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Environmental Performance Evaluation of New Type Thermal Power Enterprises Considering Carbon Peak and Neutrality

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Abstract: Starting from the definition of traditional thermal power generation enterprises, this paper defines thermal power enterprises that are committed to achieving the carbon peak and neutrality by developing new energy sources as new type thermal power enterprises. Considering that China's current environmental management and environmental performance evaluation mainly focus on the treatment of pollutants in terms of prevention and control, an indicator system that comprehensively considers the whole process of environmental management of power generation enterprises has been constructed, and the factors affecting the environmental performance of enterprises have been effectively identified. The factor analysis method comprehensively evaluates the environmental performance of China's new type thermal power enterprises, realizes the comparability of environmental performance among power generation enterprises, and enables stakeholders such as the government and the public to conduct supervision in a timely, accurate, and comprehensive manner. In addition, it is the first time to combine the environmental performance evaluation with the carbon peak and neutrality and introduce the carbon reduction capability evaluation indicator into the indicator system, which enriches the practical significance of the environmental performance of power generation enterprises.

Keywords: carbon peak and neutrality; new type thermal power enterprises; environmental performance; performance evaluation

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1. Introduction

At present, China's energy industry has shifted from a high-speed development stage to a high-quality development stage. The supply and demand of energy power show new characteristics, and the transformation of energy consumption is imminent. The power industry is an important foundation and support for economic transformation and plays an essential role in economic development and the improvement of people's living standards. The security, stability, and full supply of electricity are important guarantees for the comprehensive, coordinated, and sustainable development of the national economy.

China is the largest electricity producer and consumer in the world, and coal-fired power generation has long represented a large proportion of the power supply due to resource endowment [1]. According to data released by the China Electricity Council, in 2020, China's total installed power generation capacity will reach 2.2 billion kW, and the annual power generation capacity will reach 7.42 trillion kWh, ranking first in the world and its proportion increasing year by year. China's power generation energy is mainly based on thermal power (56.58%), water power (16.82%), wind power (12.79%), and solar energy (11.52%). In recent years, new power generation energy sources such as nuclear energy and biomass have been developed significantly, and the scale of installed coal power has dropped to less than 50%. However, among the single power generation type, coal-fired power generation is still the leader, accounting for 65% of the country's 7.42 trillion kWh of power generation. By comparison, the proportion of clean energy is far below the global average [2]. The power structure dominated by thermal power has the characteristics of high energy consumption, high pollution, and low efficiency, which has caused a serious negative impact on the environment and aggravated environmental consequences such as global warming and water pollution.

Due to the introduction of China's supply-side structural reforms, the gradual strengthening of environmental protection concepts, and the impact of the frequent promulgation of environmental protection-related policies, especially the proposal of the carbon peak and neutrality in 2020, the contradiction between power pollution and environmental protection has become increasingly acute [3]. Therefore, China's hydropower, wind power, and nuclear power industry will meet a tremendous need in the following decades under the encouragement of energy structure adjustment and an emission reduction policy [4]. At the same time, China is still in the process of accelerated urbanization at the middle stage of industrialization, and the demand for electricity in China is increasing at a rate of about 10% per year. The dominant position of coal-fired thermal power in energy consumption will not change in a short period of time [5]. In addition, due to current economic and technical constraints, renewable energy power generation in China still cannot completely replace coal-fired power generation [6]. For traditional thermal power companies, seeking new and clean energy development opportunities can adjust the asset structure, resist market risks, and achieve a balance between economic and environmental benefits, especially in the context of soaring coal prices, to effectively improve the profitability of enterprises [3], so many new type thermal power enterprises have emerged in the thermal power industry that focus on environmental protection and vigorously develop new energy sources. Based on the definition of traditional thermal power enterprises, this paper defines the thermal power enterprises which are committed to the carbon peak and neutrality by developing new energy as new type thermal power enterprises.

Compared with the development of environmental performance evaluation of all types of power generation enterprises, the practical evaluation and specification of the exploration of new type thermal power enterprises' fulfillment of environmental protection responsibilities is relatively backward, especially under the current environmental regulations; if the power sector and even the country as a whole want to achieve the carbon peak and neutrality, they must devote themselves to exploring the emission reduction path of coal power and continue the penetration of renewable energy. However, at present, there is still a lack of an authoritative model for evaluating the environmental performance of new type thermal power enterprises in academia, and the understanding and practice of environmental responsibility of various enterprises are still more in the aspect of management level and capital investment, and there is a lack of profound analysis on the characteristics of new type thermal power enterprises and the environmental background of carbon peak and neutrality. Therefore, it is urgent to propose an environmental performance evaluation system for power generation enterprises that not only takes into account the characteristics of China's new type thermal power enterprises, but also manifests the requirements of the carbon peak and neutrality. This paper intends to reflect the implementation and evaluation results of the environmental performance of new type thermal power enterprises in a hierarchical, multi-faceted, and comprehensive manner, and to provide suggestions for how new type thermal power enterprises can fulfill their environmental responsibilities more economically and contribute to the achievement of the carbon peak and neutrality more efficiently.

2. Theoretical Background

2.1. Definition of Environmental Performance

The U.S. Environmental Protection Agency (USEPA) first proposed the concept of environmental performance, and in its National Environmental Policy Act published in 1969, there were many narrations that encouraged the industry to adopt a systematic environmental impact assessment process. Since then, the research on environmental performance has gradually developed.

W-Q Judge et al. [7] define environmental performance from the perspective of corporate social responsibility as the benefits that an enterprise produces when faced with problems related to the natural environment, meeting or exceeding social expectations. From the perspective of enterprise output, AB Carroll et al. [8] proposed that environmental performance refers to the extent to which the business activities of an enterprise cause damage to the environment. B-M Ruf [9] combines performance and stakeholder concepts and considers environmental performance is the degree to which an enterprise meets stakeholder expectations about environmental responsibility. Jasch [10] defines environmental performance as an internal process and management tool designed to provide management with reliable and verifiable information on an ongoing basis to determine whether an organization's environmental performance is meeting the criteria set by the management of the organization. Teece [11] argues that environmental performance reflects firms' environmental capabilities generated from the implementation of environmental strategies as underpinned by the dynamic capability theory. In addition, the aggregated measurement of environmental performance, which is in the form of an environmental performance index (EPI), can provide condensed information for analysts and decision makers dealing with energy and environment-related issues [12]. The International Organization for Standardization (IOS) defines environmental performance as the measurable results of an organization's management of its environmental factors. This paper intends to adopt this definition to evaluate the environmental performance of enterprises by observing and analyzing the measurable results of their environmental management.

