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Environmental management zoning of coal-fired power plants in China in the context of carbon neutrality

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Abstract: The total amount of greenhouse gas emissions directly or indirectly generated by thermal power enterprises at any given time can be offset through afforestation, energy conservation and emission reduction. The present situation and control methods of CO_2 emission in China's coal-fired thermal power industry are introduced. The complex ecosystem is a unity of ecological functions composed of human society, economic activities and natural conditions. In the context of carbon neutrality and based on the theory of composite ecosystem, this paper divides the coal-fired thermal power plants in China into environmental management zones, calculates the atmospheric environmental capacity, and puts forward the concept of regional atmospheric environmental capacity, classification and zoning control. Finally, the management and control units are classified, and differentiated management and control requirements are put forward to provide a reference for regional air quality standard planning.

Keywords: Composite ecosystem; Carbon neutralization; Coal-fired power; Environmental management zoning; Coordination and control

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1. Introduction

Energy is the material basis of social development, while the environment is the carrier of energy and also the living space for all kinds of organisms [1-2]. China's long-term and current energy consumption structure are dominated by coal. At present, the proportion of coal consumption in China is as high as 68% [3-4]. However, with the accelerating process of industrialization and the rapid development of the economy, the unreasonable development and use of coal and other natural resources for energy, and the arbitrary emission of CO_2, SO_2, NO_x and other pollutants, make the world face severe challenges of resource depletion, the deterioration of the ecological environment, global warming and imbalance of social and economic development [5-7]. Among these severe challenges, gaseous pollutants from coal-fired power and coal-fired processes are one of the main sources of air pollution in China [8-9]. In order to solve these problems, the coordinated development of resources, environment and social economy has attracted the world's attention [10-11]. The historical experience on a global scale shows that energy, environment and economy form a complex organic unity. Seeking the coordinated development of energy, economy, and environment subsystem is not only the most essential requirement of sustainable development theory but also an effective way to realize the sustainable, steady and high-speed development of a national economy.

Tansley, a British scholar, first proposed the concept of an ecosystem. He believed that an ecosystem is a unity composed of a biological community and a natural environment [12]. Professor Ma Shijun, a famous ecologist and environmental scientist in China, first put forward the theory of complex ecosystem in 1981. He said that the complex ecosystem includes three subsystems, namely, society, economy and nature [13-14]. He pointed out that the society, economy and nature in which human beings live and produce is indeed an inseparable complex system. Society is the superstructure of the economy, while the economy supports the society and also serves as a bridge between society and nature. On the other hand, nature supports the whole human society and the economy, and exists as a basic situation in the complex ecosystem.

The theory of a complex ecosystem can better explain the current energy and environmental problems in the region [15-16]. The regional complex ecosystem can be divided into two parts: the human system and the natural system. The human system is composed of both social and economic systems. Rapid economic growth and social development often come at the expense of the regional ecological environment, leading to the imbalance and damage of the regional complex ecosystem.

The damaged regional natural system, in turn, affects the economic and social development of the region. Compound ecosystem management refers to the process of applying ecological, scientific and sustainable methods to carry out adaptive management of local affairs on the basis of a full understanding of the relationship among social, economic and natural systems within a certain space [17-18]. The ultimate goal of composite ecosystem management is to make the overall structure of the composite ecosystem stable. In such a stable composite ecosystem, the subsystems coexist harmoniously and promote each other, thereby guaranteeing the coordinated and efficient operation of the whole composite ecosystem.

Many scholars in China and beyond have studied the theory and method of regional energy environment complex ecosystem regulation in China. Wang Rusong et al. [19] pointed out that cities and regions of China are a kind of a social economic natural complex ecosystem. Studying the dynamic mechanism and cybernetic method of the complex ecosystem as well as creating a demonstration model of planning, construction and management of the complex ecosystem at different scales can provide a reference for the implementation of the scientific outlook on development, the promotion of a circular economy, the promotion of sustainable development and the promotion of sustainable development. Scientific methods and decision support are provided for the construction of a harmonious society and healthy environment. On the basis of analyzing the characteristics of the coordinated energy environment economy complex system, Lianhong et al. [20] established the analysis model of the coordination of China's energy environment economy complex system and put forward the corresponding control measures. The results show that in the past 15 years, the "energy environment economy" complex system in China is slowly evolving towards coordination. Suresh et al. [21] analyzed the energy, exergy, environment, economy and other factors of a coal-fired power plant to determine their technical and economic feasibility. Their research showed that under the "fuel-saving mode" operation of a steam turbine, by replacing all the exhaust steam with a feedwater heater, the coal consumption of a coal-fired power plant can be instantly reduced by about 14-19%. Also, the authors found that based on exergy rather than energy,

