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Evaluation of industrial green development based on set pair analysis

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ABSTRACT

Industrial green development is an important part of the global sustainable development goals, and it is the only way for China to achieve the "dual carbon goals". This paper aims to explore the methods and indicators for the assessment of the level of industrial green development, and emphasizes its applicability in the "city area" scale. According to the characteristics of industrial green development, an evaluation system including 4 first-level indicators of economic benefits and structure, technological innovation and investment, environmental impact and governance, resource consumption and reuse, and a total of 16 s-level indicators were established, each indicator was determined using the entropy value theory The weight value is based on the conditions of 15 sub-provincial cities across the country to determine the standard value of each indicator. Through the set pair analysis of the five-element connection number and partial connection number, the comprehensive connection degree and the full partial connection number are obtained, so as to evaluate the level of industrial green development in Chengdu static evaluation and dynamic analysis. The results show that the constructed index system and evaluation method are applicable to the evaluation of industrial green development at the "city" scale. The current status of Chengdu's industrial green development is at a qualified level, and the industrial process will have a more active and green development trend in the future. The government management department should formulate appropriate management policies and strengthen comprehensive evaluation and research, so as to take the green industrial development process of Chengdu to a new level.

1. Introduction

The construction of ecological civilization and beautiful China is an important part of realizing the great rejuvenation of the Chinese nation, Chinese Dream, in which the realization of green and high-quality development of industry is the top priority in the construction of ecological civilization. In practice, the construction of ecological civilization and industrial green development promote each other and develop together, enhance the level of industrial green development, and form a harmonious development between man and nature is the inherent requirement of promoting sustainable economic and social development and promoting the construction of ecological civilization. Under the new situation, it is imperative to carry out evaluation and research on the greening of industrial development in order to change the development mode of traditional industries with high pollution and high consumption [1].

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At present, there are many researches on industrial green development at home and abroad, which mainly focus on the construction of green development index system, efficiency evaluation methods and analysis of influencing factors. For example, Yang [2] constructed multi-level evaluation indicators from the perspective of development benefit, technological innovation, environmental impact and resource utilization on the basis of defining green industry. Yue et al. [3] based on the panel data of 57 cities along the Yellow River basin, measured the green development efficiency of the cities in the basin by Super-SBM model; Zhang et al. [4] measured the industrial ecological efficiency of 31 provinces in China, and investigated the spatial characteristics and influence mechanism of regional industrial ecological efficiency with the help of spatial econometric analysis model. From the research perspective, it is mainly concentrated on the national scale [5,6], the zone scale [7,8] and the provincial scale [9–11]. From the perspective of evaluation method system, it is mainly divided into green GDP accounting [12], total factor productivity method [13,14], comprehensive index method based on multi-index measure [15,16] and so on. Among them, the multi-index evaluation comprehensive method establishes the evaluation index system by screening comprehensive and effective evaluation indicators, and then selects the appropriate method to evaluate, because its technical means are simple and the results are reliable, it is widely used in the overall evaluation of regional and national green development, as well as the evaluation of green development in the industrial field.

Generally speaking, related research has achieved rich results, but many evaluation methods are difficult to have a comprehensive understanding and grasp of green development, and there is an urgent need to have a more objective and accurate evaluation of the current level of development. Set pair analysis is a powerful mathematical tool for evaluating the fuzzy information of certainty and uncertainty, which has good reliability and operability [17]. And the theory is mature, the principle is simple, the calculation is simple, and it has been widely used in the fields of urban sustainable development, risk analysis and so on [17,18]. However, this method has not been involved in the evaluation system of industrial green development level. At the same time, the existing research on small-scale "city" is still lacking, and it is still in the preliminary stage of exploration. In view of this, this paper attempts to establish an evaluation model by using the quantitative analysis of connection number and partial connection number in set pair analysis theory, and takes Chengdu as the research object to evaluate the current situation and analyze the development trend of its industrial green development.

2. Evaluation method

From the perspective of system theory, the evaluation of industrial green development is to evaluate a system with many uncertain factors. The concrete manifestations are as follows: first, "green industry" is an uncertain fuzzy concept, on the connotation of "green industry" and its extension has not reached a unified consensus; Secondly, because of the unclear connotation and extension, the evaluation index system and evaluation standard of industrial green development are fuzzy, and the evaluation result is uncertain. Third, as the evaluation system of industrial green development is a complex system, many factors affecting the level of industrial green development are uncertain, so the evaluation method is fuzzy and uncertain [19]. These characteristics determine the particularity of its theoretical research methods. Set pair analysis (SPA) method, based on its theoretical characteristics, can better deal with the problem of uncertain system [20–22]. Its core idea is to regard certainty and uncertainty as an uncertain system that influences and restricts each other and can transform each other under certain conditions. The global and local relationships of the relationship are shown through the correlation degree expression. Set pair analysis conforms to the characteristic that the evaluation index of industrial green development has a certain fuzzy uncertainty on the boundary of evaluation criteria. Set up a set pair between evaluation samples and evaluation standards from the same, different and opposite aspects. According to the number of evaluation standards, determine the five element connection number as the evaluation model of industrial green development status, and determine the level of industrial green development status through the size of the connection degree. In order to better understand the trend of industrial green development, on the basis of the current situation evaluation, the partial connection coefficient model [23] that can describe the development trend of the same, different and anti fuzzy states is introduced, which has good applicability for judging the future green development trend of industry.

