Evaluation for Low-carbon Development of Industrial Parks Based on Combined AHP-entropy Method: a case Study in Jiangsu Province

Huayi Zhang[a*], Mingxuan Zou[b], Ming Yang[c], Tianhao Zhu[d]

State grid Nanjing power supply company, Nanjing, 210000, China

[a*]1026529641@qq.com, [b]112466228@qq.com
[c]2582400300@qq.com, [d]xxdxxxdx9@163.com

Abstract. Under the Dual Carbon targets, industrial parks in China are in the tide of developing toward near zero carbon or zero carbon parks to enhance their competitiveness to better attract enterprises. In order to evaluate low carbon performance of industrial parks, the research established the evaluation index, and used the panel data from industrial parks in Jiangsu Province with the application of the combined AHP-entropy method to determine the weights of each indicator within the evaluation index system. Based on the weighted indicators, the study conducted a case analysis of a typical industrial park in Jiangsu province to assess its progress in low-carbon development.

Keywords: Dual-Carbon target, industrial parks, evaluation index, AHP method, entropy weight method, zero-carbon parks

1 Introduction

Industrial parks in China account for the main proportion of industrial activities which generate significant economic output. Consequently, the energy and material consumption, along with related carbon emissions occurring in industrial parks, contribute to a significant portion of the overall industrial development. Therefore, industrial parks have long been the main battle field in China to balance economic growth and environmental protection with different development priorities during different periods. Initiated in 2007 and continued to date, the National Demonstration Eco-industrial Parks(EIPs) program aims to minimize environmental impacts and improve resource efficiency, and several research have been carried out on EIPs[1][2][3], and the evaluation index system is well developed. Since the introduction of China's Dual Carbon goals, industrial parks have become the primary vehicle for low-carbon development initiatives. Demonstration projects of low carbon/near zero carbon/zero carbon industrial parks have been carried out in many areas of China encouraged by policies with different emphasis, for example, industrial parks in Inner Mongolia with abundant solar or wind energies may focus on local consumption of renewable energy to fully replace traditional fossil fuels, while parks in Guangdong Province may put efforts in active

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industry restructure, promoting energy efficiencies as well as electrification rate and increasing installed capacity of distributed PV systems. The significance of evaluating the industrial parks' low carbon performance is increasing [4][5][6]. And due to different pathways for parks to achieve low carbon development resulted by diversities in resource endowment and industrial structure, the evaluation index may differ in different areas in China.

Currently, comprehensive evaluation weighting methods are mainly divided into three groups: subjective, objective, and combined methods. Subjective methods include AHP, Delphi, fuzzy evaluation. Objective methods include principal component analysis, factor analysis, entropy weight, etc. Combined methods overcome individual shortcomings, reducing subjectivity of subjective methods and enhancing applicability of objective methods. Common combined methods are AHP-entropy, AHP-PCA, etc. The AHP-Entropy method is typical. The AHP breaks complex problems into hierarchical components and uses experts' opinions for weight determination. The entropy weight method quantifies data dispersion, assigns larger weights to criteria with higher entropy. The AHP-entropy approach balances the two methods' advantages and disadvantages and is used in multi-criteria decision-making, weight allocation, and comprehensive evaluation[7][8][9][10].

Jiangsu Province is one of the most economically developed provinces in China, and an active player in promoting low carbon development in industrial parks by introducing a series of policies in recent years. However, few researches have been conducted to set up indicator system to evaluate its current low-carbon development progresses and challenges. Therefore, the study employed the AHP-entropy method to establish an indicator system tailored to Jiangsu's context in order to evaluate the progress of low-carbon development in industrial parks in Jiangsu Province.

2 Methodology

2.1 Evaluation Index

Based on research of national policies and provincial policies of Jiangsu Province[11][12], the study concluded that the evaluation index system for low-carbon development in industrial parks needs to encompass the following aspects: (A)outcome-oriented carbon emission indicators to measure actual carbon reduction effectiveness, and it should include annual changes in total carbon emissions and carbon emission intensities; (B) implementation status of specific decarbonization measures, including energy utilization, transportation and building infrastructure, and resource efficiency; (C)last but not least, the establishment of a low-carbon management system as an essential component, which can ensure the long-term and effective implementation of low-carbon development strategies.

When diving into the indicator layer, the evaluation index should cover indicators with significancy to low carbon performance of industrial parks, while yet the data can be obtained with at least an annual consistency to be evaluated annually. For example, in Jiangsu Province, several industrial parks are designated as National Ecological Industry Demonstration Parks, and these parks are required to report their changes in key indicators annually as part of the project. Many of the indicators in this index system reflect the concept of low-carbon development, and the panel data from these demonstration parks can provide a data foundation for this study.