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solar energy was more effective for water heating and that using the best possible solar-assisted feed water heating scheme can reduce CO_2 emissions from coal-fired power plants. Nevertheless, there are few studies on the application of composite ecosystem to energy-environment by far, especially the energy-environment management and control of thermal power enterprises, and there are few literature reports. Against the backdrop of carbon neutrality, the work applies the "complex ecosystem theory" to the zoning of environmental management and control of coal-fired power plants, calculates the atmospheric environmental capacity, and puts forward the concept of regional atmospheric environmental capacity, classification and zoning management and control. Lastly, the study divides the environmental management and control of coal-fired thermal power plants in China by combining qualitative analysis with quantitative analysis and puts forward differentiated management and control requirements so as to provide a reference for regional air quality standard planning. The research results can be utilized to explore a new set of coal-fired thermal power environmental management and control theory and method system.

2. Research methods

2.1. Research progress of complex ecosystem theory

1) Energy-economic-environment-ecology complex ecosystem and sustainable development

The economy energy environment (3e) system is a complex system that includes three subsystems of economy, energy and environment[22-23]. Each of these subsystems is closely related to each other. At the same time, there are also mutual communications, mutual influences and mutual stimulations among economy, energy and environment both inside and outside of the region [24-25]. In the process of the interaction of the three subsystems, the economic system plays the role of intermediary, controller and coordinator.

The evaluation of the coordinated development of the economy and environment is one of the hot issues in the study of sustainable development in developing countries. At present, the research on the coordinated development evaluation of the economic environment composite ecosystem has

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gradually changed from qualitative and static analyses to quantitative and dynamic trend evaluations. There are many evaluation models, but the main ones include the input-output model [26], EKC measurement model [27], grey system model [28], and comprehensive evaluation model of coordinated scheduling and coordinated development degree [29]. Each of these models has its advantages, disadvantages and application scope, which determine the research progress in this field to a certain extent.

2) Evaluation index system of coordinated development

A composite system is an open, nonlinear, dynamic and complex large-scale system, which involves many objectives and is easily affected by external factors. Different factors also directly affect the results of empirical analysis. According to the above analysis of game and coordination of economic and environmental development, the state or degree of system coordination can be reflected by mathematical models or quantitative methods. In this paper, a comprehensive evaluation index system of the economy and environment composite system is established to realize this process, as shown in Table1. Based on the principles of comprehensiveness, representativeness, quantification, operability and scientificalness, the evaluation index system of energy environment composite system was constructed by selecting appropriate indexes.

3) Analysis on coordination degree of compound ecosystem

It is necessary to use coordination degree to calculate coordination degree among multiple systems so as to evaluate coordinated development. Coordination degree is a measure of the degree of harmony between the system or the internal elements of the system in the development process, reflecting the trend of the system from disorder to order. It is a quantitative indicator of the coordination of energy, economy, environment and ecosystem. By referring to the capacity coupling coefficient model in physics, the coupling coordination degree model between composite ecosystems was constructed. Then, the coupling degree between the energy system, economic system, environmental system and economic system was calculated as follows:

$$C = 4\left[\frac{U_1 \times U_2 \times U_3 \times U_4}{(U_1 + U_2 + U_3 + U_4)^4}\right]^{\frac{1}{4}} \quad (1)$$

where, C is the coupling degree, and U_1, U_2, U_3, and U_4 are the development indexes for each subsystem (energy, economic, environmental and ecological subsystem respectively).

In order to avoid the pseudo coordination evaluation results and reflect the actual development level of each system and the contribution to the system order degree, the coupling coordination degree coefficient is defined on the basis of the reference coupling degree. The formula for calculating the comprehensive coupling coordination degree of the energy, economy, environment and ecosystem systems were as follows:

$$D = \sqrt{CT} \quad (2)$$

$$T = \alpha f_1 + \beta f_2 + \gamma f_3 + \theta f_4 \quad (3)$$

Where D is the coupling coordination coefficient; C is the coupling degree; T is the comprehensive development index; α, β, γ, θ. It is considered that energy, economy, environment and ecosystem are equally important, all of which are taken as 0.25. The size of the coordination coefficient indicates the degree of coordination between systems, and different intervals of coordination coefficient can be used as the measurement standard of different coordination degrees. The research on the coordination degree of the composite ecosystem provides theoretical and application basis for the environmental management and control of thermal power coal-fired power plants in China.