2.2. Selection of Evaluation Indicators

Since 1989, when the Coalition for Environmentally Responsible Economies attempted to define the notion of environmental performance, academic research has used numerous and diverse indicators in order to measure it. These indicators can refer to a level of pollution or pollution reduction, relay organizations' initiatives, or reflect a variety of practices, such as recycling and reprocessing of waste [13]. Gray [14] believes that corporate environmental performance should include corporate environmental policy, environmental management structure, environmental behavior, sustainable development and other aspects, and determine the environmental performance indicator system from the perspective of information users. Henri [15] builds a corporate environmental performance indicator system from four perspectives: monitoring compliance, motivating continuous improvement, supporting decision-making and providing external reporting data, and makes the point that the selection of environmental indicators has a direct impact on corporate governance and environmental issues. Fabien [16] studied environmental performance evaluation by considering the economic benefits and environmental responsibility of enterprises and believed that environmental management should be placed in the strategic position of enterprise production and operation, so as to obtain long-term economic benefits. It can be seen that the current academic community mostly analyzes the environmental performance of enterprises and sets evaluation indicators from the perspectives of environmental management and economic efficiency, and the indicator system established based on this is universal, unable to measure the environmental performance of new type thermal power enterprises, and accordingly lacks social system background and industry characteristics.

The ISO14031 "Environmental Performance Evaluation Standard" issued by the International Organization for Standardization divides the environmental performance indicators into Environmental Status Indicators (ECIs), Management Performance Indicators (MPIs), and Operational Performance Indicators (OPIs), and lists specific evaluation indicators to provide reference for enterprises to conduct environmental performance evaluation [17]. This paper will follow this classification method to classify environmental performance evaluation indicators. References [18,19] use a number of indices that assess the reduction in a firm's environmental impact to measure environmental performance; these indices include reductions in use of water and energy, noise and air emissions, soil waste, risk of severe accidents, and landscape damage. Reference [20] has found that organizations with an environmental management system demonstrated improvements in environmental performance, especially in the areas of air and waste emission reductions, energy and water conservation, waste recycling, and environmental incidence reduction. Reference [21] evaluates the environmental performance of 30 provincial-level administrative regions in China according to the ratio of thermal power generation, which inspires us to introduce indicators such as the ratio of new energy power generation and the ratio of new energy installed capacity into the environmental performance evaluation of new type thermal power enterprises. Reference [22] regards the consumption of environment-related resources, the level of environmental investment and the emission of pollutants in the whole life cycle of power generation enterprises as their main environmental output. Reference [23] considers that CO_2, SO_2, NOx, and PM2.5 are the bad outputs of the environment, and their emissions should be listed as key factors in environmental performance evaluation.

The new type thermal power enterprises studied in this paper inevitably have inherent limitations of high energy consumption, high pollution, and low efficiency in thermal power generation. Therefore, when establishing the environmental performance evaluation indicator system, the above traditional thermal power environmental performance evaluation indicators are used while some clean power generation indicators are introduced. Relevant indicators combine the social background of the carbon peak and neutrality with the unique nature of new type thermal power enterprises, which are innovative and practical.

2.3. Determination of Evaluation Methods

Environmental performance evaluation is a systematic procedure for continuously measuring and evaluating the environmental performance of an enterprise. The evaluation contents include the organization's management system, production system, and surrounding environmental conditions. From the perspective of economic growth and long-term development, environmental performance evaluation is an indispensable part of realizing a sustainable development model and promoting the harmonious coexistence of human beings and nature. A reasonable environmental performance evaluation can monitor and evaluate the input and output of enterprises in environmental protection. From the perspective of environmental management system construction, environmental performance evaluation is an essential link in the system. It can monitor the operation and benefits of the system in a timely manner and output quantitative evaluation results, which is helpful for enterprises to apply improvement measures for bad results and bad indicators. At present, academia uses the Delphi method [24,25], analytic hierarchy process [26], fuzzy comprehensive evaluation model [27], factor analysis [28], principal component analysis [29], multi-objective decision-making [30], data envelopment analysis [31], and other models to evaluate environmental performance.

In view of the repetition of indicator information and the subjectivity of indicator weight setting in the process of variable fuzzy comprehensive evaluation, the subjective weighting method can help solve the problem of relative indicator weight and reduce the comprehensive evaluation dimension of variable fuzzy comprehensive evaluation. Rolf et al. [32] applied the environmental performance indicators (EPIs) to assess the environmental performance of coal-fired power plants in terms of toxic gas emissions from power generating enterprises. The results show that the adoption of cleaner and more efficient alternative materials is not realistic in the short term, and enterprises should improve their environmental performance in a reasonable way by improving the efficiency of end-of-pipe treatment and increasing the investment in environmental treatment. Toshiyuki et al. [33] used a new data envelopment analysis (DEA) window analysis method to evaluate the environmental performance of the data of coal-fired power plants in the United States from 1995 to 2007. The study concluded that it is necessary to expand the scope of the Clean Air Act (CAA) in the United States to control carbon dioxide emissions. Drawing on the nonparametric DEA method, You takes the initiative to take the insolation, annual sunshine duration, and covering area as input variables into account, as well as the installed capacity, annual electricity generation, CO_2 emission reduction, and coal saving as output variables, to provide a unified measure of environmental efficiency of PV plants in China [34]. Zhang et al. [35] believed that attention should be paid to the internal resource loss and external environmental damage caused by environmental pollution waste, and developed the "internal loss—external damage" (ILD) method for evaluating the environmental performance of coal-fired power plants, which effectively identified the key environmental pollution impact factors and successfully quantified internal resource loss costs and environmental damage costs.

