Research on Carbon Audit Evaluation Model Based on Entropy Weight Method

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Abstract. In order to achieve the ambitious goals of "carbon peak" and "carbon neutrality" as soon as possible, it is necessary to study China's carbon emission level and emission reduction path. This research paper constructs a carbon audit evaluation model based on the "5E" theory using the entropy weight method and the red-green light scoring method, and empirically analyzes the national carbon audit scores from 2010 to 2022. The research results show that the carbon audit score of China is influenced by factors such as carbon emissions from economic contribution and improvement in low-carbon technology efficiency, and it shows an upward trend and will continue to grow rapidly in the future. The audit score demonstrates the effectiveness and direction of carbon governance in China. Based on the research results of the model and in combination with relevant policies and regulatory requirements, this paper proposes specific measures for green development and energy conservation and emission reduction from six aspects: industry characteristics and corporate behavior, energy structure, product and service quality, ecological civilization, environmental policies and regulations, and environmental publicity and raising public awareness.

Keywords: Carbon Audit, Correlation Analysis, Entropy Weight Method, Red-Green Light Scoring Meth.

1. Introduction

Currently, climate change has gradually become an important problem faced by the whole world. On September 22, 2020, China announced the "dual carbon" goals of "carbon peak" and "carbon neutrality" at the United Nations Sustainable Development Summit, making carbon reduction an important topic of current research.

Currently, the research on carbon dioxide focuses on factors influencing carbon emissions, carbon emission prediction, carbon audit evaluation indicators, and models. Regarding the factors influencing carbon dioxide emissions, Li Yan used the K-means clustering analysis method to construct the STIRPAT model and identified economic factors that influence carbon emissions [1]. Deng Guangyao studied the regional differences in carbon emissions from energy consumption in China over the past decade using the Gini coefficient and geographically weighted regression models, and concluded that different regions should formulate carbon emission reduction policies based on their own actual situations [2]. In terms of carbon emission prediction, Zhao Xiaonan, Xie Xinlian, and Zhao Ruijia used the grey relational analysis method to calculate the correlation values of various influencing factors of carbon emissions in railway transportation and established an improved LSTM model to predict future carbon emissions from railway transportation for the next 10 years [3]. She Lihui et al. used Markov models and the LEAP model to consider the impact of optimized energy structure and reduced energy demand on carbon emissions, and predicted the regional carbon emissions under different scenarios, providing feasible paths for low-carbon development of railway transportation in the future [4].

The current research on carbon auditing mainly focuses on two aspects: the construction of carbon auditing evaluation indicator system and the study of carbon auditing methods.In terms of the construction of carbon auditing evaluation indicator system, Zheng Guofang, Xu Ronghua, and Zhu Xiaorong developed a carbon auditing evaluation indicator system based on the theory of carbon auditing. They used the entropy weight method and the "4M2E" evaluation indicator system to construct the carbon auditing evaluation indicator system [5]. Luo Ling and Zhang Tian constructed a

carbon auditing evaluation indicator system for the sugar industry based on the DSR model. They also introduced environmental premiums in their research, providing reference for carbon auditing in the sugar industry [6]. Chen Lilan and Wuyun Taoli integrated RPA technology into the carbon auditing trust system, further enhancing the security and credibility of carbon auditing [7].

In terms of carbon auditing research methods, Yuan Guangda, Gu Jianli, and Wang Yuqin conducted carbon auditing for Sinopec based on the "5E" principle. They combined the analytic hierarchy process and expert scoring method to formulate a series of recommendations and measures for CO_2 energy conservation and emissions reduction [8]. Based on the conclusions drawn from carbon auditing research, Qi Xiaoyan and Chu Xingyu summarized valuable experiences in carbon auditing subjects, content, regulations, and promotion, combining them with carbon auditing experiences from some developed countries, and advocated for practical implementation [9]. Wu Xiaobo and Xu Liwei discussed the integration strategy of energy conservation and environmental protection, and proposed suggestions to further enhance the effectiveness of energy conservation, emissions reduction, and environmental protection work [10].