2.2. Estimation of atmospheric environmental capacity

Atmospheric environmental capacity refers to the maximum load of pollutants in an environment on the premise that human survival and development are not harmed, and the balance of the natural ecosystem is not damaged [30-31]. Many accounting methods have been proposed by scholars at home and abroad. A-P value method is one of the important methods for estimating atmospheric environmental capacity, which has been widely used in the current air pollution

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prevention and control work [32-33]. In this study, A-P value method was used to calculate the atmospheric environmental capacity of each control unit [34-35]. According to the estimation results of atmospheric environmental capacity, the environmental management of coal-fired power plants in China was divided into different zones, and the differentiated management and control requirements are put forward. The formula for calculating atmospheric environmental capacity is as follows:

$$Q = A(C_s - C_b)\sqrt{S} \qquad (4)$$

Where: Q is the annual allowable total emission limit of pollutants, (i.e., the ideal atmospheric capacity), 10^4t/a; A is the total amount control coefficient of geographical region, 10^4 km^2/a; S is the total area of the control area, km^2; C_s is the annual average concentration limit of a pollutant corresponding to each province, mg/m^3; and C_b is the local concentration in the control area, mg/m^3.

3. Results and analyses

3.1. CO_2 emission status and control methods of coal-fired thermal power industry

Research shows that China will reach a peak CO_2 emission of 10.6 billion tons around 2027 [36]. However, at present, China's coal-fired thermal power industry has no relevant statistical data on carbon dioxide emissions, so it can only be estimated from the coal consumption, fuel emission factor, the average low-temperature calorific value of fuel, carbon oxidation rate and data on other relevant parameters [37]. Through afforestation, energy conservation and emission reduction, the carbon dioxide or greenhouse gas emissions directly or indirectly generated by thermal power enterprises in a certain period of time can be offset. With the rapid development of China's economy and society, and the acceleration of coal electricity integration construction, CO_2 emissions will gradually increase. In China, the control methods of carbon dioxide in thermal power industries are mainly management methods, such as shutting down small thermal power units, reducing the power consumption rate of power plants, and the collaborative reduction of carbon dioxide by sulfur dioxide emission reduction. These CO_2 control methods are adopted given that China's carbon dioxide emission reduction technology is still at the stage of research and project demonstration, including pre-combustion capture and post-combustion capture.

3.2. Coordination degree analysis of complex ecosystem

Coordination degree is a measure of the degree of harmony between the system or the internal elements of the system in the development process. It reflects the trend of the system from disorder to order. Furthermore, coordination degree is a quantitative indicator of the coordination of energy, economy, environment and ecosystem. By referring to the capacity coupling coefficient model in physics, the coupling coordination degree formula of China's energy, economic, environmental and ecological composite ecosystem was constructed. The results are presented in Table 2. As shown in Table2, Item 1 to Item 21 refer to different provinces/citis/districts. Unfortunately, there are not too many data can be calculated through SPSS19.0 software. The larger the C value of coupling degree in different regions, the greater the interaction between the systems. Similarly, the larger the D value of coupling coordination degree, the higher the coordination degree. As can be seen from Table 2, the coupling coordination degree of the energy economic environmental ecology composite ecosystem in most provinces in China is low, and most of them are low-quality coordination. This shows that it is urgent to adjust the energy structure, strictly control the total amount of coal consumption, strengthen the clean utilization of coal, expand natural gas utilization to apply the composite ecosystem to the environmental management and control of coal-fired power plants, implement the scientific outlook on development, promote a circular economy, and properly manage the ecological environment.

3.3. Analysis of atmospheric environmental capacity

In this study, the A-value of each province in China was obtained by referring to the manual of the total amount control method of urban air pollutants. The minimum A-value of each province was taken as the national recommended value to determine the total amount of air pollutants in each province. It is assumed that the first-class standard limit of pollutants in the ambient air quality standard (GB3095-2012) is taken as the air quality standard. Going by this air quality standard, the annual concentration limit of SO_2 in each province is 0.02 mg/m^3. The estimated atmospheric environmental capacity for each province in China is presented in Table 3. In this paper, atmospheric environmental capacity intensity is classified into high, medium, and low according to 20 ~ 5 million tons, 5 ~ 1 million tons and 0 ~ 1 million tons, respectively.