According to the above reference, most of the current academic research on the environmental performance evaluation of power generation enterprises follows the DEA model of radial efficiency measurement. However, the use of radial efficiency measures may not make full use of the information reflected in the input and output. From a comprehensive viewpoint, many academic studies on environmental performance theory focus on the theoretical level, ignoring the internal and external environment of Chinese enterprises' production and operation, lack of operability in actual operation, and lack of understandability from the perspective of stakeholders. The research on the evaluation standard and indicator system of environmental performance has not yet reached a unified viewpoint and method. Finally, scholars mostly use typical listed enterprises and large enterprises as research samples, and there is a lack of relevant research on sub-sectors. Therefore, it is necessary to further study the environmental performance evaluation of new type thermal power enterprises in the power industry.

3. Establishment of an Evaluation Indicator System for New Type Thermal Power Enterprises

3.1. Setting Ideas

In constructing the environmental performance evaluation indicator system for new type thermal power enterprises, the current environmental strategy, economic development requirements, and the actual situation of the industry in China should be taken into account. In order to cope with the environmental deterioration caused by extensive economic development and the major trauma to the ecological environment, the Fifth Plenary of the 19th Central Committee will promote green and low-carbon development and promote green economic and social transformation as a major task during the 14th Five-Year Plan period. Especially under the new situation proposed by the carbon peak and neutrality, since China's electricity and heat production accounts for more than half of the carbon emissions, the power industry is also a resource and energy-intensive industry, which is highly dependent on resources and heavily pollutes the environment. Therefore, power generation enterprises will undoubtedly play a vital role in helping to achieve the carbon peak and neutrality.

In establishing the environmental performance evaluation indicator system for new type thermal power enterprises, it is necessary to focus on improving resource utilization efficiency and reducing pollutant emissions, and explore the manifestation of environmental performance of new type thermal power enterprises under the dual framework of government and market at the macro level; analyze the special indicators and specific performance of environmental performance under the characteristics of power industry at the meso level; and explore the specific influencing factors with the characteristics of new type thermal power enterprises at the micro level.

In order to make the environmental performance evaluation for new type thermal power enterprises reflect the objective situation as much as possible on the premise of fully reflecting the carbon peak and neutrality, this paper follows the factors of environmental resource consumption, environmental protection capital investment, and pollutant emission repeatedly mentioned in existing studies in establishing the environmental performance evaluation indicator system; on this basis, factors such as investment and pollutant emissions have been added to the consideration of the level of environmental management and the level of carbon emission reduction such as the development of new energy power and clean power generation reform. In addition, some indicators that were vaguely expressed and difficult to quantify were qualitatively dealt with.

3.2. Setting Indicators

The two widely used indicator systems—GRI and CARCASS of the Chinese Academy of Sciences—due to their popularity and universality, lack the targeted description and differentiated treatment of specific industries, and cannot accurately characterize and evaluate new type thermal power enterprises under the new situation. Therefore, this paper absorbs the essence of domestic and foreign enterprise environmental performance evaluation systems, standards, and literature research, follows the ideas and principles of indicator design, and fully considers the assistance of the power industry to achieve the carbon peak and neutrality goal from the perspective of the carbon peak and neutrality. For the whole process of environmental responsibility performance of power generation enterprises, its environmental performance evaluation indicator system is divided into the following three levels, and appropriate indicators are selected for comprehensive reflection.

- The management level of environmental responsibility includes two aspects: policy implementation and environmental management. The level of policy implementation is used to characterize the enterprise's compliance with environmental protection-related rules and regulations. The number of environmental safety incidents and the amount of environmental pollution penalties received are used to reflect the level of implementation in environmental protection and safe production. The environmental management level is used to characterize the enterprise's environmental management plan and management structure and use the environmental assessment pass rate of new projects and whether the enterprise has obtained ISO14001 certification to reflect the construction and operation of the enterprise's internal environmental management system.
- The response level of environmental responsibility includes three aspects: energy saving, waste treatment, and carbon emission reduction. The level of energy saving and consumption reduction is used to characterize the energy consumption of the enterprise in the whole process of production and operation. The coal consumption of power supply, boiler efficiency, total water consumption, and comprehensive power consumption rate are used to reflect the energy consumption efficiency and its technical aspects in the power production process of the enterprise. The waste treatment level is used to characterize the waste discharge and recycling of the enterprise in the production and operation process. The desulfurization efficiency, comprehensive denitration efficiency, SO_2 emission performance, NOx emission performance, and smoke emission performance are used to reflect the waste emission level of the enterprise and its treatment effect. The carbon emission reduction level is used to characterize the comprehensive carbon source and carbon sink level in the production and operation process of the enterprise. It adopts the proportion of new energy installed capacity, the approval of new energy projects, the intensity of CO_2 emissions, the proportion of ultra-low emission unit capacity, the saving of standard coal, and the reduction of carbon emissions. The amount reflects the current power generation structure and carbon emission level of the enterprise, and it also reflects the measures to reduce carbon emissions and their effectiveness.
- The financial aspect of environmental responsibility mainly includes the level of investment in environmental protection. The level of environmental protection investment is used to characterize the enterprise's direct or indirect use of funds for various environmental protection undertakings during the operating cycle, and the environmental protection investment rate (ratio of environmental protection investment to operating income) is used to reflect the enterprise's financial environmental performance.

Based on the above analysis, this paper divides the environmental performance evaluation criteria of new type thermal power enterprises into six levels: policy implementation level, environmental management level, energy saving level, waste disposal level, environmental investment level, and carbon reduction level from the perspective of carbon peak and neutrality. There are twenty indicators under each category, which fully guarantees the scientific and operability of the indicator system. This study defines the "positive indicator" as a positive correlation between indicator values and enterprise environmental performance or efficiency, and vice versa as an "inverse indicator". The details are shown in Table 1.

Table 1. Environmental performance evaluation indicator system of new type thermal power enterprises considering carbon peak and neutrality.

