Research on Comprehensive Carbon Efficiency Evaluation and Impact Analysis of Science and Technology Park

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Abstract. In the development of China 's industrial economy, science and technology industrial parks have an increasingly important position and role, but the carbon emissions of industry and related equipment in the park cannot be ignored. It is necessary to analyze and evaluate the carbon emissions of the park and its impact. Combined with the characteristics of the park and the law of data distribution, an analysis model based on entropy method and a carbon efficiency factor contribution model are proposed to evaluate the comprehensive carbon efficiency of the park and analyze the impact of related factors. The results show that the comprehensive carbon efficiency of the park is on the rise as a whole, and the maximum value of the comprehensive carbon efficiency in 2022 is 0.5883. The most influential carbon efficiency factor is the investment in environmental protection funds, with a value of 0.0729. The worst in 2020 is 0.2925, and the total carbon emission of carbon efficiency factor is 0.0773, which has the greatest impact on the carbon efficiency of this year. Through the comparison of comprehensive carbon efficiency in different periods, we can find out the indicators that affect the improvement of carbon efficiency, which will provide scientific decision support for the park in reducing carbon emissions, optimizing energy utilization and promoting sustainable development of the park.

Keywords: science and technology park; analysis model; comprehensive carbon efficiency; factor contribution; carbon efficiency.

1 Introduction

Low-carbon and high-quality development has become an inevitable choice for China. Countries around the world have also carried out carbon emission control work and have made more and more achievements. In view of the relevant evaluation indicators of carbon dioxide emissions, especially the efficiency of carbon emissions, from the perspective of economics, efficiency is the ratio between output efficiency and input cost, or between output and input, while carbon efficiency refers to the fact

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that the unit of carbon dioxide emissions consumes less resources and obtains more economic output. Therefore, when conducting carbon efficiency evaluation, it is necessary to combine economic, resource and environmental indicators into a comprehensive index through appropriate calculation models. Only by comprehensively considering environmental and economic related factors can a reasonable evaluation and analysis be achieved. At present, there are more than 15,000 various types of science and technology industrial parks in China, and the scale and number of parks continue to expand. As a whole, the park has large energy consumption and a large number of energy systems and equipment. Therefore, studying the construction of an efficient low-carbon park system can not only effectively alleviate the main contradictions in the promotion of low-carbon emissions, but also explore the realization of an efficient integrated energy system. Therefore, it is particularly important to evaluate and analyze the carbon efficiency of the park scientifically and reasonably.

At present, there are many evaluation methods for carbon efficiency. For example, SU has constructed a multi-level evaluation system for urban low-carbon development level from the aspects of economic development level, energy structure and living consumption12[1]. YE F F et al.used principal component analysis to study the factors affecting the operation efficiency of cold chain low-carbon distribution[2]. SUN Y M et al.used the grey correlation analysis method to obtain the grey correlation degree of time series and regional grey correlation degree of each influencing factor and traffic carbon emission[3]. However, among many carbon efficiency evaluation methods, DEA model and TOPSIS model are widely used.In the research and application of DEA model, ZHOU X et al.used the DEA-CCR model to calculate the low-carbon economic development efficiency of 30 provinces (autonomous regions and municipalities) in China in 2017, and used the fuzzy set qualitative comparative analysis method to study the factors affecting the efficiency of China 's low-carbon economic development[4]. Based on the data envelopment analysis model, KMEHMOOD discussed the temporal and spatial variation of low-carbon efficiency in the world 's major economies in recent years[5]. The results show that China 's efficiency value is better among middle-income countries, CHEN J H et al.used the Super-SBM model to measure the low-carbon efficiency of cities and prefectures in Sichuan Province, and used GIS technology to analyze the spatial characteristics of low-carbon efficiency in Sichuan Province[6]. YIFTIKHAR used the network DEA model to analyze the carbon dioxide emission efficiency of major economies. The results show that 89 % of carbon dioxide emissions are due to low economic and distribution efficiency[7]. In the research and application of TOPSIS, ZHENG F et al.used TOPSIS method to construct a carbon emission reduction responsibility allocation model for major industries in Hebei Province and a carbon emission reduction responsibility allocation model for various sub-sectors of manufacturing industry, and comprehensively evaluated and analyzed the carbon emission reduction potential of its manufacturing industry[8]. XU S used the OWA operator weighting method and the TOPSIS comprehensive evaluation model to evaluate and analyze the carbon emission economic efficiency of cities in Shandong Province from 2005 to 2009 from the time and space dimensions, and put forward some suggestions[9]. LI H S used the ANP-TOPSIS model to construct a comprehensive evaluation system for construction suppliers from the five indicators of product advantages, comprehensive strength, service level, development potential, and low-carbon level under the environment of low-carbon construction supply chain. The concept of low-carbon supply chain is introduced into the selection of suppliers, which provides a reference for the selection of suppliers for low-carbon operation of enterprises[10].MARQUEZ B et al. conducted a low-carbon evaluation of Barcelona and Malaga from three aspects of energy use, system and flow through the entropy weight method[11].