3.4 Stability of atmospheric environment zoning

1) The thesis fully considers the theories and concepts of atmospheric environmental capacity, puts forward an evaluation method of atmospheric environmental capacity and conducts case studies, which can effectively analyze and evaluate the atmospheric environmental capacity of the regional ecological environment.

2) Cointegration test between atmospheric carrying capacity and economic development

In order to examine the stability of the atmospheric environment zoning over time, Spss19 statistical analysis software to test the above 26 evaluation factors by ADF inspection.The results (shown in Table 4) show that under the original hypothesis, the value of the unit root t-test statistic is higher than the corresponding DW critical value at three significance levels (1%, 5% and 10%). Therefore, our initial hypothesis was confirmed, indicating that the initial data set was dynamic, that there is unit root, and the data need to be stabilized. After the first-order difference, the significance level of 5%, and the critical value of unit root test was lower than the corresponding DW critical value. The original hypothesis was thus rejected, indicating that the data in the original data set was stable after the first-order difference, and the stability test was completed.

3) Model identification and fitting

We used spss19 statistical analysis software to built a ARIMA (P, D, q) model to predict China's atmospheric carrying capacity. The results (illustrated in Table 5) showed that the ARIMA model requires the model residual to be white noise, that is, no autocorrelation. The model basically meets the prediction requirements of atmospheric carrying capacity in China. Predicted by ADF test and ARIMA (P, D, q) model show that the energy, economy, environment and ecosystem complex ecosystem in most parts of China were stable.

3.5. Coal-fired thermal power area division and control requirements

In order to evaluate the impact of coal-fired power plants on regional atmospheric environment in China, based on the theory of complex ecosystem, this paper preliminarily divides the types of coal-fired power plants in China into environmental management categories, analyzes the atmospheric environmental capacity, and puts forward the requirements and suggestions for the differentiated environmental management of different types of control areas of atmospheric environmental capacity. The results are presented in Table 6. Inner Mongolia, Heilongjiang, Xinjiang and some other places have relatively large atmospheric environmental capacity and abundant coal resources (Table 6). Therefore, the establishment of modern large-scale coal power bases focusing on power transmission and capable of producing up to 10 million kilowatts of energy should be undertaken. Liaoning, Jilin and some other places still have certain environmental capacities, and the emission of air pollutants from new power plants must be regulated to meet the standards of gas-fired power plants. Beijing, Shanghai, Chongqing and Tianjin have no environmental capacities; therefore, new coal-fired power units should be prohibited.

4. Conclusions and suggestions

China's energy and environment vary greatly in time and space, and the constraints of the energy industry are different. The environmental protection type of thermal power plants energy industry include the existing zoning, the restrictive factors and spatial distribution of existing enterprise are sufficiently taken into account by researchers. Based on the complex ecosystem theory, this paper divided the environmental management area of coal-fired power plants in China, which is conducive to the implementation of "adjusting measures to local conditions", " development of dislocation", "classified management" and "zoning and management" in the field of thermal power generation. Differentiated management and control requirements are put forward to provide a reference for regional air quality standard planning. The zoning environmental policy is advantageous to the benign development of thermal power industry. According to the types of atmospheric environmental capacity in different areas of China, a new set of theories and methods for environmental management of coal-fired thermal power plants were explored. It is suggested that the prevention and control of environmental pollution should be carried out according to the goal of "taking improving environmental quality as the core". The following conclusions and suggestions are drawn from the environmental management of coal-fired power plants in China:

1) Considering the impact of coal-fired thermal power on the regional atmosphere, it is suggested that the layout of coal-fired thermal power in China should be appropriately adjusted according to the development situation of different regions to organize and coordinate the coordinated development of energy, environment, economy and ecology.

2) With the rapid development of economics, sustainable development has increasingly become the ideal goal of development and environmental management, and the measurement, qualitative and quantitative evaluation of sustainable development is one of the key issues. In the face of the problems of environmental monitoring and environmental management in sustainable development, a series of development strategies and research countermeasures are put forward.