General Objective	First Grade Indicators	Second Grade Indicators	Unit	Indicator Attribute
Environmental Performance Evaluation of New type Thermal Power Enterprises Considering Carbon Peak and Neutrality	Policy implementation level	Environmental safety events A_1	Piece	Inverse
		Environmental pollution penalties A_2	Million Yuan	Inverse
	Environmental management level	Environmental assessment pass rate of new projects A_3	%	Positive
		ISO14000 Certification rate A_4	%	Positive
	Energy saving level	Power supply coal consumption A_5	g/kWh	Inverse
		Boiler efficiency A_6	%	Positive
		Total water consumption A_7	Million Tons	Inverse
		Integrated plant electricity rate A_8	%	Inverse
	Waste disposal level	Desulfurization efficiency A_9	%	Positive
		Integrated denitration efficiency A_{10}	%	Positive
		SO_2 Emission performance A_{11}	g/kWh	Inverse
		NOx Emission performance A_{12}	g/kWh	Inverse
		Smoke emission performanceA_{13}	g/kWh	Inverse
	Environmental investment level	Environmental investment rate A_{14}	%	Positive
	Carbon reduction level	New energy installation ratio A_{15}	%	Positive
		New energy project approval A_{16}	MW	Positive
		CO_2 emissions intensity A_{17}	g/kWh	Inverse
		Capacity ratio of ultra-low emission units A_{18}	%	Positive
		Saving standard coal A_{19}	Million Tons	Positive
		Reducing carbon emissions A_{20}	Million Tons	Positive

3.3. Setting Evaluation Model

The above evaluation indicator system can be used to measure and evaluate the environmental performance of new type thermal power enterprises from different aspects. Evaluation methods and evaluation models are important parts of a comprehensive evaluation system, which will have a direct impact on the scientific and accuracy of evaluation results. Therefore, evaluation methods should be reasonably selected and designed according to the research issues. This paper will adjust the importance of each evaluation indicator in a timely manner considering changes in environmental regulations from the perspective of carbon peak and neutrality. However, the subjective weighting method cannot adapt to changes in objective conditions due to its own characteristics, so it is not suitable for use in this paper. The objective weighting method applies a series of mathematical methods to analyze the relationship between the original data and determine the weight, which has stronger objectivity than the subjective method and can dynamically assign weights according to the changes of objective circumstances. Based on the above analysis, this paper proposes to adopt the objective weighting evaluation method for environmental performance evaluation.

In the objective weighting evaluation method, most of the current academic research on the environmental performance evaluation of power generation enterprises follows the DEA model of radial efficiency measurement. However, the use of radial efficiency measures may not make full use of the information reflected in the input and output and is contrary to the objective of this paper to reflect environmental performance in a comprehensive manner [36].

The factor analysis method can eliminate the information overlap between indicators by reducing the dimension, and generate objective weight coefficients according to the original information provided by the indicators, which has certain advantages in dealing with the problem of weighting evaluation indicators with high correlation [37,38]. Firstly, the correlation between the multivariables in the indicator system of this paper is relatively high, and the use of factor analysis can ensure the accuracy and scientific of the study and make the evaluation method better fit with the evaluation problem [39]; secondly, by using this method, the first-level indicators can be considered separately and their weights, scores, and other factors can be analyzed in a targeted manner; moreover, this method can condense a large number of indicators, and the resulting generalized indicators can make the evaluation results more intuitive and convincing.

The basic idea of factor analysis is to find out a small number of random attributes that can control all attributes by studying the internal structure of the correlation coefficient matrix of attributes and use them to describe the correlation between multiple attributes. Although the number of transformed indicator variables decreases, it still contains information for most of the pre-conversion metric variables. The basic principle is to synthesize a small number of common factors through the study of the correlation between a set of variables and use the common factors to represent the linear model of the original variables.

With n evaluation objects, each object has p evaluation indicators, forming the original data. x_{ij}, $F_1, F_2, \ldots, F_k$ are k objective common factors, ε represents the random error term, and the factor analysis mathematical model is:

$$\begin{cases} x_1 = a_{11}F_1 + a_{12}F_2 + \cdots + a_{1k}F_k + \varepsilon_1, \\ x_2 = a_{21}F_1 + a_{22}F_2 + \cdots + a_{2k}F_k + \varepsilon_2, \\ x_3 = a_{31}F_1 + a_{32}F_2 + \cdots + a_{3k}F_k + \varepsilon_3, \\ \cdots \\ x_p = a_{p1}F_1 + a_{p2}F_2 + \cdots + a_{pk}F_k + \varepsilon_p \end{cases} \quad (1)$$

The above formula is expressed as a matrix: $X = AF + \varepsilon$. where a_{ij} is called factor loading, which is the loading of the i-th variable on the j-th common factor, reflecting the relative degree of the variable x_i dependent on the factor F_j, and also indicating the relative importance of the variable x_i on F_j, so the A matrix also is called the "factor loading matrix". The larger the absolute value of a_{ij}, the closer the relationship between x_i and F_j, or the larger the load of F_j on x_i. $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_p$ represent special factors, which refer to the part of the original variables that cannot be explained by the factors, that is, the residual value between the measured variable and the estimated value. The specific steps of the factor analysis comprehensive evaluation method are as follows:

(1) All the original observed data of all evaluation objects corresponding to the evaluation indexes were collected and standardized, and the standardized covariance matrix was calculated. At the same time, there are two commonly used test methods to test whether the data of the evaluation object can be applied with factor analysis method, Kaiser–Meyer–Olkin (KMO) test, and Bartlett sphericity test. The KMO test is mainly used to test whether the variables have high bias correlation; the KMO value is generally between 0 and 1, and when its value is less than 0.5, it means that the variable is not suitable for factor analysis, while when its value is greater than 0.9, it means that the variable is very suitable for factor analysis. The Bartlett Sphericity test is mainly used to test whether the correlation matrix between the variables to be analyzed is a unit matrix. The original hypothesis is that "variables are independent". If the test result does not reject the original hypothesis, it means that the correlation between the evaluation indicators of the evaluation object is low, and it is not suitable for factor analysis.

(2) Build an initial factor model and estimate the relevant parameters. The general representation of the factor model is shown in (1), and the parameters to be estimated include the minimum number of factors k, the common variance and factor contribution rate, and the factor loading coefficient. There are many methods for parameter estimation, and the default principal component method is generally adopted. The number of factors k is different, and the results of the final comprehensive evaluation will also be different. Therefore, the number of factors must follow certain principles. In this study, the basic principle commonly used by scholars is adopted, that is, the cumulative variance contribution rate is greater than 85%.

