-10	0-5
	X_{35}	³5	3-5	1-3	0-1	< 0
X_4	X_{41}	0-10000	10000-15000	15000-20000	20000-25000	³25000
	X_{42}	0-15	15-20	20-25	25-30	³30
	X_{43}	0-300	300-350	350-400	400-500	³
	X_{44}	0-70	70-150	150-200	200-300	>300
	X_{45}	0-70	70-150	150-200	200-300	>300
	X_{46}	0-70	70-150	150-200	200-300	>300
X_5	X_{51}	³ 5000	4000-5000	3000-4000	2000-3000	0-2000
	X_{52}	³ 3.0	2.5-3.0	2.0-2.5	1.5-2.0	0-1.5
	X_{53}	90-100	80-90	70-80	60-70	0-60
	X_{54}	90-100	80-90	70-80	60-70	0-60
	X_{55}	90-100	80-90	70-80	60-70	0-60
	X_{56}	³300	200-300	150-200	70-150	0-70

objects from 2013 to 2020 shall be repeated according to the following procedures:

(1) Basic data normalization process. Taking the provincial manufacturing industry as the evaluation object, 30 evaluation indicators were used to evaluate the comprehensive performance of the 31 evaluation objects. The basic data needs to be normalized using Formula (2). The maximum value was selected from the data in the evaluation criteria, and the membership of the evaluation indicators was transformed into the interval [0,1] through normalization calculation to form a membership matrix;

(2) Calculation of the relative weight matrix of the evaluation indicators. On the basis of the normalization of the basic data of the evaluation indicators, the data in the membership matrix was calculated using formula (4) to obtain the relative weight value of each evaluation

object corresponding to each evaluation indicator, forming a relative weight value matrix;

(3) Calculation of composite fuzzy matter-element. The composite fuzzy matter-element was calculated using formula (6-8) to form the composite fuzzy matter-element matrix, laying the foundation for the calculation of closeness;

(4) Calculation of the closeness of the fuzzy matter-element model. Using Formula (9) to calculate the closeness of the evaluation indicators as the annual evaluation result of the evaluation object, so as to determine the comprehensive performance of the evaluation object.

Comprehensive Performance Evaluation Results of High-Quality Development of China's Manufacturing Industry

By repeating the above evaluation process, the evaluation results of the comprehensive performance

Table 3. Comprehensive performance evaluation results of high-quality development of China's provincial manufacturing industry.