Integrating the above two aspects, the study constructs an evaluation index system comprised with 3 layers, i.e. under the target layer of low carbon development of industrial parks, the criterion layer is with 5 aspects and indicator layer with 15 indicators as listed in Table 1.

Table 1. Evaluation Indicators for Low-Carbon Development of Industrial Parks.

Target layer	Criterion layer		Indicator layer	
Low carbon development of industrial parks	Carbon efficiency during production	A	Annual decreasing rate of total carbon emission	A_1
			Annual decreasing rate of average carbon emission per unit added value created	A_2
			Annual decreasing rate of average energy consumption per unit added value created	A_3
	Low carbon energy consumption	B	Proportion of renewable energy in total energy consumption	B_1
			Terminal electrification rate	B_2
	Low carbon development in infrastructure	C	Proportion of newly constructed buildings that meet or exceed the two-star level of green building standards[13]	C_1
			Proportion of clean transportation of goods	C_2
			Proportion of new energy and clean energy-powered transportation vehicles	C_3
	Low carbon development with resource utilization	D	Comprehensive utilization rate of general industrial solid waste	D_1
			Reuse rate of industrial water	D_2
			Recovery and utilization rate of industrial waste heat	D_3
	Establishment of carbon management system	E	Whether or not establish the park-level carbon emission management platform	E_1
			Proportion of enterprises that have conducted carbon emission verification	E_2
			Proportion of enterprises that have conducted carbon footprint accounting and certification	E_3
			Proportion of key enterprises that conduct environmental information disclosure	E_4

2.2 Analytic Hierarchy Process (AHP)

The study first calculated the weights based on AHP method. The process involves four steps: (1) decompose the problem into a multi-level hierarchy which of this study has been done in chapter 2.1; (2) construct judgment matrix via expert-based pairwise comparisons of indicators; (3) weight calculation based on computing eigenvectors of the matrix; (4) consistency test by calculating the consistency ratio.

Based on expert consultation, the study constructed the judgment matrix, as listed in Table 2.

Table 2. The judgment matrix.

	A_1	A_2	A_3	B_1	B_2	C_1	C_2	C_3	D_1	D_2	D_3	E_1	E_2	E_3	E_4
A_1	1	1	1.5	1.5	1.8	1.8	2	2	2	2	1.8	1.5	1.8	2	2
A_2	1	1	1.5	1.5	1.8	1.8	2	2	2	2	1.8	1.5	1.8	2	2
A_3	0.667	0.667	1	1	1.5	1.5	1.8	1.8	1.8	1.8	1.5	1.2	1.5	1.8	1.8
B_1	0.667	0.667	1	1	1.4	1.5	1.5	1.5	1.5	1.5	1.4	1.2	1.5	1.5	1.8
B_2	0.556	0.556	0.667	0.714	1	1.2	1.4	1.4	1.4	1.4	1.2	1.1	1.4	1.4	1.5
C_1	0.556	0.556	0.667	0.667	0.833	1	1.1	1.1	1	1	0.9	0.9	0.9	0.9	1.4
C_2	0.5	0.5	0.556	0.667	0.714	0.909	1	1	1	1	0.8	0.7	0.8	0.9	1.3
C_3	0.5	0.5	0.556	0.667	0.714	0.909	1	1	1	1	0.8	0.7	0.8	0.9	1.3
D_1	0.5	0.5	0.556	0.667	0.714	1	1	1	1	1	0.9	0.9	1	1	1.2
D_2	0.5	0.5	0.556	0.667	0.714	1	1	1	1	1	0.9	0.9	1	1	1.2
D_3	0.556	0.556	0.667	0.714	0.833	1.111	1.25	1.25	1.111	1.111	1	1	1.2	1.2	1.4
E_1	0.667	0.667	0.833	0.833	0.909	1.111	1.429	1.429	1.111	1.111	1	1	1.8	1.8	2
E_2	0.556	0.556	0.667	0.667	0.714	1.111	1.25	1.25	1	1	0.833	0.556	1	1	1.4
E_3	0.5	0.5	0.556	0.667	0.714	1.111	1.111	1.111	1	1	0.833	0.556	1	1	1.3
E_4	0.5	0.5	0.556	0.556	0.667	0.714	0.769	0.769	0.833	0.833	0.714	0.5	0.714	0.769	1

The study then calculated the eigenvectors and weights, as shown in Table 3.