In summary, there is currently limited research on carbon auditing evaluation in China. Existing studies mainly focus on the provincial level, and the auditing evaluation methods used are primarily expert scoring and analytic hierarchy process, which have certain subjectivity and can lead to deviations in carbon auditing results. Moreover, research on carbon auditing evaluation models is still in the stage of theoretical construction, lacking effective empirical analysis.

Therefore, this paper first clarifies the indicators that affect carbon emissions in China through the "5E" theory combined with correlation analysis, and constructs a carbon auditing evaluation indicator system. Then, the entropy weight method and the traffic light scoring method are employed to build a carbon auditing evaluation model. Empirical analysis is conducted using data related to carbon emissions from 2009 to 2022, and the carbon auditing scores and annual growth rates for the research period are synthesized. Finally, based on the national carbon auditing scores, the main influencing factors of current carbon auditing, as well as future improvement paths, are studied. Taking into account the contemporary background and relevant policy requirements, this paper proposes recommendations for overall carbon reduction improvements and relevant emission reduction methods, aiming to further promote China's emission reduction development and achieve the "dual carbon" target at an early date.

2. Model introduction

2.1. Correlation Analysis based on the “5E” Theory

The traditional "3E" theory refers to economy, efficiency, and effectiveness, which are the core contents of performance auditing. Building upon the "3E" theory, the environmental aspect and fairness have been incorporated into the core content of performance auditing evaluation, forming the "5E" theory, specifically including economy, efficiency, effectiveness, fairness, and environmental aspects.

Correlation analysis refers to the statistical analysis indicators used to measure the degree of correlation between two or more variables that have a correlation relationship. The correlation coefficient, also known as Pearson's product-moment correlation coefficient, is denoted by the letter γ, and its value ranges between -1 and +1. The correlation coefficient, represented by the Greek letter γ, has a range of (-1, 1), where $\gamma > 0$ indicates positive correlation, $\gamma < 0$ indicates negative correlation, and $\gamma = 0$ indicates no correlation. $|\gamma|$ represents the degree of correlation between variables, and typically, when $|\gamma|$ is greater than 0.8, it is considered to have a strong linear correlation between the two variables. The formula for calculating the correlation coefficient is as follows:

$$r_{XY} = \frac{\sum_{i=1}^{N}(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{N}(X_i-\bar{X})^2}\sqrt{\sum_{i=1}^{N}(Y_i-\bar{Y})^2}} \quad (1)$$

2.2. Entropy Weight Method

Entropy is a measure of the degree of disorder in a system. The entropy weight method is a decision analysis method used to determine the weights of multiple evaluation indicators. It evaluates the comprehensive contributions of different decision alternatives by normalizing the different indicators and calculating the entropy value of each indicator. The principle and calculation process of the entropy weight method are shown in Figure 1.