Province	2013	2014	2015	2016	2017	2018	2019	2020	Average	Ranking
Beijing	0.8604	0.8728	0.8816	0.8892	0.8946	0.9027	0.8986	0.9057	0.8882	2
Tianjin	0.8346	0.8428	0.8486	0.8538	0.8587	0.8628	0.8748	0.8804	0.8571	7
Hebei	0.7804	0.7879	0.7904	0.7943	0.8036	0.8052	0.8084	0.8176	0.7985	16
Shanxi	0.7726	0.7803	0.7884	0.7905	0.7983	0.8026	0.8068	0.8117	0.7939	17
Inner Mongolia	0.7638	0.7682	0.7717	0.7784	0.7817	0.7864	0.7905	0.7987	0.7799	20
Liaoning	0.7648	0.7705	0.7769	0.7816	0.7875	0.7927	0.7968	0.8027	0.7842	18
Jilin	0.7602	0.7726	0.7764	0.7802	0.7854	0.7894	0.7932	0.8005	0.7822	19
Heilongjiang	0.7436	0.7475	0.7517	0.7567	0.7628	0.7682	0.7738	0.7802	0.7606	23
Shanghai	0.8802	0.8895	0.8927	0.8986	0.9028	0.9049	0.9089	0.9158	0.8992	1
Jiangsu	0.8561	0.8582	0.8628	0.8686	0.8718	0.8836	0.8931	0.9036	0.8747	3
Zhejiang	0.8648	0.8579	0.8605	0.8668	0.8692	0.8758	0.9016	0.8946	0.8739	4
Anhui	0.8127	0.8204	0.8328	0.8379	0.8421	0.8495	0.8537	0.8589	0.8385	10
Fujian	0.8275	0.8308	0.8368	0.8406	0.8487	0.8526	0.8614	0.8695	0.8460	9
Jiangxi	0.7326	0.7361	0.7428	0.7484	0.7506	0.7562	0.7629	0.7701	0.7500	24
Shandong	0.8326	0.8386	0.8421	0.8476	0.8517	0.8585	0.8673	0.8793	0.8522	8
Henan	0.7902	0.7985	0.8018	0.8053	0.8138	0.8204	0.8286	0.8356	0.8118	14
Hubei	0.8103	0.8156	0.8189	0.8217	0.8256	0.8306	0.8354	0.8437	0.8252	12
Hunan	0.8047	0.8102	0.8176	0.8237	0.8302	0.8385	0.8438	0.8501	0.8274	11
Guangdong	0.8527	0.8584	0.8617	0.8656	0.8682	0.8693	0.8879	0.8904	0.8693	5
Guangxi	0.7502	0.7548	0.7606	0.7658	0.7703	0.7748	0.7806	0.7856	0.7678	22
Hainan	0.7528	0.7585	0.7627	0.7672	0.7768	0.7792	0.7839	0.7865	0.7710	21
Chongqing	0.8467	0.8516	0.8562	0.8593	0.8621	0.8672	0.8754	0.8879	0.8633	6
Sichuan	0.8056	0.8083	0.8139	0.8165	0.8194	0.8237	0.8286	0.8357	0.8190	13
Guizhou	0.7026	0.7085	0.7127	0.7203	0.7257	0.7305	0.7485	0.7527	0.7252	26
Yunnan	0.7217	0.7287	0.7363	0.7386	0.7427	0.7462	0.7528	0.7656	0.7416	25
Tibet	0.6216	0.6352	0.6426	0.6505	0.6616	0.6737	0.6854	0.6927	0.6579	31
Shaanxi	0.7886	0.7935	0.7963	0.8015	0.8042	0.8076	0.8158	0.8295	0.8046	15
Gansu	0.6752	0.6802	0.6872	0.6905	0.7037	0.7137	0.7247	0.7367	0.7015	28
Qinghai	0.6639	0.6735	0.6816	0.6875	0.6901	0.7032	0.7146	0.7246	0.6924	29
Ningxia	0.6442	0.6502	0.6636	0.6756	0.6863	0.6968	0.7128	0.7247	0.6818	30
Xinjiang	0.6867	0.6901	0.6952	0.7027	0.7128	0.7237	0.7376	0.7468	0.7120	27

of high-quality development of 31 provincial manufacturing industries from 2013 to 2020 can be easily obtained. The specific evaluation results are shown in Table 3.

According to the average value of eight years' average closeness from 2013 to 2020, the ranking of the comprehensive performance of high-quality development of China's manufacturing industry in 31 provinces is listed in the last column of Table 3. It can be seen that the comprehensive performance of high-quality development of the manufacturing industry in Shanghai ranks first. The top five provinces in the comprehensive performance of the manufacturing industry are Shanghai, Beijing, Jiangsu, Zhejiang and Guangdong. As the comprehensive performance evaluation of high-quality development of China's provincial manufacturing industry in this paper focuses on the economic development ability and environmental pollution governance effect, the evaluation results are consistent with the requirements of China's "double carbon" goal, which reflects the requirements of low-carbon constraints.

Discussion on the Composition and Trend of Comprehensive Performance Evaluation Results

This paper used the fuzzy matter-element extension model to evaluate the comprehensive performance of high-quality development of China's manufacturing industry, the evaluation period is 2013-2020. There are two methods to determine the comprehensive performance level of the evaluation object by using the evaluation results: One is to directly use the evaluation results and evaluation criteria of each year to determine the comprehensive performance level of the evaluation object. The other method is to determine the comprehensive performance level of the evaluation object by using the average value and evaluation criteria of eight years during the evaluation period. This paper chose the latter method mainly because this method considers a long evaluation period and overcomes the impact of short-term fluctuations in the evaluation results on the determination of the grade level of the evaluation object. In order to clearly reflect the composition and difference of the comprehensive performance evaluation results of high-quality development of China's provincial manufacturing industry, and to overcome the weakness of too many evaluation objects and relatively few evaluation results, the authors chose the method of radar chart to analyze the composition and difference of the evaluation results, and drew the radar chart using the average value of the eight years' evaluation results from 2013 to 2020. The specific contents of the radar chart are shown in Fig. 1.