Based on this, this paper puts forward the hypothesis: because the green development of urban industry has great uncertainty, the uncertain factors can be evaluated objectively through the set pair analysis method which has the advantage of analyzing the uncertain research objects.

2.1. Expression of the connection number of industrial green development level

According to the evaluation criteria, the set pair analysis five element connection number method is applied to the evaluation of the status quo of industrial green development, and the same, different and inverse hierarchical method [24] is used to obtain the five element connection coefficient expression of each secondary index.

For the smaller the better indicator, the contact number expression is:

$$\mu_t = \begin{cases} 1 + 0i_1 + 0i_2 + 0i_3 + 0j & x_t \geq s_1 \\ (x_t - s_2)/(s_1 - s_2) + (s_1 - x_t)i_1/(s_1 - s_2) + 0i_2 + 0i_3 + 0j & s_2 \leq x_t < s_1 \\ 0 + (x_t - s_3)i_1/(s_2 - s_3) + (s_2 - x_t)i_2/(s_2 - s_3) + 0i_3 + 0j & s_3 \leq x_t < s_2 \\ 0 + 0i_1 + (x_t - s_4)i_2/(s_3 - s_4) + (s_3 - x_t)i_3/(s_3 - s_4) + 0j & s_4 \leq x_t < s_3 \\ 0 + 0i_1 + 0i_2 + (x_t - s_5)i_3/(s_4 - s_5) + (s_4 - x_t)j/(s_4 - s_5) & s_5 \leq x_t < s_4 \\ 0 + 0i_1 + 0i_2 + 0i_3 + 1j & x_t < s_5 \end{cases} \tag{1}$$

For the larger and better indicator, the contact number expression is:

$$\mu_t = \begin{cases} 1 + 0i_1 + 0i_2 + 0i_3 + 0j & x_t \leq s_1 \\ (x_t - s_1)/(s_2 - s_1) + (s_2 - x_t)i_1/(s_2 - s_1) + 0i_2 + 0i_3 + 0j & s_1 < x_t \leq s_2 \\ 0 + (x_t - s_2)i_1/(s_3 - s_2) + (s_3 - x_t)i_2/(s_3 - s_2) + 0i_3 + 0j & s_2 < x_t \leq s_3 \\ 0 + 0i_1 + (x_t - s_3)i_2/(s_4 - s_3) + (s_4 - x_t)i_3/(s_4 - s_3) + 0j & s_3 < x_t \leq s_4 \\ 0 + 0i_1 + 0i_2 + (x_t - s_4)i_3/(s_5 - s_4) + (s_5 - x_t)j/(s_5 - s_4) & s_4 < x_t \leq s_5 \\ 0 + 0i_1 + 0i_2 + 0i_3 + 1j & x_t > s_5 \end{cases} \tag{2}$$

In the formula, X_t represents the actual value of an indicator, μ_t represents the contact degree of an indicator, and S_i represents the evaluation grades.

In the evaluation of industrial green development, the weight determination methods of each evaluation index can be divided into subjective weighting method and objective weighting method. The subjective weighting method mainly includes analytic hierarchy process, network analysis method and expert scoring method. For example, Wang [25] and Han [26] used AHP method to determine the weight of evaluation index of industrial green development. Xue [27] used AHP method to give weight to all three indexes of Jinan green economy development measurement system. Yin [28] used ANP method to determine the weight of indicators, which effectively solved the evaluation problem of incomplete independence among indicators. Entropy method and factor analysis method are the objective weighting methods most often used by scholars in research. For example, Chu [29], Zhang [30] and Liu [31] used entropy method to assign weights to the evaluation index system of industrial green development. Huang [32] and Huang [33] used factor analysis to empower the index system of industrial green development.

This paper uses the entropy value weighting method [34] based on the objective actual data, which maximizes the development of the utility value of the index data, and is suitable for the determination of the weight of each index in the evaluation of industrial green development. See Table 1 for the weight values of indicators at all levels. The expression of comprehensive contact degree is:

$$\mu = \sum_{t=1}^{m} \omega_t \mu_t = \sum_{t=1}^{m} \omega_t a_t + \sum_{t=1}^{m} \omega_t b_{t1} i_1 + \sum_{t=1}^{m} \omega_t b_{t2} i_2 + \sum_{t=1}^{m} \omega_t b_{t3} i_3 + \sum_{t=1}^{m} \omega_t c_t j \tag{3}$$

Where: ω_t is t index weight; μ_t is the contact degree value of t index.