3) The "complex ecosystem theory" is applied to the research of coal-fired thermal power environmental management, and the coal-fired thermal power environment in China is preliminarily classified. The result can better coordinate the relationship between humanity and nature and play a good effect in dealing with environmental issues.

4) According to the comprehensive evaluation results of the atmospheric environmental capacity of the study area, aiming at the existing energy and environmental problems in the region, the paper puts forward the strategy of insisting on sustainable development and differentiated environmental management requirements so as to protect China's ecological environment.

5) The compound ecosystem theory can be applied to the division of coal-fired thermal power

environmental management zones in China, studies and research from the methods and experience of environmental management at home and abroad, especially the energy and environmental management of thermal power enterprises needs to be improved and modified further.

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Tables

Table 1. Evaluation index system for regulation and control of regional energy and composite ecosystem

Target layer	Subsystem	Criterion layer	Index layer
Assessment of atmospheric environmental capacity of coal-fired thermal power plants in China under the background of carbon neutralization index system	A_1: energy subsystem	Energy production	C_{11}: per capita energy production/T standard coal
			C_{12}: raw coal output per capita/T
			C_{13}: power generation per capita/(kWh)
		Energy consumption	C_{14}: per capita energy consumption/T
			C_{15}: elasticity coefficient of energy consumption/%
		Energy utilization	C_{16}: 10000 yuan GDP energy consumption/T standard coal/10000 yuan
			C_{17}: energy processing and conversion efficiency/%
	A_2: economic subsystem	Economic scale	C_{21}: per capita GDP/yuan
		Economic structure	C_{22}: proportion of tertiary industry in GDP/%
		Economic growth	C_{23}: GDP growth rate/%

			C_{24}: growth rate of the added value of tertiary industry/%
		Economic performance	C_{25}: per capita income of urban residents/yuan C_{26}: per capita net operating income of rural households/yuan C_{27}: per capita education expenditure/yuan
	A_3: environment subsystem	Environmental pollution	C_{31}: SO_2 emission/10000 t C_{32}: PM_{10}/μ g/m^3 C_{33}: domestic waste per capita/T
		Environmental governance	C_{34}: comprehensive utilization rate of industrial solid waste/% C_{35}: harmless treatment rate of domestic waste/%
		Environmental investment	C_{36}: proportion of environmental pollution investment in GDP/%
	A_4: ecological subsystem	Ecological scale	C_{41}: water resources per capita/m^3 C_{42}: plantation area/hm^2 C_{43}: per capita cultivated land area/mu
		Ecological quality	C_{44}: forest coverage/% C_{45}: urban green coverage rate/%
		Ecological protection	C_{46}: proportion of nature reserves in land area/%

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Table 2. Calculated coupling coordination degree of different regions

Term	C value of coupling degree	Coordination index T value	D value of coupling coordination degree	Coordination level	Coupling coordination degree
Item 1	1	0.01	0.1	2	Severe imbalance
Item 2	1	0.01	0.1	2	Severe imbalance
Item 3	1	0.01	0.1	2	Severe imbalance
Item 4	1	0.01	0.1	2	Severe imbalance
Item 5	0.359	0.179	0.253	3	Moderate disorder
Item 6	1	0.01	0.101	2	Severe imbalance
Item 7	1	0.01	0.1	2	Severe imbalance
Item 8	1	0.01	0.1	2	Severe imbalance
Item 9	0.474	0.097	0.215	3	Moderate disorder
Item 10	0.88	0.018	0.127	2	Severe

					imbalance
Item 11	0.905	0.016	0.122	2	Severe imbalance
Item 12	1	0.01	0.101	2	Severe imbalance
Item 13	1	0.01	0.1	2	Severe imbalance
Item 14	1	0.01	0.101	2	Severe imbalance
Item 15	0.999	0.01	0.101	2	Severe imbalance
Item 16	1	0.01	0.1	2	Severe imbalance
Item 17	0.275	0.068	0.137	2	Severe imbalance
Item 18	0.977	0.946	0.961	10	Close coordination
Item 19	1	0.01	0.1	2	Severe imbalance
Item 20	1	0.01	0.1	2	Severe imbalance
Item 21	1	0.01	0.1	2	Severe imbalance