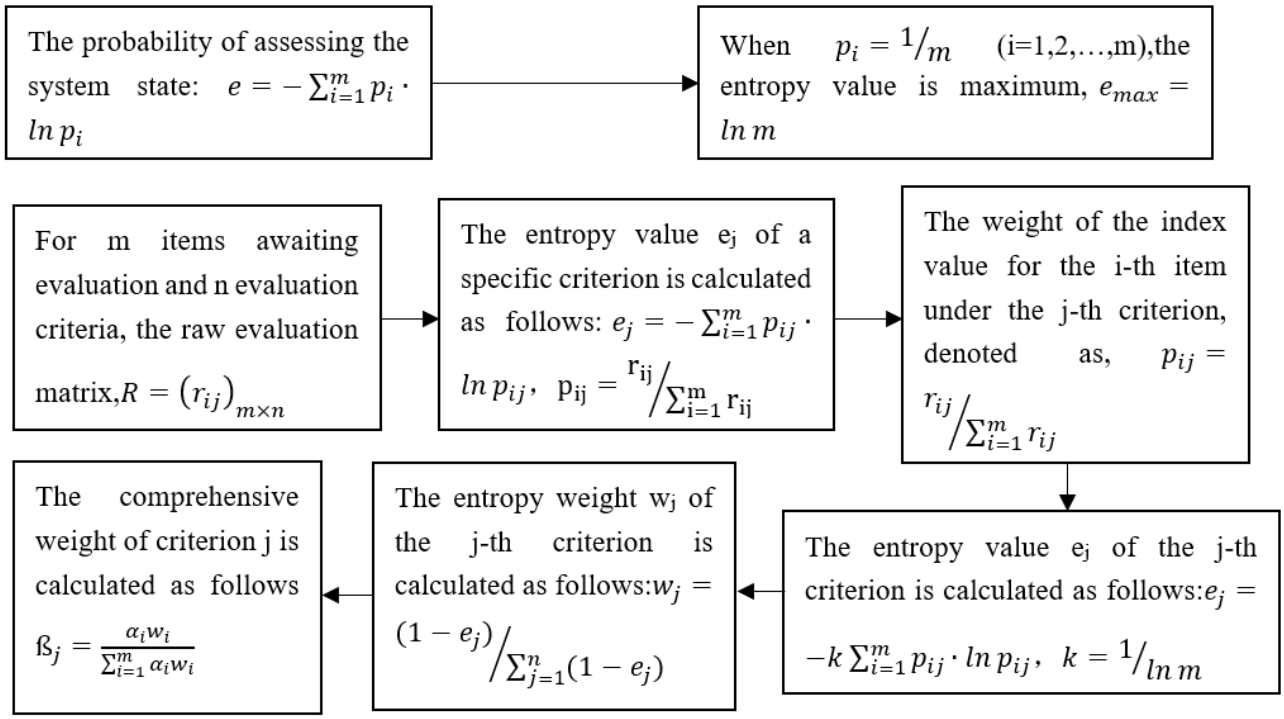


Figure 1. Principle and calculation process diagram of entropy weight method

2.3. Traffic light scoring method

The traffic light scoring method is based on the principle of traffic lights. Depending on the different intervals and changes in data growth rate, the carbon audit score is divided into multiple levels to focus on different levels of data and implement targeted measures.

2.4. Carbon audit evaluation model based on entropy weight method:

Through correlation analysis, entropy weight method, and traffic light scoring method, this paper constructs the process diagram of the carbon audit evaluation model as shown in Figure 2.