Contact degree of each indicator μt Value can be used to judge the current level of this indicator. Formula (1) - (2) is brought into Formula (3), and the comprehensive contact number of indicators on the upper level is determined by the contact degree value of each indicator, so as to finally obtain the overall industrial green development level.

2.2. Classification of current status assessment

Through the contact degree of various indicators μ_t to evaluate the current level of indicators at the upper level, it is necessary to establish corresponding quantitative level standards. In this paper, the difference value method [35] is used to determine the value of *i* and *j*, where $i_1 = 0.5$, $i_2 = 0.01$, $i_3 = -0.5$, $j = -1$. The "average" value method [36] is used to determine the grade division interval of the comprehensive connection degree $\mu_t = [-1, 1]$, divide the $[-1, 1]$ interval into 6 equal intervals, corresponding to each level of industrial green development level, and the grading results are shown in Table 1.

2.3. Establish the evaluation index system and status quo evaluation standards for industrial green development

Industrial green development is a complex system that is jointly affected by society, economy, nature, environment and other aspects. Various factors have different degrees of influence on the level of industrial green development. Scientific and reasonable screening of evaluation indicators and determination of indicator evaluation standards are the key to the evaluation work. In terms of

Table 1
Classification of industrial green level.

Grade	advanced	good	qualified	relatively backward	backward
Threshold limit value	[0.6, 1]	[0.2, 0.6)	[-0.2, 0.2)	[-0.6, −0.2)	[-1, −0.6)

green development index system research, Beijing Normal University, Southwestern University of Finance and Economics and the National Bureau of Statistics jointly put forward the first set of monitoring index system and index measurement system for green development in China, including three primary indexes, namely, greening degree of economic growth, resource and environment carrying potential and government policy support, which are specifically divided into nine secondary indexes and more than 50 tertiary indexes. And 30 provinces and regions in China were calculated [37]; Huang et al. built a comprehensive and systematic evaluation index system for urban green development from three levels of macro urban construction, meso industrial development and micro technological innovation, and evaluated the current situation of green development in Guangzhou [38]. In terms of the research on the index system of resource-saving and environment-friendly industries, Qian et al. put forward the evaluation index system of resource-saving and environment-friendly industrial structure consisting of 3 levels and 28 indicators, and analyzed it by taking Guangdong and other 5 provinces and cities as examples [39]. Song et al. [40] proposed a sustainable development evaluation index system for coal industry. Wei et al. [41] studied and established the evaluation index system of resource and environmental carrying capacity of paper industry. Yang et al. [42] established a set of sustainable development index system (NREF) including four evaluation fields, "meeting needs", "limited resources", "valuable environment" and "better future", reflecting the requirements of circular economy and taking the consumption rate of natural resources into consideration as a dynamic indicator of development. Based on the principles of scientificity, systematicness and operability, and on the basis of the previous research results and the characteristics of industrial development status, a set of industrial green development evaluation index system including four first level indicators and 16 second level indicators, including economic benefits and structure, technological innovation and investment, environmental pollution and governance, resource consumption and reuse, is constructed, as shown in Table 2.

Due to the lack of unified evaluation and grading standards for industrial green development at present, on the basis of summarizing the previous studies [43], five evaluation grades for industrial green development level are established, namely $\{S_1, S_2, S_3, S_4, S_5\}$ = {advanced, good, qualified, relatively backward, backward}. The determination method of each grade value is as follows: take the average value of 15 sub provincial cities in China as the qualified grade value of the index, the average value that is superior to the qualified grade value is the good grade value, the average value that is inferior to the qualified grade value is the backward grade value, the optimal value of the index is the advanced grade value, and the lowest value of the index is the backward grade value. According to such grading standards, the evaluation standard value of secondary indicators can be obtained. See Table 3 for specific grading standards. See Table 4 for the same, different and opposite relationship between the evaluation grade of industrial green development level and set pair analysis.

As a central city in western China, Chengdu is not only the window of western opening to the outside world, but also the core city of Chengdu-Chongqing Shuangcheng economic circle, the central city in the upper reaches of the Yangtze River and the new first-tier leading city in China. The economy of Chengdu has developed rapidly in recent years. In the past 10 years, the operating income of Chengdu's industrial enterprises has reached 1.65 trillion, with an average annual growth rate of 7.4%, ranking fourth in China's

Table 2
Comprehensive rating index system of green industry.