Combined with the characteristics of industrial parks, a multi-index evaluation system for industrial parks is proposed. The entropy method based on objective evaluation is studied, and an improved entropy weight-TOPSIS model is formed to comprehensively evaluate and analyze the carbon efficiency of industrial parks in different years. By collecting and processing the data of a series of key evaluation indexes, the carbon efficiency is calculated and analyzed, and the influence degree of each index is analyzed by the carbon efficiency factor contribution model.

2 Determination of Carbon Emission Evaluation Index

In order to ensure the accuracy, comprehensiveness and feasibility of the evaluation of the carbon efficiency of the park, and improve the reliability, applicability and practicability of the evaluation results of the carbon efficiency, the carbon efficiency index system of the park needs to truly reflect the carbon emission status of the park, and comprehensively consider the economy, energy, environment and other aspects, combined with the relevant index data section to calculate and analyze.

According to the principle of index system construction, combined with the development characteristics of industrial parks, the carbon information data of industrial parks were collected. From the three dimensions of ' economy-energy-environment ', six evaluation indexes were selected, including the total output value of the park, the total green output value, the total power consumption, the investment in environmental protection funds, the carbon emissions per unit output value and the total carbon emissions of the park. The specific index system of the selected park is shown in Table 1.

Table 1. Park carbon efficiency index evaluation system

First grade indexes	Secondary indicators	Numbering	Indicator direction
Economy	The total output value of the park (ten thousand yuan)	A1	+
	Green total output value (ten thousand yuan)	A2	+
Energy	Total power consumption (million degrees)	N1	-
Environment	Environmental protection funds investment (ten thousand yuan)	E1	+
	Carbon emissions per unit of output value (tons / million yuan)	E2	-
	The total carbon emissions of the park (tons)	E3	-

In 2018, the park was put into use, vigorously promoting the low-carbon transformation of industrial parks and forming related low-carbon economic industries. Through the analysis of the production and operation status of the park from 2019 to 2023, the corresponding index data are obtained. The specific indicator data are shown in Table 2.

Table 2. The initial data of carbon efficiency evaluation index of the park

	Index					
Time(year)	A1	A2	N1	E1	E2	E3
2019	51552.76	15164.41	2488.67	3.60	979.96	100171.07
2020	56429.22	13924.94	1192.51	3.54	1071.49	108166.10
2021	57842.28	24359.58	644.59	3.43	1101.26	107491.04
2022	55747.03	27926.63	81.43	3.15	1063.63	95470.51
2023	62599.61	29466.04	343.01	3.07	1196.27	104743.04

3 Evaluation and Impact Analysis Model

3.1 Entropy Weight-TOPSIS Improved Model

In physics, entropy can characterize the energy dissipation of the system. The greater the entropy increase, the greater the available energy loss of the system. On the contrary, the smaller the entropy increase, the higher the energy conversion efficiency of the system. In the real society, information orderliness is an important parameter to characterize the stability of the system. Therefore, in order to enhance the orderliness of the system, information entropy is needed to supplement, so information entropy is a measure of the orderliness of the system. Entropy has both physical and social attributes. It is the basis for judging the stability of the scientific expression system in the objective world. Therefore, using entropy to calculate the index weight has strong objectivity and reality. Its reliability is superior to other weight assignment methods. Therefore, based on the entropy method, a comprehensive evaluation of the entire index system is carried out.