(3) The expressions of the common factors are given. Based on the above parameter estimation, the factor model determined by the number of public factors and the factor loading matrix can be obtained. To obtain the evaluation value of the evaluation object, the expression of the public factor is also obtained on this basis, as shown in (2), where Fi represents the i-th common factor, and c_{ij} is the coefficient to be estimated of the common factor expression. The method uses regression analysis.

$$F_i = \sum_{j=1}^{p} c_{ij} x_j, i = 1, 2, \cdots, k, j = 1, 2, \cdots, p \tag{2}$$

(4) A comprehensive evaluation model was constructed, and a comprehensive evaluation analysis was implemented. After obtaining the public factor expressions using the above steps, its comprehensive evaluation model is shown in (3).

$$y_i = \sum_{j=1}^{p} w_{ij} F_{ij}, i = 1, 2, \cdots, k, j = 1, 2, \cdots, p \tag{3}$$

where y_i represents the comprehensive evaluation value of the i-th evaluation object, F_{ij} represents the value of the j-th common factor of the i-th evaluation object, and its value is mainly obtained by (2), and w_j represents the weight of the j-th common factor F_j; w_j generally takes the variance contribution rate of the j-th common factor as the weight. Finally, using (3), the evaluation value of each evaluation object can be obtained, and the comprehensive evaluation ranking and comparative analysis can be carried out.

It is worth noting that if the information repetition of a variable with other variables is higher, the role of this variable in the indicator system will be smaller, and in the results of factor analysis, there must be a high degree of correlation between similar indicators, so directly using a weighted result as the evaluation set will have a large deviation. To solve this problem, the correlation analysis needs to be performed again after the first weighted summation, and the second analysis results are weighted twice to improve the accuracy of the evaluation results.

The environmental performance evaluation indicator system of the new type thermal power enterprises in this paper is divided into three levels. In order to have a comprehensive understanding, reasonable analysis and in-depth interpretation of it, and to obtain accurate evaluation results for all samples after analysis. This paper draws on the idea of combining secondary weighting and factor analysis in comprehensive evaluation by scholars such as Xiang D.J. [40] and Li X.H. [41]. An improved objective weighting method-secondary weighting factor analysis method is used for comprehensive evaluation when evaluating the environmental performance of new type thermal power enterprises so as to make the evaluation results more reasonable. Firstly, the first order factor analysis is carried out on the indicators under the six dimensions of policy implementation level, environmental management level, energy saving level, waste disposal level, environmental investment level, and carbon reduction level, and each dimension is weighted according to the factor score. The second order factor analysis is to carry out a second weighted factor analysis on the comprehensive score of the six dimensions on the basis of the first time, so as to obtain the comprehensive evaluation score of the environmental performance of the sample.

4. Environmental Performance Evaluation of New Type Thermal Power Enterprises

4.1. Data Sources and Processing

Considering the availability of indicator data, this paper selects listed enterprises in the thermal power generation sector of the power industry on the Shanghai and Shenzhen stock exchanges as research samples to evaluate enterprise environmental performance on company data in 2020. In order to ensure the validity of the research institute's receipt data, the startup sector, small and medium sectors, and companies with incomplete and obviously abnormal data in listed companies were excluded, and eighteen representative listed companies that met the definition of new type thermal power enterprises in this paper were finally determined for research. The index values involved in the research samples come from the Guotai'an database, the Juchao information website, and annual reports of listed companies.

Due to the different attributes, scales, and quantitative levels of each indicator, the data are firstly processed positively before the analysis, and all negative indicators are inverted to positive indicators with reference to the common practice of scholars; secondly, the dimensionless processing of indicators is carried out, and indicators of different scales and quantitative levels are uniformly processed into indicators of the same scale to eliminate their influence on the comprehensive evaluation results.

4.2. Sub-Item Evaluation Based on First Order Factor Analysis

Based on the above analysis, the six dimensions of environmental performance of power generation enterprises based on carbon peak and neutrality are firstly evaluated based on first order factor analysis, i.e., the level of policy implementation, environmental management, energy saving, waste disposal, environmental investment, and carbon reduction are evaluated in turn, and this paper takes the carbon reduction level sub-evaluation as an example to complete the factor analysis sub-evaluation process.

Step1: The applicability test was carried out on the data of six secondary indicators of the primary indicator of carbon reduction corresponding to the eighteen samples. In this paper, the Bartlett sphericity test and KMO statistic are used to judge whether the factor analysis is suitable [42]. The statistic of the Bartlett sphericity test is obtained according to the determinant of the correlation coefficient matrix. If the value is large and the corresponding concomitant probability value is less than the specified significant level, it indicates that the correlation coefficient matrix is not a unit matrix, and the original variable is not a unit matrix and there is a correlation between them, which is suitable for factor analysis; the KMO statistic is suitable for comparing the observed correlation coefficient value and the partial correlation coefficient value. It is generally believed that a KMO value above 0.6 indicates that these variables are suitable for factor analysis. The applicability test results of the six secondary indicators of the primary indicators of carbon reduction corresponding to the eighteen samples are shown in Table 2. The results showed that the KMO test value was 0.635, and the chi-square test p value of the Bartlett sphericity test was 0.000. The test results were significant, indicating that the original variables were suitable for factor analysis.

Table 2. Applicability test.

KMO and Bartlett Tests		
KMO sampling suitability quantity		0.635
Bartlett Sphericity test	Approximate chi-square	230.395
	Freedom	136
	Obvious	0.000

Step2: Extract common factors. According to the principle of selecting the main factor with the eigenvalue greater than 1 or the cumulative contribution degree greater than 85%, the results of the cumulative variance contribution rate of the first-level indicator factor analysis of carbon reduction are shown in Table 3. It can be seen from the table that the first three factor components contain 76.263% of the information expressed by the original indicator, so three common factors F_1, F_2 and F_3 are selected.

Table 3. Common factor abstraction.

Total Variance Explanation						
Component	Initial Eigenvalue			Extraction of Square Sum of Loads		
	Total	Variance Proportion	Cumulative Proportion	Total	Variance Proportion	Cumulative Proportion
1	2.269	37.812	37.812	2.269	37.812	37.812
2	1.220	20.337	58.149	1.220	20.337	58.149
3	1.087	18.115	76.263	1.087	18.115	76.263
4	0.670	11.162	87.425			
5	0.410	6.841	94.266			
6	0.344	5.734	100.000			

Step3: Establish the sub-evaluation function. According to the common factor score coefficient matrix in Table 4, the score functions of F_1, F_2 and F_3 can be obtained:

$$\begin{cases} F_1 = 0.626X_1 + 0.673X_2 + 0.799X_3 + 0.466X_4 - 0.150X_5 + 0.738X_6 \\ F_2 = -0.241X_1 + 0.241X_2 + 0.281X_3 - 0.706X_4 + 0.676X_5 + 0.263X_6 \\ F_3 = 0.516X_1 - 0.466X_2 + 0.179X_3 + 0.269X_4 + 0.651X_5 - 0.263X_6 \end{cases} \quad (4)$$

Table 4. Common factor score coefficient matrix.