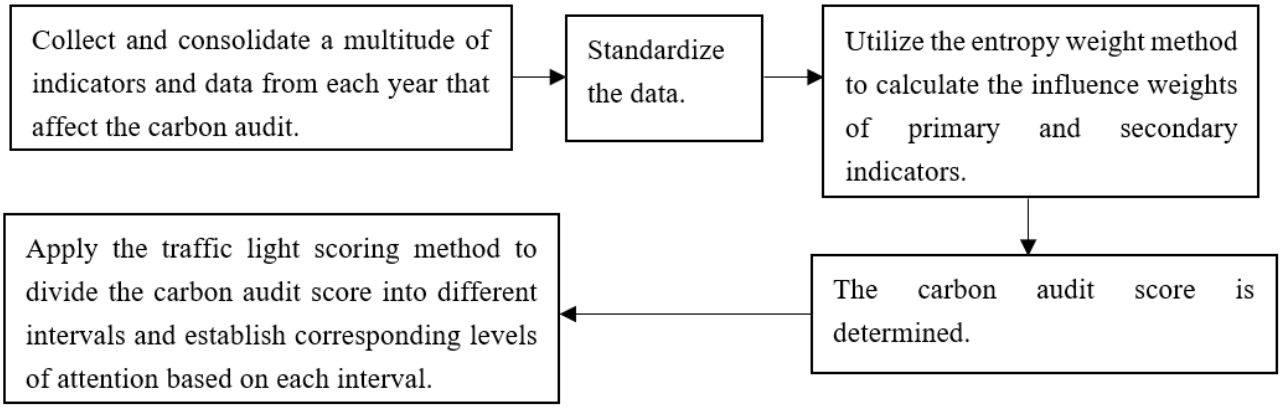


Figure 2. Carbon Audit Evaluation Model Process Flowchart

3. Empirical Analysis

3.1. Data Source and Preprocessing

The data used in this study mainly comes from the official website of the National Bureau of Statistics. The research period covers the years 2009 to 2022. In order to eliminate the influence of different units of measurement, the data is standardized using 2009 as the base year. The standardization formula is given by Equation (2).

$$Z = \frac{(X-MIN)}{(MAX-MIN)} \tag{2}$$

3.2. Construction of Indicator System

After collecting research and indicator data from previous literature, a correlation analysis is conducted to determine the indicators related to carbon auditing. The carbon audit evaluation indicator system is constructed as shown in Table 1. The primary indicators and secondary indicators of each evaluation indicator are represented by the letters Xi and Yi, respectively.

Table .1. Carbon Audit Evaluation Index System

Primary indicators	Secondary indicators	Representation
Economic contribution carbon emissions(X1)	GDP	Y_{11}
	Per capita GDP	Y_{12}
	Carbon emissions per unit of GDP	Y_{13}
	Value added of the secondary industry	Y_{14}
	Value added of the tertiary industry	Y_{15}
	Investment in urban environmental infrastructure construction	Y_{16}
	Total fixed asset investment of the whole society	Y_{17}
	Household consumption level	Y_{18}
Industrial and regional structure(X2)	Total population	Y_{21}
	Urban employed population	Y_{22}
	Rural employed population	Y_{23}
	Employment in the primary sector	Y_{24}
	Employment in the tertiary sector	Y_{25}
Environmental protection measures(X3)	Forest area	Y_{31}
	Urban green space area	Y_{32}
	Per capita Park and green area	Y_{33}
	Green coverage rate in built-up areas	Y_{34}
	Investment in environmental pollution control	Y_{35}
	Annual total carbon dioxide emissions in China	Y_{36}
Energy consumption carbon emissions(X4)	Per capita carbon emissions	Y_{41}
	Per capita energy consumption	Y_{42}
	Total energy consumption	Y_{43}
	Major fossil energy sources	Y_{44}
	Major clean energy sources	Y_{45}
Improvement in low-carbon technology efficiency(X5)	Total energy consumption in comprehensive utilization of waste resources industry	Y_{51}
	Losses in energy processing and conversion	Y_{52}

3.3. Weight Setting

To ensure the rationality of the weights, this paper uses the entropy weight method to determine the weights of each indicator. The weight allocation results are shown in Table 2.

Table .2. Carbon Audit Indicator Weights

	item	information entropy value "e"	information utility value "d"	weight (%)	weight (%)
X_1	Y_{11}	0.871	0.129	5.465	36.55
	Y_{12}	0.87	0.13	5.528	
	Y_{13}	0.845	0.155	6.59	
	Y_{14}	0.919	0.081	3.454	
	Y_{15}	0.897	0.103	4.366	
	Y_{16}	0.916	0.084	3.546	
	Y_{17}	0.918	0.082	3.49	
	Y_{18}	0.903	0.097	4.109	
X_2	Y_{21}	0.92	0.08	3.377	19.57
	Y_{22}	0.922	0.078	3.293	
	Y_{23}	0.895	0.105	4.468	
	Y_{24}	0.924	0.076	3.232	
	Y_{25}	0.878	0.122	5.201	
X_3	Y_{31}	0.956	0.044	1.879	15.60
	Y_{32}	0.908	0.092	3.893	
	Y_{33}	0.937	0.063	2.692	
	Y_{34}	0.953	0.047	1.994	
	Y_{35}	0.949	0.051	2.169	
	Y_{36}	0.93	0.07	2.977	
X_4	Y_{41}	0.938	0.062	2.63	17.56
	Y_{42}	0.934	0.066	2.819	
	Y_{43}	0.922	0.078	3.295	
	Y_{44}	0.898	0.102	4.323	
	Y_{45}	0.894	0.106	4.49	
X_5	Y_{51}	0.82	0.18	7.636	10.72
	Y_{52}	0.927	0.073	3.082	
sum				100	100