Target layer	First-level indicators	Weight	Secondary indicators	Unit	Weight
Green development level of industry	Economic benefits and structure	0.2440	Per capita industrial added value	Yuan/person	0.2516
			Profit margin of industrial main business above designated size	%	0.2603
			Growth rate of industrial added value above designated size	%	0.2314
			Proportion of industrial output value of high energy consuming industries above designated size	%	0.2567
	Technological innovation and investment	0.2618	R&D internal funds of large-scale enterprises account for the proportion of main business income	%	0.2410
			Proportion of new product sales revenue of large-scale enterprises in main business revenue	%	0.2486
			Number of patent applications per enterprise above designated size	pieces	0.2472
			Proportion of main business income of industrial high-tech industry above designated size	%	0.2632
	Environmental impact and governance	0.2466	Wastewater discharge of ten thousand Yuan industrial added value	tonne/100 million Yuan	0.2474
			Sulfur dioxide and smoke and dust emissions per unit of industrial value added	m^3/ten thousand Yuan	0.2671
			Solid waste production per unit of industrial value added	tonne/100 million Yuan	0.2517
			Comprehensive utilization rate of general industrial solid waste	%	0.2338
	Resource consumption and reuse	0.2476	Total amount of comprehensive energy consumption per unit of industrial value added	tce/ten thousand Yuan	0.2645
			Land for added value per unit of industry	m^2/100 million Yuan	0.2456
			Water intake per unit of industrial value added	m^3/ten thousand Yuan	0.2546
			Repeated utilization rate of industrial water	%	0.2353

Table 3
Grading criteria of secondary indicators for industrial green development evaluation.

Secondary indicators	S_1	S_2	S_3	S_4	S_5
Industrial value added per capita	6.497	4.453	3.410	2.497	1.209
Profit margin of industrial main business above designated size	0.198	0.176	0.154	0.143	0.128
Growth rate of industrial added value above designated size	0.099	0.066	0.047	−0.076	−0.197
Proportion of industrial output value of high energy consuming industries above designated size	0.027	0.092	0.168	0.233	0.334
R&D internal funds of large-scale enterprises account for the proportion of main business income	0.174	0.101	0.025	0.013	0.001
Proportion of new product sales revenue of large-scale enterprises in main business revenue	0.381	0.290	0.223	0.146	0.087
Number of patent applications per enterprise above designated size	21.925	17.432	4.936	3.014	0.970
Proportion of main business income of industrial high-tech industry above designated size	0.704	0.525	0.369	0.191	0.110
Wastewater discharge of ten thousand Yuan industrial added value	1.019	2.691	4.608	9.879	13.965
Sulfur dioxide and smoke and dust emissions per unit of industrial value added	0.893	8.714	18.322	32.734	44.248
Solid waste production per unit of industrial value added	0.020	0.135	0.244	0.409	0.577
Comprehensive utilization rate of general industrial solid waste	0.993	0.961	0.870	0.767	0.409
Total amount of comprehensive energy consumption per unit of industrial value added	0.241	0.426	0.675	1.177	1.488
Land for added value per unit of industry	22.334	34.376	45.158	61.331	85.991
Water intake per unit of industrial value added	5.506	10.932	18.755	27.696	37.000
Repeated utilization rate of industrial water	0.963	0.884	0.788	0.525	0.161

Table 4
The level of industrial green development and the similarities, differences and oppositions of set pair analysis.

	S1	S2	S3	S4	S5
Green development level of industry	advanced	good	qualified	relatively backward	backward
Similarity, difference and opposition	Identical degree	Degree of deviation, sameness and difference	Degree of difference	Deviation contrast degree	Degree of opposites

vice-provincial and above cities. At the same time, with the help of the central European train, the new land and sea corridor in the west and the international aviation hub created by the "double airports", Chengdu has become an international comprehensive transportation hub and an airport-type international logistics hub, with certain location advantages, as shown in Fig. 1. In order to objectively reflect the level of industrial green development in Chengdu, we select the data of 15 vice-provincial cities in China to construct evaluation criteria to measure the status of industrial green development in Chengdu, which is of great significance to the high-quality development of Chengdu and regional industry. It has a certain reference and guiding significance for Chengdu to recognize the current situation and identify the obstacles of development.

The data come from China Statistical Yearbook (2020), China Environmental Statistical Yearbook (2020), China Science and Technology Statistical Yearbook (2020), Chengdu Statistical Yearbook (2020), 2020 Chengdu Water Resources Bulletin, 2020 Chengdu Environmental Quality Bulletin, 2020 Chengdu National Economic and Social Development Statistical Bulletin and 2020 statistical yearbooks of 31 provinces, municipalities and autonomous prefectures. Statistical bulletin of national economic and social development in 2020.

3. Evaluation result

Through the expression of five-element connection number and comprehensive connection degree from formula (1) to formula (3), on the basis of the evaluation grade standard of the current situation in Table 3, the present situation of industrial green development in Chengdu is evaluated. The results are shown in Table 5. The comprehensive connection number of the target layer of industrial green development in Chengdu is:

$$\mu = 0.1459 + 0.2305 i_1 + 0.2655 i_2 + 0.3358 i_3 + 0.0223 j = 0.0736 \quad (4)$$

Substitute $i_1 = 0.5$, $i_2 = 0.01$, $i_3 = -0.5$, $j = -1$ into equation (6) to get $\mu = 0.0736 \in [-0.2, 0.2)$.