Component Score Coefficient Matrix			
Indicator Variable	Common Factor		
	F_1	F_2	F_3
New energy installation ratio X_1	0.626	−0.241	0.516
New energy project approval X_2	0.673	0.241	−0.466
CO_2 emissions intensity X_3	0.799	0.281	0.197
Capacity ratio of ultra-low emission units X_4	0.466	−0.706	0.269
Saving standard coal X_5	−0.150	0.676	0.651
Reducing carbon emissions X_6	0.738	0.263	−0.263

The ratio of the contribution rate of each principal component to the total contribution rate is used as the weight of the principal component, and Y_i is used to represent the sub-item evaluation score of the environmental performance of each power generation enterprise, and then the sub-item evaluation score model is obtained:

$$Y_1 = (37.812F_1 + 20.337F_2 + 18/115F_3)/76.263 \quad (5)$$

Step 4: Calculate the sub-item score. Combining the above sub-evaluation score function and score model and substituting the data of eighteen samples after standardization and dimensionless processing, respectively, the sub-evaluation results of the carbon emission reduction level of eighteen new type thermal power enterprises are obtained.

According to the above steps, the evaluation results of other sub-items of eighteen power generation enterprises can be obtained. After calculation, the policy implementation level, environmental management level, energy saving level, waste disposal level, environmental investment level, and carbon reduction level of eighteen power generation enterprises can be obtained. The evaluation results are shown in Figure 1. Descriptive statistics are shown in Figure 2.

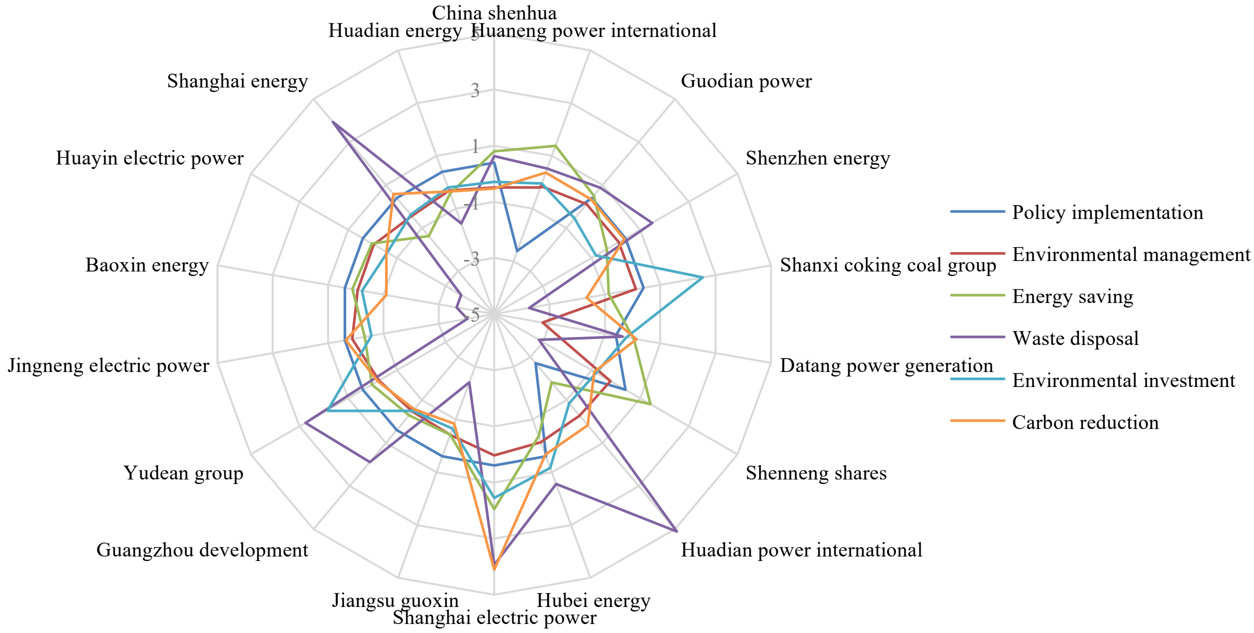

Figure 1. Sub-item evaluation of new type thermal power enterprises.

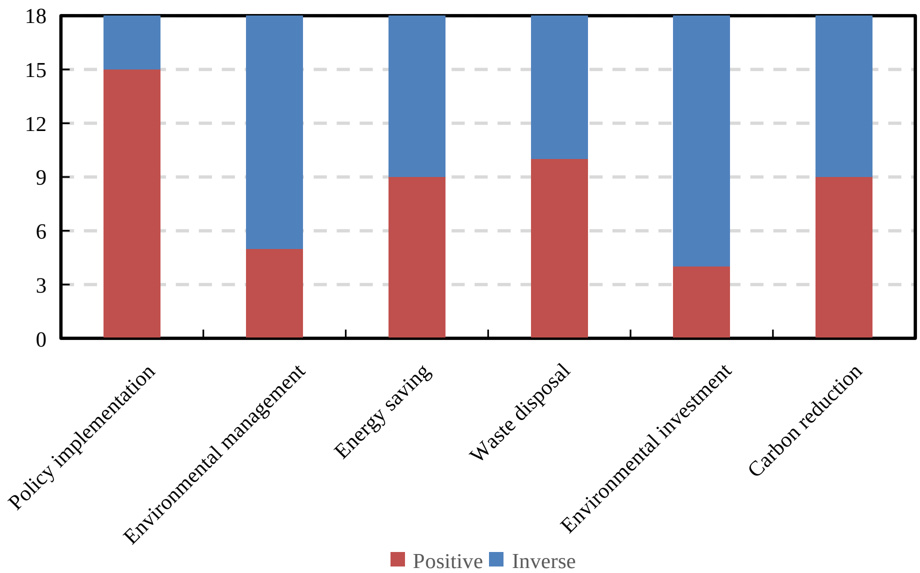

Figure 2. Descriptive statistics of the evaluation results of the first-level indicators: red indicates the sample size of the indicator that meets the standard, and blue indicates the amount that does not meet the standard.