It can be clearly seen from the above figure that the variation range of the comprehensive performance evaluation results of high-quality development of China's provincial manufacturing industry is from 0.6216 to 0.9158, the difference is 0.2942, and the difference rate is 47.33%. The overall difference is not too much. This is because China's provincial manufacturing industry enjoys a basically equal development environment and supportive policies given by the Chinese government, which reflects the superiority of the manufacturing industry in the economic development of socialist countries.

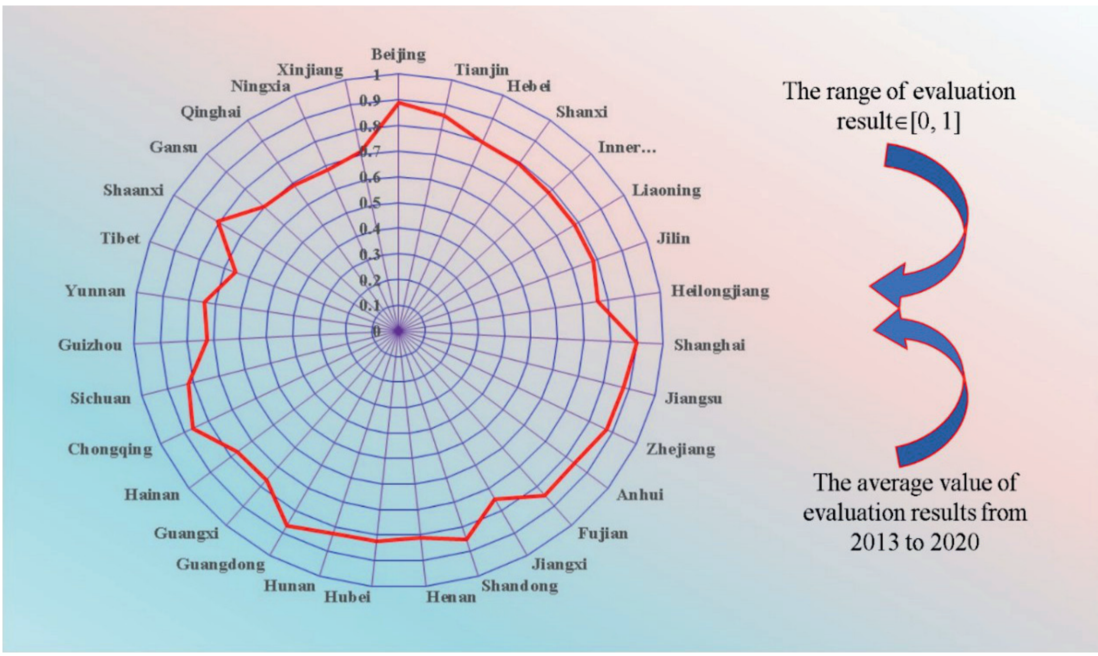

Fig. 1. Radar chart of comprehensive performance evaluation results of high-quality development of China's provincial manufacturing industry.