Table 3. Coal resource reserves of China's provinces

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Name of province/city/district	Sulfur dioxide emissions/10000 tons	Coal reserves/tons	Land area/10000 square kilometers	A value /10^4 (km^2/a)	Annual concentration limit C_s (μg • m^{-3})	Average annual concentration C_b (μg • m^{-3})	Environmental capacity/SO_2 10000 tons	Atmospheric environmental capacity intensity(tons/a)
Beijing	11.50	3.79	1.641054	4.2	20	7.0077	69.90315323	Medium
Hebei	123.38	60.59	18.7693	4.2	20	6.5735	244.3071315	Medium
Shanxi	124.90	844.01	15.67	3.5	20	7.9706	166.6658067	Medium
Inner Mongolia	139.40	769.86	118.665226	3.5	20	1.1747	717.7474952	High
Liaoning	91.40	46.63	14.86	5.6	20	6.1507	298.9683776	Medium
Jilin	35.60	12.40	18.7	5.6	20	1.9037	438.2264812	Medium
Heilongjiang	49.00	217.80	45.253226	5.6	20	1.0827	712.6428799	High
Shanghai	35.80	—	0.634050	3.5	20	56.4624	-101.6190309	None
Jiangsu	105.05	14.23	10.72	3.5	20	9.7994	116.8937	Medium

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Zhejiang	67.80	0.49	10.56	3.5	20	6.4205	154.4485313	Medium
Anhui	53.30	81.93	14.013985	3.5	20	3.8033	212.214672	Medium
Fujian	40.91	4.06	12.4	3.5	20	3.2992	205.8335489	Medium
Jiangxi	55.70	6.74	16.69	3.5	20	3.3373	238.2547611	Medium
Shandong	154.00	77.56	15.7965	4.2	20	9.7490	171.1181041	Medium
Henan	133.87	113.49	16.7	4.2	20	8.0162	205.684743	Medium
Hubei	63.30	3.30	18.59	3.5	20	3.4051	250.4277081	Medium
Hunan	80.10	18.76	21.18	3.5	20	3.7819	261.2347794	Medium
Guangdong	105.50	1.89	17.972507	3.5	20	5.8701	209.6580119	Medium
Guangxi	85.00	7.74	23.76	3.5	20	3.5774	280.1774495	Medium
Hainan	2.90	0.90	3.5354	3.5	20	0.8203	126.2202782	Medium
Sichuan	71.94	54.37	48.6052	2.8	20	1.4801	361.5247512	Medium

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Chongqing	113.10	22.49	8.24	1.4	20	13.7527	25.10637452	None
Guizhou	116.17	118.46	17.62	2.8	20	6.5931	157.5757393	Medium
Yunnan	50.07	62.47	39.41	2.8	20	1.2705	329.2209262	Medium
Tibet	0.39	0.12	122.84	7.0	20	0.0032	1551.416646	High
Shaanxi	77.90	119.89	20.56	2.8	20	3.7889	205.8173922	Medium
Gansu	55.20	58.05	42.58	2.8	20	1.2964	341.7323286	Medium
Qinghai	14.34	16.22	72.23	7.0	20	0.1985	1178.026168	High
Ningxia	38.30	54.03	6.64	3.5	20	5.76807	128.3559138	Medium
Xinjiang	58.85	148.31	166.4897	7.0	20	0.3535	1774.503736	High
Tianjing	23.50	2.97	1.196645	4.2	20	19.6382	1.662265986	None

Table 4. Stability of atmospheric environment zoning

Province, city, or district	**T statistic**	**1% critical value**	**5% critical value**	**10% critical value**	**Conclusion**