3.4. Results and Analysis

After standardizing the data of various indicators between 2009 and 2022 and multiplying them by the weights assigned to each indicator, the carbon audit scores for each indicator and year are obtained. The growth rates of individual indicators and the growth rates of carbon audit scores are calculated to observe trends, highlight significant data, analyze the main indicators influencing the carbon audit score for each year. The results of carbon audit scores and growth rate are shown in Table 3.

Table .3. Carbon Audit Scores and Growth Rates for Each Indicator and Year

Year	scores of each year	annual score growth rate
2009	-123.05	
2010	-110.05	10.57%
2011	-97.81	11.12%
2012	-86.21	11.85%
2013	-75.17	12.81%
2014	-54.44	27.58%
2015	-35.88	34.09%
2016	-12.31	65.69%
2017	22.77	284.96%
2018	58.52	156.95%
2019	86.06	47.07%
2020	97.14	12.88%
2021	152.73	57.22%
2022	177.70	16.36%

Based on the analysis results, the main indicators influencing the carbon audit score for each year are as follows: gross domestic product (GDP), employment in the tertiary industry, major fossil energy and clean energy, and comprehensive utilization of waste resources.

While economic development has shown growth, the control of carbon emissions has improved compared to previous years, resulting in an overall trend of economic growth accompanied by a decrease in carbon emissions. This represents the development pattern of a 'green economy.' The transformation and upgrading from the primary industry to the tertiary industry, as well as the shift of employment from rural to urban areas, have had a positive impact on the carbon audit score. There is a trend of transitioning from fossil energy to clean energy consumption, although fossil energy still remains a major component of economic development in terms of total volume.

In terms of environmental protection measures, investments in environmental pollution control have varied significantly but generally show an increasing trend. Forest area and green space have been growing steadily at a fixed growth rate each year. In terms of low-carbon technological efficiency, there have been continuous improvements in low-carbon emission reduction technologies, resource utilization efficiency, multiple recycling, and processing of different resources, which have contributed to reducing carbon emissions and improving the carbon audit score. The carbon audit score has turned positive since 2016 and has maintained a considerable growth rate annually.

Since 2014, almost all indicators have shown a significant upward trend, which is closely related to the national policy emphasis on green development and the concept of harmonious coexistence between humans and nature. From 2015 to 2017, the carbon audit score experienced the largest increase due to the global economic recovery, improvement in China's foreign trade situation, and the launch of the world's largest carbon market pilot, which encouraged companies to reduce carbon emissions and improve energy efficiency. In recent years, the impact of the COVID-19 pandemic has led to a slowdown in growth across various industries, resulting in relatively stable growth of carbon audit indicators.

In conclusion, the overall trend of the carbon audit score is on the rise, with continuous green economic development, optimization of industrial structure, improvement in energy utilization efficiency, and enhancement of environmental protection measures and awareness. Numerous factors are contributing to the improvement of the carbon audit score.