According to Table 1, the industrial green development level of Chengdu is qualified. In the past, Diao [19] and others have conducted a comprehensive evaluation ranking of industrial green development in 15 vice-provincial cities in China, among which Chengdu industrial green development belongs to the middle level, which is close to the results of this study and consistent with the theoretical hypothesis of this paper.

The contact degree of evaluation indicators at all levels is shown in Table 5. From the perspective of first-level indicators, economic benefits and structure, technological innovation and investment are at a relatively backward level, while environmental impact and governance, resource consumption and reuse are at a good level. Under the joint action of the four factors, the green performance of industrial development in Chengdu is not prominent. From the perspective of secondary indicators, the growth rate of industrial added value above designated size, wastewater discharge per 10000 Yuan of industrial added value, sulfur dioxide and smoke and dust discharge per unit of industrial added value, total comprehensive energy consumption per unit of industrial added value, and land use per unit of industrial added value are at an advanced level, which are the "plus points" for green industrial development in Chengdu;

Fig. 1. location advantage map of Chengdu.

Only the output of solid waste per unit of industrial added value is at a good level; The proportion of industrial output value of high energy consuming industries above designated size, the proportion of new product sales revenue of large-scale enterprises in the main business income, and the number of patent applications of each large-scale enterprise are at a qualified level; Per capita industrial added value, profit margin of main business income of industries above designated size, proportion of main business income of high-tech industries above designated size, comprehensive utilization rate of general industrial solid wastes, water intake per unit of industrial added value, and reuse rate of industrial water are at a relatively backward level; The proportion of R&D internal funds in the main business income of large-scale enterprises is at a backward level. The relatively backward and backward indicators have, to a certain extent, lowered the comprehensive level of green industrial development in Chengdu.

4. Conclusions and policy suggestions

4.1. Conclusions

(1) This paper evaluates and analyzes the current level and trend of industrial green development in Chengdu based on the index data in 2020. Combined with the characteristics of regional industrial green development and the construction of an evaluation system including three levels and 16 indicators, a five-element connection number model and a trend analysis partial connection number analysis model are established on the basis of set pair analysis. It provides a new idea for the evaluation of industrial green development level in "city".

(2) According to the results of the analysis of the current situation, the industrial green development of Chengdu is at the qualified level in 15 vice-provincial cities. Economic efficiency and structure, technological innovation and investment are relatively backward, among which the per capita industrial added value, profit margin of main business income of industries above designated size, proportion of main business income of high-tech industries above designated size, comprehensive utilization rate of general industrial solid waste, water intake per unit of industrial added value, reuse rate of industrial water, proportion

Table 5
Calculation value of contact degree of evaluation indicators of Chengdu's industrial green development level.

First-level indicators	Secondary indicators	Weight		Expression of connection degree	Comprehensive degree of connection	
Economic benefit and structure	Per capita industrial added value	0.2440	0.2516	$0 + 0 i_1 + 0.1216 i_2 + 0.8784 i_3 + 0 j = -0.4379$	$0.0561 + 0.2158 i_1 + 0.3414 i_2 + 0.3867 i_3 + 0 j = -0.0259$	$0.1459 + 0.2305 i_1 + 0.2655 i_2 + 0.3358 i_3 + 0.0223 j = 0.0736$
	Profit margin of industrial main business above designated size		0.2603	$0 + 0 i_1 + 0.3636 i_2 + 0.6364 i_3 + 0 j = -0.3146$		
	Growth rate of industrial added value above designated size		0.2314	$0.2424 + 0.7576 i_1 + 0 i_2 + 0 i_3 + 0 j = 0.6212$		
	Proportion of industrial output value of high energy consuming industries above designated size		0.2567	$0 + 0.1579 i_1 + 0.8421 i_2 + 0 i_3 + 0 j = 0.0874$		
Technological innovation and investment	R&D internal funds of large-scale enterprises account for the proportion of main business income	0.2618	0.2410	$0 + 0 i_1 + 0 i_2 + 0.6667 i_3 + 0.333 j = -0.6664$	$0 + 0 i_1 + 0.5619 i_2 + 0.3578 i_3 + 0.0803 j = -0.2535$	
	Proportion of new product sales revenue of large-scale enterprises in main business revenue		0.2486	$0 + 0 i_1 + 0.9830 i_2 + 0.0170 i_3 + 0 j = 0.0013$		
	Number of patent applications per enterprise above designated size		0.2472	$0 + 0 i_1 + 0.7523 i_2 + 0.2477 i_3 + 0 j = -0.1163$		
	Proportion of main business income of industrial high-tech industry above designated size		0.2632	$0 + 0 i_1 + 0.5 i_2 + 0.5 i_3 + 0 j = -0.2450$		
Environmental impact and governance	Wastewater discharge of ten thousand Yuan industrial added value	0.2466	0.2474	$0.3726 + 0.6274 i_1 + 0 i_2 + 0 i_3 + 0 j = 0.6863$	$0.1624 + 0.5830 i_1 + 0.0208 i_2 + 0.2286 i_3 + 0.0052 j = 0.3346$	
	Sulfur dioxide and smoke and dust emissions per unit of industrial value added		0.2671	$0.2629 + 0.7371 i_1 + 0 i_2 + 0 i_3 + 0 j = 0.6314$		
	Solid waste production per unit of industrial value added		0.2517	$0 + 0.9174 i_1 + 0.0826 i_2 + 0 i_3 + 0 j = 0.4595$		
	Comprehensive utilization rate of general industrial solid waste		0.2338	$0 + 0 i_1 + 0 i_2 + 0.9777 i_3 + 0.0223 j = -0.5112$		
Resource consumption and reuse	Total amount of comprehensive energy consumption per unit of industrial value added	0.2476	0.2645	$0.7322 + 0.2678 i_1 + 0 i_2 + 0 i_3 + 0 j = 0.8661$	$0.3724 + 0.1377 i_1 + 0.1208 i_2 + 0.3691 i_3 + 0 j = 0.2579$	
	Land for added value per unit of industry		0.2456	$0.7279 + 0.2721 i_1 + 0 i_2 + 0 i_3 + 0 j = 0.8640$		
	Water intake per unit of industrial value added		0.2546	$0 + 0 i_1 + 0.0667 i_2 + 0.9333 i_3 + 0 j = -0.4660$		
	Repeated utilization rate of industrial water		0.2353	$0 + 0 i_1 + 0.4411 i_2 + 0.5589 i_3 + 0 j = -0.2750$		