- From the perspective of policy implementation level, most of the sample enterprises strictly abide by the laws and regulations related to environmental protection and safety, and ensure that they abide by the environmental protection rules under the premise of safe production; the comparison also shows that Huadian Power International, Huaneng Power International, and Datang Power Generation are characterized by insufficient enforcement and attention in policy implementation, resulting in a large gap between industries;
- From the perspective of environmental management level, only five sample enterprises, Jingneng Electric Power, Shenzhen Energy, Shanxi Coking Coal Group, Guodian Power, and Shanghai Power, exceed the average level, which is closely related to the size of the enterprise, region, and CEO attitude, etc.; The number of digits shows that the

overall management level of the industry is not high, and it is urgent to improve the level of environmental protection response;
- From the perspective of energy saving level, the gap between Shanghai Electric Power, which ranks first, and Huadian International, which ranks last, is enormous. The lower median indicates that the overall energy saving efficiency of the industry is general, and the larger variance indicates that there are large technical barriers for upstream and downstream enterprises, and there is still more room for technological progress and breakthrough. It is worth noting that half of the enterprises exceed the average level, indicating that enterprises are willing to pay attention to energy saving ability and investment;
- From the perspective of waste disposal level, more than half of the sample enterprises are higher than the average, which fully shows the standardization degree of this indicator and the importance the industry attaches to it, the huge gap between leading enterprises and tailing enterprises also shows that there is a huge difference in the level of waste disposal technology between enterprises and that there exists ample room for improvement;
- From the perspective of environmental investment level, only four sample enterprises, Shanxi Coking Coal, Yudean Group, Shanghai Electric Power, and Hubei Energy, exceeded the average level, indicating that the industry as a whole is less concerned about environmental investment, making this level the lowest point among the sub-indicators;
- From the perspective of carbon reduction level, leading enterprises such as Shanghai Electric Power and Shanghai Energy have developed relatively well, while Shanxi Coking Coal and Shenneng Shares started late and developed slowly. This is closely related to the scale, region, and energy structure of the enterprises. The overall development level of the industry in general is poor and there is a large room for development.

It can be seen that the basic levels of policy implementation, environmental management, energy saving, waste disposal, environmental investment, and carbon reduction of different power generation enterprises are uneven, and each has its own advantages and disadvantages. It is worth mentioning that the higher level of policy implementation shows that the current environmental regulation by government departments is effective, while the lower level of environmental management and environmental investment reflects the current phenomenon of poor incentive results of market players and insufficient management of market segments, while the average performance of other indicators reflects the pursuit of environmental performance by enterprises themselves, but apparently some lack of motivation.

4.3. Comprehensive Evaluation Based on Second-Order Factor Analysis

4.3.1. Comprehensive Evaluation

The six basic level sub-items of policy implementation, environmental management, energy saving, waste disposal, environmental investment, and carbon reduction were used as variables for the second-order factor analysis, and the steps were the same as those used for the factor analysis of carbon reduction level in the previous section, and the comprehensive evaluation results of the environmental performance of the eighteen sample enterprises can be obtained as shown in Figure 3.

From the results of the comprehensive evaluation of the environmental performance of power generation enterprises based on carbon peak and neutrality, Shanghai Electric Power ranks first in terms of environmental performance among the eighteen sample enterprises, indicating that it has actively assumed environmental responsibility and has balanced economy and efficiency. In terms of sub-evaluation results, Shanghai Electric Power ranks first in policy implementation, energy saving, and carbon reduction, but only fifth in environmental management, which is mainly due to the low coverage of ISO14001 certification of its subordinate power plants. Therefore, Shanghai Electric Power should recognize the importance of environmental certification and strive to improve its own environmental management level. Yudean Group ranks second in the comprehensive environmental performance score. In terms of sub-items, except for energy saving and carbon reduction, all other scores are in the forefront, so the most important work for Yudean Group is to enhance production efficiency, improve resource utilization efficiency and vigorously develop clean energy. The comprehensive evaluation results of Shanghai Energy, Huadian Power International, Hubei Energy, and Shenzhen Energy are relatively close. Although Huadian Power International ranks first, it ranks last in terms of policy implementation, energy saving, and environmental investment, reflecting its paralysis and fluke mentality towards taking environmental responsibility. Although it has achieved a good comprehensive score by virtue of its technological leadership in waste disposal, it will have a lot of risks in the future if it does not overcome its current problems and take positive action to assume environmental responsibility. Baoxin Energy ranked last in the comprehensive evaluation, mainly in terms of waste disposal, environmental investment, and carbon reduction, but the level of energy saving is in a high position. Therefore, Baoxin Energy should maintain its own development advantages while actively promoting the technological progress of environmental protection pre-treatment, improving environmental protection awareness, increasing environmental protection investment, and improving the economy and feasibility of its own environmental protection measures.

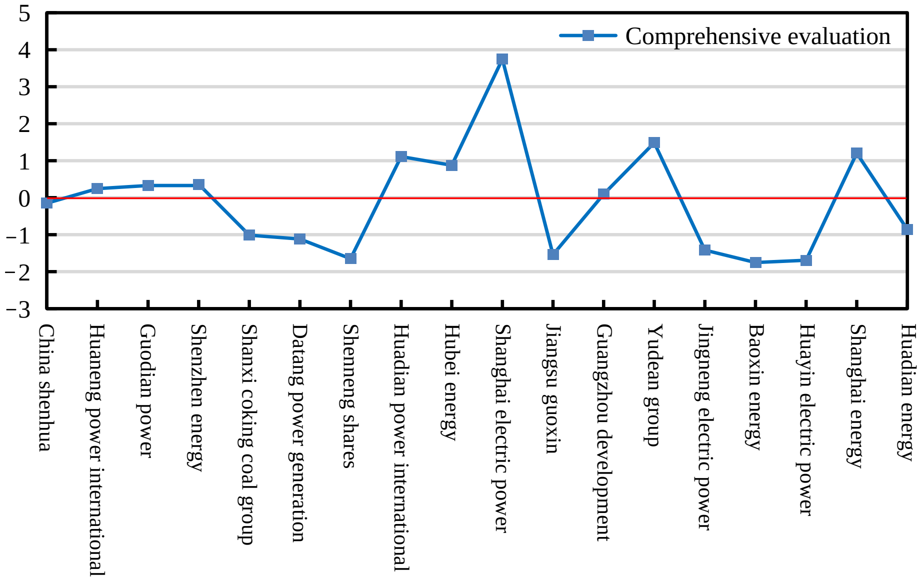

Figure 3. Comprehensive evaluation of environmental performance of new type thermal power enterprises.