When using the TOPSIS method, the comprehensive carbon efficiency ranking is used as the basis for the advantages and disadvantages of each evaluation object, and the evaluation effect of the comprehensive carbon efficiency cannot be fully utilized. When calculating the comprehensive carbon efficiency, it is necessary to add the distance between each scheme and the ' positive ideal solution ' and the ' negative ideal solution ', and the distance between the ' positive ideal solution ' and the ' negative ideal solution ' is two indicators in the opposite direction. Mixing the indicators in different directions will lead to the evaluation of the calculation results that cannot fully reflect the actual situation. At the same time, when the distance between the ' positive ideal solution ' and the ' negative ideal solution ' is inconsistent, the reasonable interpretation of the calculation results will become difficult.

In view of the above problems, the distance from the evaluated object to the ' positive ideal solution ' and the ' negative ideal solution ' is normalized, and the distance from the evaluated object to the ' positive ideal solution ' and the ' negative ideal solution ' is transformed into the same direction index to solve the unreasonable problem caused by the direct addition of different classes of positive distance and negative distance. At the same time, the distance between the evaluated object and the ' positive ideal solution ' and the ' negative ideal solution ' is standardized, so that both distances are mapped to the [0,1] interval, ensuring that their values are in the same order of magnitude, so as to achieve reasonable scientific evaluation.

The specific index evaluation model is divided into five parts, including matrixization of initial data, dimensionless, entropy weight, ideal solution calculation and comprehensive carbon efficiency evaluation.

(1)Matrixization of index initial data

The initial carbon efficiency index data of the park (see Table 2), and the matrix formed by it is a matrix of 5 rows and 6 columns. Two-dimensional data matrix composed of n indicators in m years. The initial data matrix is expressed by the following formula:

$$X=\begin{bmatrix} x_{11} & \cdots & x_{1j} \\ \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} \end{bmatrix}=\left(x_{ij}\right)m\times n \tag{1}$$

where $i=1,2,....,m$; $j=1,2,....,n$. Here m = 5, n = 6

(2)Index non-dimensionalization

Since the selected indicators are evaluated and measured for the carbon efficiency of each year from the aspects of j different indicators, the dimensions of each indicator j are different and cannot be directly analyzed. It is necessary to carry out dimensionless processing of the original data to eliminate the dimensional differences between the indicators in order to achieve comparability. The common index directions are positive direction index and negative direction index. There are different processing formulas for different types of indicators.

The calculation method of the positive directional index is as follows:

$$y_{ij}=\frac{x_{ij}-\min x_{j}}{\max x_{ij}-\min x_{ij}} \tag{2}$$

The calculation method of negative directional index is as follows:

$$y_{ij}=\frac{\max x_{ij}-x_{ij}}{\max x_{ij}-\min x_{ij}} \tag{3}$$

where $i=1,2,....,m$; $j=1,2,....,n$. And are the $\max x_{ij}$ and $\min x_{ij}$ values of the index of column j in matrix X, respectively. For the normalized dimensionless values of each index, the normalized matrix is expressed by the following formula:

$$Y = \begin{bmatrix} y_{11} & \cdots & y_{1j} \\ \vdots & \ddots & \vdots \\ y_{i1} & \cdots & y_{ij} \end{bmatrix} = \left(y_{ij}\right) m \times n \tag{4}$$

(3)Constructing weighted standard matrix

In the comprehensive index system of carbon efficiency, there are six indicators, each of which has different effects and relative importance on the evaluation. Therefore, it is necessary to distinguish them by giving different weights to each indicator. The entropy weight method is an effective method to calculate the weight of each index objectively. When calculating the weight of each index by entropy weight method, first of all, calculate the proportion k_{ij} of the i-year tempering value to the sum of the j-index under the j-index. Then, the entropy value H_j and weight w_j of the j index are obtained. Finally, the weighted normalized matrix V can be obtained.