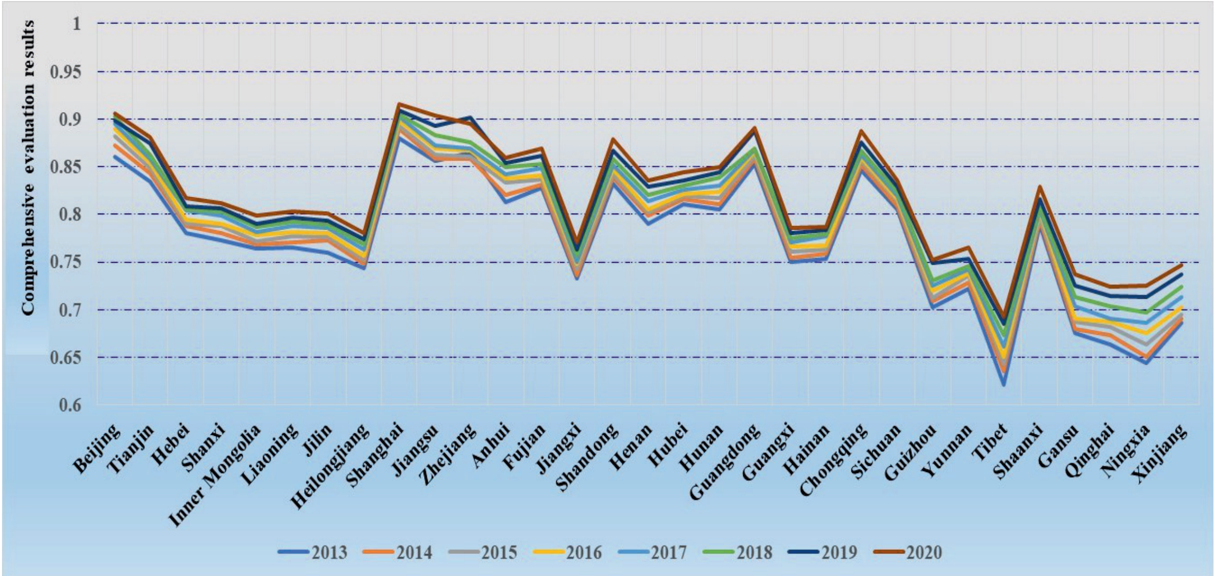

Fig. 2. Composition and trend chart of comprehensive performance evaluation results of high-quality development of China's provincial manufacturing industry.

Discussion on the Composition and Trend of Comprehensive Performance Evaluation Results

Because there are too many evaluation indexes in this paper, and the dimension of the data matrix composed of evaluation object and evaluation indicators is also very large, data analysis cannot be carried out directly. In order to analyze the composition and trend of the evaluation results, the existing evaluation results should be used. This paper chose the curve graph to analyze the composition and trend of the comprehensive performance evaluation results of the high-quality development of China's provincial manufacturing industry. Using the comprehensive performance evaluation object of high-quality development of China's manufacturing industry in 31 provinces and the specific evaluation results from 2013 to 2020, the corresponding curve cluster composition and trend chart were drawn in the rectangular coordinate system. The specific contents of the curve are shown in Fig. 2.

It can be clearly seen from Fig. 2 that there are some differences in the comprehensive performance evaluation results of high-quality development of China's provincial manufacturing industry. The main differences are the environmental differences between different provincial manufacturing industries and the differences in the time period of different provincial manufacturing industries. Although the evaluation results of manufacturing industry in 31 provinces are different, the trend of the evaluation results has strong regularity, indicating that the development environment, environmental regulation and government policy support of manufacturing industry in different provinces have the same characteristics. The differences and laws in the above evaluation results are also the direct basis for exploring strategies to improve the high-quality development of China's provincial manufacturing industry.

Conclusion

In order to explore an effective way to evaluate the comprehensive performance of high-quality development of China's provincial manufacturing industry based on low-carbon constraints, this paper, based on the analysis of research background and literature review, drew on the latest research achievements and valuable experience in practice of the academia, and fully considered the actual situation of high-quality development of China's manufacturing industry based on low-carbon constraints. Among the five criteria-layer evaluation index of economic development, energy consumption, technological innovation, environmental pressure and environmental pollution governance, 30 representative operating-layer evaluation indicators were selected, and a fuzzy matter-element extension evaluation model for the comprehensive performance evaluation of China's provincial high-quality development based on low-carbon constraints was constructed. By using the relevant statistical data in China Statistical Yearbook, China Energy Statistical Yearbook and China Environmental Status Bulletin, this paper conducted an evaluation study on the comprehensive performance of high-quality development of China's manufacturing industry based on low-carbon constraints in 31 provinces, verified the effectiveness of the fuzzy matter-element extension evaluation model, and provided an effective quantitative analysis method for the comprehensive performance evaluation of high-quality development of China's manufacturing industry based on low-carbon constraints. Therefore, based on the specific evaluation results, the following policy recommendations to promote the comprehensive performance improvement of high-quality development of China's provincial manufacturing industry based on low-carbon constraints were proposed:

(1) The growth of gross output value of manufacturing industry is the key to promote the comprehensive performance of high-quality development. Economic growth is an important factor influencing the performance evaluation index of high-quality development of China's manufacturing industry. Therefore, with other conditions unchanged, it is crucial to increase the gross output value of the manufacturing industry;

(2) Energy conservation and environmental pollution governance are the core of improving the comprehensive performance of high-quality development. These two tasks involve all aspects of the high-quality development of the manufacturing industry, and determine the final results of the performance evaluation of the high-quality development of the manufacturing industry;

(3) Technological innovation is an important means to improve the comprehensive performance evaluation effect of high-quality development of manufacturing industry. At present, the effect of technological innovation in China's manufacturing industry is relatively poor, and this work has good stamina.

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Conflict of Interest

The authors declare no conflict of interest.

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