Table 3. Eigenvectors and weights.

Items	Eigenvector	Weight	Items	Eigenvector	Weight
A_1	1.609	10.73%	D_1	0.8	5.33%
A_2	1.609	10.73%	D_2	0.8	5.33%
A_3	1.301	8.67%	D_3	0.92	6.13%
B_1	1.21	8.07%	E_1	1.082	7.21%
B_2	1.027	6.85%	E_2	0.833	5.56%
C_1	0.837	5.58%	E_3	0.793	5.29%
C_2	0.763	5.08%	E_4	0.654	4.36%
C_3	0.763	5.08%			

The consistency ratio (CR) as shown in Table 4 is 0.003 and is less than 0.1, which means the judgment matrix has acceptable consistency and the weights and the above weights can be adopted as results of AHP method.

Table 4. Consistency test results.

Max eigenvalue	CI	RI	CR	Consistency Test Results
15.066	0.005	1.59	0.003	Pass

The combined weight of indicators under the criterion carbon efficiency ranked the highest, which implies that the priority of actual low carbon results.

2.3 Entropy Weight Method

Then the study calculated the objective weights using the entropy method. The method assigns higher weights to indicators with greater data variability, as these indicators better distinguish performance, while on the contrary, indicators with no data variability generally obtain the weight of 0 and are removed from the indicator system. It involves five steps: (1) normalization of original data; (2) calculate the proportion of each value relative to the total for each indicator; (3) use the probability distribution to determine the entropy of each indicator; (4) subtract entropy values from 1 to measure data variability; and (5) normalize divergence coefficients to obtain weights for each indicator.

For entropy weight method calculations, the study collected data from three National Ecological Industrial Demonstration Parks (Park A, B, C) in Jiangsu Province from 2020 to 2022. These parks were selected due to their compliance with provincial carbon reporting standards and representation of Jiangsu's key industries. Annual sustainability reports which were submitted to National Development & Reform Commission, served as the primary data source. However, there are some limitations including: (1) the sample size of 3 parks due to data availability may limit the generalizability to a certain extent; (2) E_1 showed no variation i.e. all parks scored 0 which might require extra consideration.

All original values were all of benefit criterions and can be firstly subjected to the normalization process using equation (1):

$$X_{ij}^{'} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \tag{1}$$

Then characteristic weight of evaluated object i under the indicator j i.e. P_{ij} can be calculated using equation (2):

$$P_{ij} = \frac{X_{ij}^{'}}{\sum_{i=1}^{n} X_{ij}^{'}} \tag{2}$$

The entropy value for each indicator e_j then can be calculated using formula (3):

$$e_j = -\frac{1}{\ln m}\sum_{i=1} \ln(P_{ij}) \tag{3}$$

The degree of divergence d_j can be calculated with formula (4):

$$d_j = 1 - e_j \tag{4}$$

Finally, the weights w_j can be calculated with formula (5) and the results are shown in Table 5:

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{5}$$

Table 5. Index weights from Entropy method.

Indicator	Weight	Indicator	Weight
A_1	9.39%	D_1	4.64%
A_2	6.42%	D_2	13.16%
A_3	6.20%	D_3	9.66%
B_1	15.71%	E_1	0.00%
B_2	3.61%	E_2	3.61%
C_1	8.93%	E_3	7.83%
C_2	3.61%	E_4	3.61%
C_3	3.61%		

In the panel data, the proportion of renewable energy and the reuse rate of industrial water varied significantly across different parks and cross-sectional years. For example, the proportion of renewable energy in Park A was around 0.38% in year 2022 while the rate in Park B was over 6%. Similarly, the reuse rate of industrial water in Park A increased from 87% in 2020 to 96% in 2022. Therefore, the entropy method assigned them with the highest weights. While the values of E_1 in all samples are the same which is 0, for that none of the parks had established the platform of carbon emission management when the historical data are collected. However, it can be predicted that platforms will emerge due to both the governmental requirements and of intrinsic needs of the industrial parks. Therefore, the research retains the indicator E_1 and later determines it weight in the combined AHP-entropy calculation.