Get the weight:

$$k_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}} \tag{5}$$

$$H_j = -\frac{1}{\ln m} \sum_{i=1}^{m} k_{ij} \ln k_{ij} \tag{6}$$

$$w_j = \frac{1 - H_j}{n - \sum_{j=1}^{n} H_j} \tag{7}$$

Among them, $1 - H_j$ represents the difference factor of the j index. The difference factor of the index is the value to measure the difference of the index data, which is opposite to the entropy value. The greater the difference of index data, the greater the value, the greater the effect on the whole evaluation scheme, and vice versa.

The matrix Y_{ij} is weighted to obtain the weighted matrix V_{ij}:

$$V_{ij} = y_{ij} \times w_j \tag{8}$$

$$V = \begin{bmatrix} v_{11} & \cdots & v_{1j} \\ \vdots & \ddots & \vdots \\ v_{i1} & \cdots & v_{ij} \end{bmatrix} = \left(v_{ij}\right) m \times n \tag{9}$$

(4)The distance from the evaluation object to the positive and negative ideal solutions

The positive ideal solution is the vector v_j^+ composed of the maximum value of each index data after weighting, and the negative ideal solution is the column vector v_j^+ composed of the minimum value of each index data after weighting.

The distance from the evaluation object to the positive ideal solution:

$$d_i^+ = \sqrt{\sum_{j=1}^{n} (v_j^+ - v_{ij})^2} \tag{10}$$

The distance from the evaluation object to the negative ideal solution:

$$d_i^- = \sqrt{\sum_{j=1}^{n} (v_j^- - v_{ij})^2} \tag{11}$$

(5)Comprehensive carbon efficiency

According to the size of the comprehensive carbon efficiency data c_i in different years, it is sorted. Through comparative analysis, the carbon efficiency of each year can be judged to provide decision-making guidance for the subsequent low-carbon operation of the park.

$$c_i^+ = \frac{1 / d_i^+}{\sqrt{\sum_{i=1}^{m} \left(1 / d_i^+ \right)^2}} \tag{12}$$

$$c_i^- = \frac{d_i^-}{\sqrt{\sum_{i=1}^{m} \left(d_i^- \right)^2}} \tag{13}$$

$$c_i = \frac{c_i^+ + c_i^-}{2} \tag{14}$$

$$T_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{15}$$

c_i^+ and c_i^- are the normalization of the distance from the evaluation object to the positive ideal solution and the distance from the evaluation object to the negative ideal solution, respectively. c_i is the improved comprehensive carbon efficiency; T_i is the comprehensive carbon efficiency of the calculation model before improvement.

3.2 Carbon Efficiency Factor Contribution Model

When evaluating the carbon efficiency of the park, it is necessary to analyze the index factors that affect the change of carbon efficiency, so as to reasonably control the energy consumption of the park equipment and adjust the development of the industry. Therefore, it is necessary to establish the contribution model of the carbon efficiency factor of the park. The carbon efficiency factor contribution model is established on the basis of the obstacle factor diagnosis and analysis method[12]. The data matrix normalized by the data of the carbon efficiency index is taken as the object to analyze the influence of the specific index on the comprehensive carbon efficiency. The specific form of the formula is as follows:

$$I_{ij} = 1 - y_{ij} \tag{16}$$

$$O_{ij} = \frac{W_j \times I_{ij}}{\sum_{j=1}^{n} \left(W_j \times I_{ij} \right)} \tag{17}$$

Among them, I_{ij} is the index deviation, O_{ij} is the factor contribution corresponding to the specific value of each index, y_{ij} is the dimensionless value of the index, and W_j is the weight of each index. The greater the value of the factor contribution, the greater the obstacle of the index to the calculated comprehensive carbon efficiency.

4 Result Analysis

After normalizing the initial value of the carbon efficiency index of the science and technology industrial park from 2019 to 2023, the weight w_j of each index is calculated as shown in Fig.1.