On the whole, the overall level of environmental performance of power generation enterprises in China is very unbalanced, and the gap is very obvious. The imbalance and inadequacy of environmental responsibilities have restricted the smooth implementation of industry environmental policies and also hindered the awakening and development of corporate environmental awareness.

4.3.2. Cluster Analysis

Based on the above analysis of the evaluation results from a micro perspective, this study uses the cluster analysis method to explore and analyze the evaluation results from a macro perspective. The original data used for clustering is the comprehensive evaluation score of environmental performance in the table above. The clustering results are shown in Table 5.

Table 5. Clustering results of comprehensive score of environmental performance of new type thermal power enterprises based on carbon peak and neutrality.

	Clustering Results			
	First Type	**Second Type**	**Third Type**	**Fourth Type**
Sample enterprises	Shanghai electric power	Hubei energy	Jingneng electric power	China shenhua
	Yudean group	Shenzhen energy	Jiangsu guoxin	Huadian energy
	Shanghai energy	Guodian power	Shenneng shares	Shanxi coking coal group
	Huadian power international	Huaneng power international	Huayin electric power	Datang power generation
		Guangzhou development	Baoxin energy	

According to the cluster analysis results, the comprehensive environmental performance levels of the eighteen sample enterprises are classified into four types.

- The first type includes Shanghai Electric Power, Yudean Group, Shanghai Energy, and Huadian Power International. The technical level of environmental protection and other aspects is leading in the industry, the development of clean energy has a good foundation, and the overall environmental performance level is relatively high. The focus of such enterprises in improving environmental performance in the future should be to ensure remaining at the leading edge of technology and to pay close attention to the environmental management of the whole process of production and operation.
- The second type of enterprises includes Hubei Energy, Shenzhen Energy, and Guodian Power. The common point of these enterprises is to vigorously develop clean energy, seize the opportunity of carbon emission reduction and carbon neutrality, take the lead in developing low-carbon related technologies, and improve their own image and development prospects in the industry. The focus of such enterprises to improve their environmental performance in the future should be to unswervingly carry out technology research and development, and to continuously adjust the energy structure of the enterprise.
- The third type of enterprises includes Jingneng Electric Power, Jiangsu Guoxin, and Shenneng Shares. The common point of these enterprises is that they have a high level of environmental management but a lack of technological breakthroughs and have failed to seize the opportunity to develop technology in the rapidly changing market. The focus of such enterprises is improving environmental performance in the future while ensuring the sustainable development of clean energy and focusing on technological innovation.
- The fourth type of enterprises includes China Shenhua, Huadian Energy, Shanxi Coking Coal and Datang Power Generation. What these enterprises have in common is that coal power accounts for the majority of the energy structure. Spending on pollution prevention and control of thermal power generation leads to the backward development of clean energy and the relatively lagging technical level. In the future, such enterprises should learn from the valuable experience of the first type of enterprises in improving environmental performance and strive to improve the investment in environmental protection based on their own advantages and characteristics to improve the economic benefits.

The results of the cluster analysis from a macro perspective are basically the same as the results from the secondary weighted factor analysis from a micro perspective. That is to say, there is a time lag between the proposal and implementation of carbon peak and neutrality, and the overall level of environmental performance of China's power generation enterprises is unbalanced and the implementation of modern environmental responsibility theory is insufficient, which gives the new type power generation enterprises huge room for improvement in environmental performance indicators represented by energy saving and consumption reduction levels and carbon emission reduction levels, etc. The two methods corroborate each other to reveal the scientific and reasonable structure of the evaluation system in this paper.

5. Conclusions and Recommendations

This paper constructs a comprehensive index system that considers the whole process of environmental management of power generation enterprises, effectively identifies the factors that affect the environmental performance of enterprises and applies the quadratic weighted factor analysis method to comprehensively evaluate the environmental performance of new thermal power enterprises in China. In combination with the above, it can be seen that new thermal power enterprises have outstanding performance in policy implementation, reflecting that the current environment-related policies are formulated and implemented strongly enough, and more detailed and perfect regulations are needed in the future to cover all aspects of corporate environmental responsibility; they have poor performance in environmental management and environmental protection investment, and there is more room for improvement. Enterprises should improve the status of environmental management in their business activities, increase environmental protection investment, and improve production efficiency and resource utilization efficiency. In terms of energy saving, waste treatment, carbon emission reduction, etc., the performance is balanced, showing the lack of motivation of enterprises to improve the level of clean power generation, which also reflects the shortcomings of industry incentives. In the future, more "industry green lights" should be given to companies with excellent environmental performance to facilitate their subsequent development.

This paper realizes the comparability of environmental performance among power generation enterprises, which enables stakeholders such as the government and the public to regulate and supervise in a timely, accurate, and comprehensive manner. In addition, for the first time, environmental performance evaluation is combined with the dual carbon target, and the carbon emission reduction capability evaluation index is introduced into the index system, which enriches the practical significance of the environmental performance of power generation enterprises.

It should be pointed out that there are still some shortcomings of this study. Firstly, this study is aimed at new type thermal power enterprises that are more demanding than traditional thermal power enterprises, so the study is limited, and the conclusions have some limitations. Second, this study is only based on data from 2020, although the level of thermal power generation technology is difficult to make a great breakthrough in the short term, which may lead to the lack of accuracy of the study results. Finally, due to the availability and accessibility of data, the assessment of the carbon reduction level of new type thermal power enterprises ignores the influence of forest and grassland carbon sinks. Therefore, in future studies, we consider expanding the time span of the research subjects to reduce random interference, improve the accuracy of the study, and cover a wider range of carbon source pathways and carbon sink measures, so as to more comprehensively and deeply assess the environmental performance level of thermal power generation enterprises in China.

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