of R&D internal funds in main business income of large-scale enterprises are slightly insufficient in the green contribution of industrial development. At the same time, environmental impact and governance, resource consumption and recycling play a positive role in the whole process of industrial green development, and are "plus points" to improve the level of industrial green development in Chengdu.

(3) It can be seen from the trend analysis results that the future development trend of technological innovation investment is not conducive to the greening of industry, and it is an important constraint factor in the process of industrial greening in Chengdu. The environmental impact and governance, resource consumption and reuse will not only develop well in the future, but also become a booster for the promotion of green industry in Chengdu.

(4) Applying set pair analysis theory to the evaluation of regional industrial green development can achieve the combination of static status analysis and dynamic trend prediction of the system, which is conducive to managers making more scientific and reasonable decisions on the maintenance and adjustment of the system. Therefore, this method is reasonable and effective for the evaluation of industrial green development.

4.2. Policy suggestions

(1) Promote the green and low-carbon upgrading of traditional manufacturing industries

Focus on promoting the green level of leading industries, build a green supply chain, and comprehensively carry out cleaner production audit and evaluation certification. To be established is a pre-evaluation system for energy consumption, carbon emissions, and land use for major projects, linking corporate incentives with green performance, and establishing a full-chain management and control mechanism for "two high" projects. Fine governance and classified measures will be implemented in the industry to reduce the emission level per unit output around the petrochemical, iron and steel, chemical, and other industries.

(2) Comprehensively carry out the industrial circular mode of production

Establish the whole industry chain from raw material production to terminal consumption, and eliminate waste pollutants through the effective connection and cooperation of all links of the industry chain. Reasonable construction of centralized sewage collection, treatment and reuse facilities in industrial parks, and strengthen sewage treatment and recycling. Strengthen industrial recycling links in industrial parks, encourage enterprises to carry out "point-to-point" inter-enterprise circular production mode, and promote the exchange and comprehensive utilization of enterprise waste resources. The construction of demonstration bases for the comprehensive utilization of bulk solid wastes will be carried out, with the channels for the comprehensive utilization of bulk industrial solid wastes such as industrial by-product gypsum being broadened, and the scale of utilization being expanded in areas such as ecological restoration.

(3) Promote the research and application of green technology

Improve the green technology scientific research project approval, acceptance, evaluation mechanism and green technology trading market, focus on the frontiers of green and low-carbon technology and the actual industrial transformation, and focus on key areas such as industrial energy conservation, carbon reduction and recycling, and continue to promote key green and low-carbon core technologies. Establish a green technology information sharing mechanism oriented to the needs of enterprises, promote the precise connection between the innovation chain and the industrial chain, and improve the efficiency of the industrialization of green technology innovation achievements. Actively create a green technology innovation application ecology, accelerate the transformation of achievements, and enrich application scenarios.

(4) Perfecting the legal and policy system of green transformation and development.

Accelerate the promotion of local legislation in the fields of atmospheric, soil and water environmental governance, strengthen the research on national and local standards in the fields of resource and energy consumption, pollutant discharge and environmental monitoring, and improve the information feedback and evaluation mechanism for standard implementation. Focusing on the fields of renewable resource recovery, energy-saving, low-carbon and circular transformation, support enterprises and industry associations in developing advanced technologies and green product standards. Promote the improvement of the ecological co-construction and environmental co-protection working mechanism of the Chengdu-Chongqing economic circle, and strengthen the joint prevention, control and treatment of atmospheric and hazardous waste pollution.