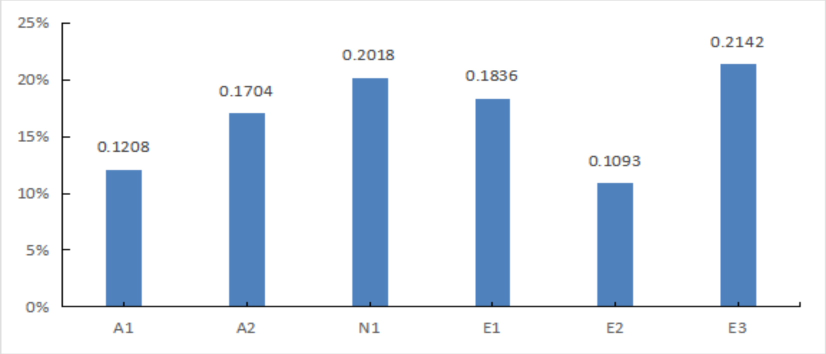

Fig. 1. The weight of each evaluation index of carbon efficiency in the park

Here, the value range of the weight is between 0 and 1, indicating that the index provides effective information in the comprehensive evaluation. When the weight value is zero, it means that the index value of each evaluation object is completely consistent, indicating that the comprehensive evaluation does not provide effective information for differential evaluation, and the index should be eliminated. On the contrary, when the weight value is close to 1, it means that the index values of each evaluation object are quite different, providing more effective evaluation information. It can be seen from Figure 1 that the total weight of carbon emissions in the park is the largest, and its value is 0.2142. Therefore, this index has a greater impact on the carbon efficiency of the park. Combined with Table 2, it can be seen that the total carbon emissions of the park in the past five years have shown a downward trend, and the total output value has shown an increasing trend. At the same time, the carbon emissions per unit of output value and the ratio of the total carbon emissions of the park to the total output value of the park have decreased year by year, indicating that the park focuses on economic development while focusing on environmental impact. At the same time, the weight of environmental protection capital investment is 0.2018, so it has a great impact on the carbon efficiency of the park. The investment in environmental protection funds has been reduced year by year as a whole, because the construction of environmental protection infrastructure in the park has been completed, and environmental protection technology has maintained a high level. The total power consumption and total output value of the park are relatively small. Although they all show an overall increasing trend, their relative changes are small, so the impact on the carbon efficiency of the park is smaller than other indicators.

Through the above entropy Weight-TOPSIS model, the comprehensive carbon efficiency comparison of the park from 2019 to 2023 can be calculated. The details are shown in Fig.2.

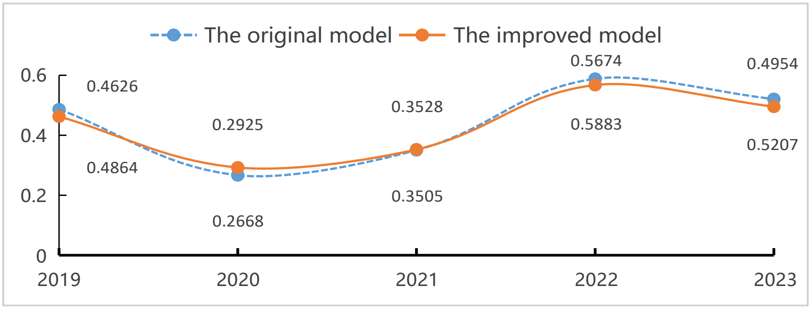

Fig. 2. The comprehensive carbon efficiency of the park from 2019 to 2023

It can be seen from the result curve of Fig.2 that the original model and the new model show consistency in the order of the size change of the comprehensive carbon efficiency calculation results, indicating that while maintaining the carbon efficiency evaluation results unchanged, it is reasonable to add the results of the model from two opposite directions to the same direction.

From the perspective of comprehensive carbon efficiency, the park 's carbon efficiency has shown a good upward trend in the past 2020-2022, indicating that the industrial effect of its low-carbon development has played a certain role. Among them, the best comprehensive carbon efficiency will be achieved in 2022, because in 2022, the park will be systematically integrated into the concept of carbon neutrality in all aspects of management and operation, adopt zero-carbon or low-carbon design, zero-carbon industry, zero-carbon energy and other aspects of comprehensive national standards, and build a carbon neutralization path covering manufacturing, office and life. In 2023, the comprehensive carbon efficiency decreased because of the increase of power consumption and carbon emissions in the park compared with 2022.