3.5. Traffic Light Scoring and Level Division of Carbon Audit Score

The positive and negative values of the carbon audit score represent the performance of carbon emissions within each indicator for the corresponding year range. The red zone represents years with

a significant increase in carbon audit score compared to the previous year, under the condition of negative carbon audit score. In this range, it is necessary to maintain economic growth while monitoring carbon emissions. The yellow zone represents years with a relatively moderate increase in carbon audit score compared to the previous year, under the condition of negative carbon audit score. This range typically indicates that the carbon audit score is about to turn positive but still requires attention to the overall situation of the carbon audit score. The blue zone represents years with a relatively moderate increase in carbon audit score compared to the previous year, under the condition of positive carbon audit score. The carbon audit score is already positive within this range and maintains a relatively stable growth rate. It is necessary to continue implementing improvement measures for carbon audit. The green zone represents years with a significant increase in carbon audit score compared to the previous year, under the condition of positive carbon audit score. This range belongs to the advantageous zone of the carbon audit score, indicating good carbon emission monitoring and substantial efforts for continuous improvement. The scoring results and level division of the traffic light system are shown in Table 4.

Table .4. Traffic Light Scoring Table

	scores of each year	score year-on-year growth	grading or classification
2010	-110.05	10.57%	red zone
2011	-97.81	11.12%	red zone
2012	-86.21	11.85%	red zone
2013	-75.17	12.81%	red zone
2014	-54.44	27.58%	red zone
2015	-35.88	34.09%	yellow zone
2016	-12.31	65.69%	yellow zone
2017	22.77	284.96%	green zone
2018	58.52	156.95%	green zone
2019	86.06	47.07%	green zone
2020	97.14	12.88%	blue zone
2021	152.73	57.22%	green zone
2022	177.70	16.36%	green zone

4. Conclusion and Recommendations

4.1. Conclusion

This article conducts an illustrative demonstration of the national carbon audit scores from 2010 to 2022 in the context of achieving the 'dual carbon' goals. It draws carbon audit conclusions and proposes a series of recommendations and measures to coordinate the relationship between our country's development and environmental protection. The conclusions are as follows:

The main indicators that affect carbon audit scores are: carbon emissions from economic contributions, improvement of energy structure, and enhancement of low-carbon technology efficiency.

The overall trend of China's carbon audit scores is increasing, driven primarily by green economic development, efficient energy utilization technology, and a low-carbon energy-saving industry structure.

4.2. Recommendations

4.2.1Regarding industrial characteristics and corporate behavior:

Companies should adopt emission reduction measures in the supply chain, reduce carbon emissions, improve production processes, use more environmentally friendly materials, reduce unnecessary energy consumption and waste, and undertake green innovation projects. Support

research and application of low-carbon and clean technologies, advocate green investment concepts, eliminate backward production capacity, and promote relevant enterprises to upgrade their technologies and achieve energy conservation and emission reduction, ultimately reducing carbon emissions.

4.2.2Regarding energy structure:

Encourage the use of cleaner, more efficient, and smarter energy consumption through the promotion of advanced energy-saving technologies, encouragement of product upgrades and replacements, the construction of smart cities, etc., in order to achieve an upgrading of energy consumption.

4.2.3Regarding product and service quality:

Enterprises can reduce greenhouse gas emissions by providing high-quality products and services, promoting consumers' green demands for other secondary products or services, continuously investing in environmental protection, conducting innovative activities, applying the latest environmental protection technologies, and improving products, processes, and services.

4.2.4Regarding ecological civilization:

Actively engage in wetland conservation, forest fire prevention, desertification control, etc., to promote the coordination of ecological civilization construction and environmental protection. Make vigorous efforts to develop renewable energy such as solar power, wind power, and hydropower for energy cleaning and low-carbonization, and promote distributed energy and new energy vehicles.

4.2.5Regarding environmental policies and regulations:

The government can introduce multiple policies to reduce pollutant emissions, attach importance to green technological innovations, increase financial support for research projects in the environmental protection field, and support enterprises and universities in strengthening scientific and technological research and development.

4.2.6Regarding environmental publicity and raising public awareness:

Continuously strengthen monitoring of companies' environmental commitments, use of clean energy, pollution control plans through social media and public opinion. Increase publicity for energy conservation and emission reduction efforts, continuously raise societal awareness of low-carbon and carbon reduction.

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