5. Discussions

It is found that the multi-level evaluation index system constructed from the point of view of "economic benefit and structure, technological innovation and input, environmental impact and governance, resource consumption and reuse" has a certain representativeness and reliability to the study of industrial green development in "urban area". Combined with the set pair analysis method of five-element connection number and partial connection coefficient, it can meet the needs of the evaluation and research of industrial green development in Chengdu. In particular, there is a more intuitive exposition on the index distinction of "promoting or hindering the green development of industry in Chengdu".

On the basis of the existing literature, this paper combs the influencing factors of industrial green development from a new point of view, and studies and constructs a comprehensive evaluation index system of industrial green development which is suitable for "urban area". And use the seldom used "five-element connection number and partial connection number set pair analysis method" to evaluate the industrial green development of Chengdu. The constructed index system and evaluation methods provide more possibilities for the study of industrial green development in "city area", and the evaluation results support further research in this field.

There are the following limitations in this study: first, in the construction of the index system, due to the unaccessibility of some index data, the selection of industrial green development potential indicators needs to be further optimized and improved; secondly, this study mainly evaluates and analyzes the overall level of industrial green development in Chengdu, which fails to involve the differences in industrial green development between cities and counties under its jurisdiction, and further research is needed in the follow-up research.

Author contribution statement

Chaoyong Zhong: Conceived and designed the experiments, Performed the experiments, Analyzed and interpreted the data, Contributed reagents, materials, analysis tools or data, Wrote the paper.

Yuanyue Chu: Performed the experiments, Analyzed and interpreted the data, Contributed reagents, materials, analysis tools or data.

Lijuan Tang: Contributed reagents, materials, analysis tools or data, Wrote the paper.

Jian Yao: Conceived and designed the experiments, Contributed reagents, materials, analysis tools or data.