It can be seen from Fig.2 that the comprehensive carbon efficiency in 2022 is 0.5674, which is the maximum; the comprehensive carbon efficiency value in 2020 is 0.2925, which is the minimum value. Through the carbon efficiency factor contribution model, we can analyze the reasons for the impact of the comprehensive carbon efficiency in 2020 and 2022, and its factor contribution is shown in Fig.3.

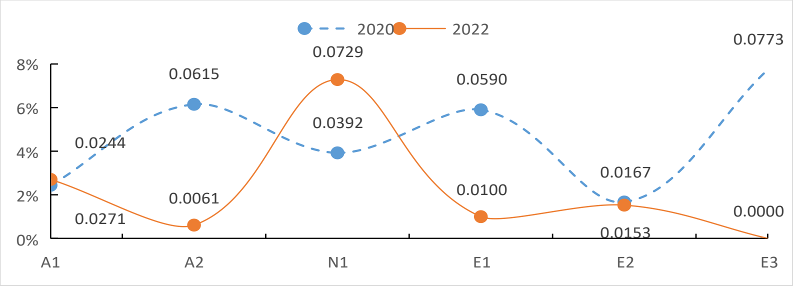

Fig. 3. The factor contribution of the park in 2020 and 2022

From Fig.3, it can be seen that the largest impact on the comprehensive carbon efficiency of the park in 2020 is the total carbon emissions of the park. The total carbon emissions of the park include direct emissions from fixed combustion and mobile combustion, indirect emissions from purchased electricity or cold and heat energy, and other indirect emissions from production, transportation and commuting. In 2020, the carbon emissions of the park are the most in five years. This is because the park relies on traditional fossil fuels as the main energy in the initial stage of operation, and the utilization ratio of clean energy and renewable energy is relatively low, which increases the carbon emissions of the park. The research and application of low-carbon technology is still in its infancy, and the park lacks advanced energy-saving and emission reduction technologies and equipment, which makes it difficult to effectively reduce carbon emissions. The biggest impact on the comprehensive carbon efficiency of the park in 2022 is the investment in environmental protection funds. From the initial data, the investment in environmental protection funds in 2022 is relatively the smallest in five years. This is because the park in 2022 With the adjustment of industrial structure and the progress of environmental protection technology, the construction of environmental protection infrastructure has been completed, and environmental protection technology has maintained a high level, resulting in a reduction in investment in environmental funds. At the same time, the contribution of the total output value, green output value and total carbon emission of the park is relatively low, which makes the comprehensive carbon efficiency of the park maintain a high level in 2022.

5 Conclusions

In order to realize the carbon emission control of the science and technology industrial park and improve the carbon efficiency, it is necessary to comprehensively analyze and optimize the selected multiple indicators to achieve better analysis and judgment to draw guiding conclusions. Based on the entropy weight-TOPSIS method, an improved analysis and evaluation method of comprehensive carbon efficiency is proposed, and the analysis and evaluation decision of the park 's carbon emission reduction capacity is realized.

Through the calculation of the comprehensive carbon efficiency of the park by the TOPSIS model and the improved model, while maintaining the consistency of the results, the interpretation of the comprehensive carbon efficiency on the model is more reasonable, and the reliability of the new model is verified.

Through the calculation results, it is found that the comprehensive carbon emission results of the park in the past five years show that the carbon efficiency is the lowest in 2020, with a value of 0.2925. The carbon efficiency is the highest in 2022, with a value of 0.5674. Combined with the carbon efficiency factor contribution model, the indicators that hinder the improvement of its carbon efficiency level are the total carbon emissions of the park and the investment in environmental protection funds. The park can find out the indicators that affect the improvement of comprehensive carbon efficiency according to the contribution of carbon efficiency factors, and make corresponding improvement measures for subsequent development and management.

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