2.4 Combined AHP-entropy Method

The study combines the weighting results from both AHP and entropy method through a linear weighting approach as shown in equation (6):

$$W_{combined} = \alpha \times W_{AHP} + (1-\alpha) \times W_{entropy} \tag{6}$$

Where $W_{combined}$ is the final combined weight of each indicator, α is the adjustment coefficient and are set to be 0.5 in this study, W_{AHP} and $W_{entropy}$ are respectively the weights from AHP and entropy method. And the results are shown in Table 6. B_1 which stands for proportion of renewable energy in total energy consumption earns the highest weight, 11.25%, which implied that greener energy system is the key element of low-carbon development for industrial parks. And the indicator group A of carbon efficiency during production which is the most outcome-oriented group, has the highest group weight of 25.7%.

Table 6. Index weights of low carbon development of industrial parks based on AHP-entropy.

Indicator	Final weight	Indicator	Final weight
A_1	9.63%	D_1	5.16%
A_2	8.71%	D_2	9.07%
A_3	7.36%	D_3	7.91%
B_1	11.25%	E_1	3.60%
B_2	5.39%	E_2	4.74%
C_1	7.29%	E_3	6.76%
C_2	4.50%	E_4	4.14%
C_3	4.50%		

3 Case Study

Based on the weights of the index derived from the AHP-Entropy method, the study carried out a case study of Park JN in Jiangsu Province. Park JN is a national economic development zone with 80% of its GDP generated by manufacturing industries, therefore it is a large-scale typical industrial park. An it is also one of China's first batch of national carbon peaking pilot parks.

After normalizing the relevant indicator value from year 2020 to 2022, the study calculated the scores of the park over the years as shown in Fig. 1. The evaluation result for industrial park JN. The score increased from 0.38 in 2020 to 0.44 in 2022, showing its overall improvement in low carbon development. However, its performance varies across different aspects.

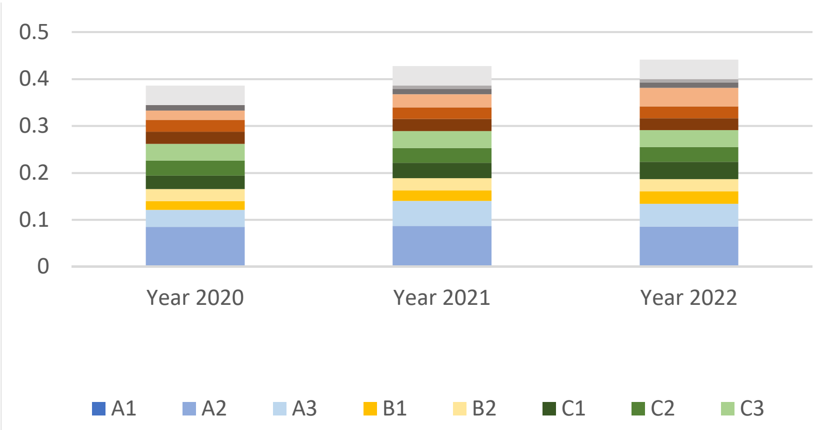

Fig. 1. The evaluation result for industrial park JN.

The scores of three aspects in criterion layer including low carbon energy consumption, infrastructure and resource utilization have seen continuous rise over the reported years. And among the individual indicators, B_1 showed the most significant rise which was followed by D_3, showing that rate of renewable energy used in the park and rate of industrial waste heat recovery have been effectively promoted. The score of carbon management remained stagnant, which was caused by lack of implementation of park-level carbon emission management platform and slow progress in enterprises' carbon management actions. Last but not the least, the scores for the most outcome-oriented aspect i.e. carbon efficiency fluctuated, with fluctuates in annual decreasing rate of carbon emission and energy consumption per unit added value created. It implies that the difficulty of reducing carbon emission and energy consumption intensity might be increasing. It should be noted that the indicator A_1 has not contributed to the scores in the evaluation years, for the total carbon emission in the park still grows yearly. As the carbon peaking pilot, the park management has set its goal to achieve carbon peaking before the year 2030 and has implemented more aggressive measures for energy transition to support the target. Therefore, A_1 is highly probable to start playing a positive role in the evaluation scores from the year 2030 on.

4 Conclusion

This study constructs a low-carbon industrial park evaluation index system based on policy and literature research. Using the AHP-entropy method and Jiangsu industrial park panel data, it determines index system weights. Results show that the actual decline in carbon emission intensity and total volume are the most intuitive indicators for measuring the low-carbon development. On the measurement side, boosting renewable energy use is the most effective way for parks to go low-carbon., and secondary measures include increasing industrial wastewater and waste heat utilization and green building numbers. Carbon management of industrial park is in its infancy and yet has much room for improvement. Using the weight results, the study assesses a typical

Jiangsu industrial park's 2020 - 2022 low-carbon performance, reflecting both its progress and weaknesses.

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