Wei Su: Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] N. Eric, Weak versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms, Edwards Elgar Publishing, Cheltenham, 2010.
[2] L.X. Yang, J. Yao, On the construction of green industry and its index system, Sichuan Environment 35 (4) (2016) 146–150.
[3] L. Yue, D. Xue, The spatio-temporal evolution of urban green development efficiency along the Yellow River basin and its influencing factors, Resource science (42) (2020) 2274–2284.
[4] R.J. Zhang, H.Z. Dong, The Spatio-temporal Evolution and influencing factors of Industrial Ecological efficiency in China based on Provincial scale, Econ. Geogr. 40 (7) (2020) 124–132.
[5] C.Y. Li, Study on the Quality Measurement and Influencing Factors of Industrial Green Development in China, Shandong University of Science and Technology, 2020.
[6] Z.Y. Wan, Y. Xiao, Research on comprehensive measurement and spatial differentiation of industrial green development quality in China, National circulation economy (16) (2021) 136–138.
[7] R.R. Zheng, J. Wang, H.B. Zhu, Study on the present situation and efficiency evaluation of industrial green development in the Yangtze River economic belt, Modern Industrial economy and Informatization 12 (6) (2022) 12–15.
[8] Y.L. Li, Study on the Performance Evaluation and Influencing Factors of Industrial Green Development in Provinces and Regions along the Silk Road Economic Belt, Shihezi University, 2020.
[9] Y. Ma, X.Y. Sun, Study on the evaluation of the green development level of provincial industry, Green technology 23 (6) (2021) 277–280.
[10] Y.Y. Zhang, Comprehensive Evaluation and Influencing Factors Analysis of Industrial Green Development Level in Liaoning Province, Jilin University of Finance and Economics, 2022.
[11] D.L. Qi, Construction and verification of evaluation model for green industry development in Gansu Province, Shanghai commerce (8) (2022) 192–194.
[12] L.Y. Guo, M. Lei, X.Q. Liu, Research on green GDP accounting based on emergy analysis method-taking Shangluo City, Shaanxi Province as an example, Journal of Natural Resources (9) (2015) 1523–1533.
[13] D.H. Oh, A. Heshmati, A sequential Malmquist-Luenberger productivity index: environmentally sensitive productivity growth considering the progressive nature of technology, Ecological Economy 32 (6) (2010) 1345–1355.
[14] S.J. Hu, Spatial Econometric Study on the Influencing Factors of Green Total Factor Productivity in Inter-provincial Industry, North China Electric Power University, 2019.
[15] A. De Serres, F. Murtin, G. Nicoletti, A framework for assessing green growth policies, OECD Economics Department Working Papers No 774 (2010).
[16] Beijing Normal University, China Green Development Index Report: Regional Comparison, Beijing Normal University Press, Beijing, 2012, pp. 3–11.
[17] Y. Chen, W.S. Wang, J.Y. Wang, J. Chen, Evaluation of urban sustainable development based on set pair analysis, Yellow River 32 (1) (2010) 11–13.
[18] Z.B. Feng, Study on Fire Risk Assessment of Construction in Progress Based on Set Pair Analysis, Xi'an University of Architecture and Technology, 2015.
[19] L.J. Diao, J. Yao, Y.N. Ai, Comprehensive evaluation of industrial green development based on SPA-TOPSIS coupling, Ecol. Econ. 36 (9) (2020) 54–57.
[20] K.Q. Zhao, Set Pair Analysis and its Preliminary Application, Zhejiang Science and Technology Press, Hangzhou, 2000.
[21] K.Q. Zhao, Uncertainty theory in set pair analysis, Nature Exploration 14 (54) (1995) 87–88.
[22] K.Q. Zhao, Connection number and uncertainty in set pair analysis (SPA), Nature Exploration (2) (1997) 92.
[23] Q. Lu, Evaluation index system of industrial green development and analysis of its application in regional evaluation of Guangdong Province, JEco Environ 22 (3) (2013) 528–534.
[24] Z.W. Pan, K.Y. Wu, J.L. Jin, X. Liu, Set pair analysis method for evaluation of renewable capacity of water resources, Hydropower Energy Science 27 (5) (2009) 24–26, 93.
[25] Y.H. Wang, W. Chen, Fuzzy evaluation of the degree of industrial greening in cities along the Yangtze River in Jiangsu, Resources and Environment of the Yangtze River Basin (2) (2008) 170–174.
[26] J. Han, Research on the efficiency of regional green innovation in China, Research on Financial Issues (11) (2012) 130–137.
[27] L. Xue, Construction of a measurement system for green economy development, Statistics and decision-making (18) (2012) 21–24.
[28] Y.B. Yin, An ANP based evaluation model for green industry development, Statistics and Decision (23) (2010) 65–67.
[29] Z.S. Chu, Evaluation of China's Industrial Green Development Level and Research on Influencing Factors, Hunan University, 2015.
[30] Y.K. Zhang, J.X. Cui, Evaluation of the green development level of urban industry in Shandong Province, J Lanzhou Univ FinEco 35 (1) (2019) 33–41.
[31] D. Liu, H.X. Zhu, T. Zhang, Research on the influencing factors of the level of industrial green development in Shanghai, Logistics Technology 42 (8) (2019) 132–136.
[32] G.H. Huang, J. Dai, C.Y. Qian, Evaluation and countermeasures for green industrial development in the Yangtze River economic belt, Old Area Construction (10) (2017) 40–44.
[33] D.P. Huang, Z.J. Liu, Comprehensive evaluation of China's industrial green development level, JHunan Univ Technol (SocSciEdition) 25 (4) (2020) 61–68.
[34] Y.Y. Feng, Empirical Study on Green Industrial Development in Hebei Province, Hebei University of Geosciences, 2016.
[35] B. Zhu, W.S. Wang, H.F. Wang, H.F. Wang, Discussion on the difference uncertainty coefficient i in set pair analysis, J. Sichuan Univ. (Eng. Sci. Ed.) 40 (1) (2007) 5–9.

[36] X.F. Wang, Multi attribute group decision-making method based on fuzzy language evaluation and connection number, Mathematical Practice and Understanding 37 (15) (2007) 54–59.
[37] Beijing Normal University Scientific Development Concept and Economic Sustainable Development Research Base, Southwest University of Finance and Economics Green Economy and Economic Sustainable Development Research Base, National Bureau of Statistics China Economic Prosperity Monitoring Center. 2011 China Green Development Index Report - Regional Comparison, Beijing Normal University Press, Beijing, 2011, pp. 7–20.
[38] Y. Huang, L. Yang, X.X. Wang, B. Xia, Research on the evaluation index system of urban green development - taking Guangzhou City as an example, Science and Technology Management Research 17 (2012) 55–59.
[39] X.H. Qian, Y.F. Yang, Construction of Resource Conservation and Environmentally Friendly Industrial Indicator System - Taking the "Five Provinces and Cities" in the East as an Example, China Management Science, 2008, pp. 622–627.
[40] M. Song, S.P. Li, S.H. Wang, Construction of Evaluation Index System for Sustainable Development of Coal Industry, Cooperative Economy and Technology, 2009, pp. 32–33.
[41] W.X. Wei, Y.J. Cheng, J. Wang, X.L. Zhu, Y.L. Jiang, B. Huang, C.H. Liu, Analysis of the evaluation index system for the environmental carrying capacity of paper industry resources, China Population, Resources and Environment 20 (115) (2010) 338–340.
[42] GH. Yang. Research on the Sustainable Development Indicator System and the Construction of Guangdong Sustainable Development Experimental Zone, China Financial & Economic Publishing House,Beijing, 2010.
[43] K.Q. Zhao, Partial Connection Coefficient. China Association of Artificial Intelligence. Progress of China's Artificial Intelligence 2005, Beijing University of Posts and Telecommunications Press, Beijing, 2005, pp. 884–886.