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Beijing	-4.951	-3.753	-2.998	-2.639	Stable
Hebei	-4.702	-3.770	-3.005	-2.643	Stable
Shanxi	-1.690	-3.964	-3.085	-2.682	Unstable
Inner Mongolia	-4.699	-3.770	-3.005	-2.643	Stable
Liaoning	-4.805	-3.753	-2.998	-2.639	Stable
Jilin	-4.483	-3.809	-3.022	-2.651	Stable
Heilongjiang	-4.801	-3.753	-2.998	-2.639	Stable
Jiangsu	-4.622	-3.788	-3.013	-2.646	Stable
Zhejiang	-4.702	-3.770	-3.005	-2.643	Stable
Anhui	-4.802	-3.753	-2.998	-2.639	Stable
Fujian	-4.694	-3.770	-3.005	-2.643	Stable
Jiangxi	-11.826	-4.138	-3.155	-2.714	Stable
Shandong	-4.595	-3.788	-3.013	-2.646	Stable
Henan	-4.805	-3.753	-2.998	-2.639	Stable
Hubei	-1.499	-4.138	-3.155	-2.714	Unstable
Hunan	-1.144	-3.964	-3.085	-2.682	Stable
Guangdong	-1.695	-4.138	-3.155	-2.714	Unstable
Guangxi	-0.644	-4.012	-3.104	-2.691	Unstable
Hainan	-1.144	-3.964	-3.085	-2.682	Unstable
Sichuan	-12.882	-4.138	-3.155	-2.714	Stable
Chongqing	-4.713	-3.770	-3.005	-2.643	Stable
Guizhou	-1.985	-4.138	-3.155	-2.714	Unstable
Yunnan	-2.244	-4.138	-3.155	-2.714	Unstable
Tibet	-3.772	-3.809	-3.022	-2.651	Stable
Shaanxi	-4.805	-3.753	-2.998	-2.639	Stable

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Gansu	-4.811	-3.753	-2.998	-2.639	Stable
Qinghai	-1.733	-4.069	-3.127	-2.702	Unstable
Ningxia	-4.872	-3.788	-3.013	-2.646	Stable
Xinjiang	-4.794	-3.753	-2.998	-2.639	Stable
Tianjin	-5.230	-3.753	-2.998	-2.639	Stable
Shandong	-4.595	-3.788	-3.013	-2.646	Stable
Shanghai	-5.352	-3.738	-2.992	-2.636	Stable

Table 5. Arima suitability of ecological environment carrying capacity

Province, city, or district	**Coefficient**	**Standard error**	**P value**	**Relevance**
Beijing	0.055	0.041	0.181	No autocorrelation
Hebei	0.045	0.042	0.294	No autocorrelation
Shanxi	0.046	0.042	0.282	No autocorrelation
Inner Mongolia	0.044	0.042	0.295	No autocorrelation
Liaoning	0.043	0.041	0.294	No autocorrelation
Jilin	0.049	0.046	0.287	No autocorrelation
Heilongjiang	0.043	0.041	0.296	No autocorrelation
Jiangsu	0.049	0.044	0.266	No autocorrelation
Zhejiang	0.045	0.042	0.289	No autocorrelation
Anhui	0.043	0.041	0.297	No autocorrelation
Fujian	0.044	0.042	0.296	No autocorrelation
Jiangxi	0.046	0.044	0.298	No autocorrelation
Shandong	0.047	0.044	0.292	No autocorrelation

Henan	0.043	0.041	0.296	No autocorrelation
Hubei	0.047	0.044	0.289	No autocorrelation
Hunan	0.046	0.044	0.301	No autocorrelation
Guangdong	0.046	0.044	0.298	No autocorrelation
Guangxi	0.044	0.043	0.302	No autocorrelation
Hainan	0.045	0.042	0.286	No autocorrelation
Sichuan	0.046	0.044	0.301	No autocorrelation
Chongqing	0.046	0.042	0.273	No autocorrelation
Guizhou	0.046	0.044	0.298	No autocorrelation
Yunnan	0.048	0.046	0.299	No autocorrelation
Tibet	0.070	0.047	0.136	No autocorrelation
Shaanxi	0.043	0.041	0.293	No autocorrelation
Gansu	0.044	0.041	0.284	No autocorrelation
Qinghai	0.103	0.048	0.031	No autocorrelation
Ningxia	0.071	0.045	0.118	No autocorrelation
Xinjiang	0.045	0.041	0.265	No autocorrelation
Tianjin	0.094	0.052	0.072	No autocorrelation
Shandong	0.047	0.044	0.292	No autocorrelation
Shanghai	0.091	0.051	0.072	No autocorrelation

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397 Table 6. Partition and control requirements of coal-fired power plants in China

Partition name	**Range(province/city/district)**	**Key points of environmental control**
Encourage	Inner Mongolia,	This kind of area has a large relative

development zone	Heilongjiang and Xinjiang	atmospheric environmental capacity and abundant coal reserves. Therefore, it is necessary to vigorously develop modern large-scale coal power bases focusing on power transmission and capable of generating up to 10 million kilowatts of energy. The development capacity of coal power units is determined according to the demand of eastern power receiving areas and the national coal consumption quota. In contrast, the layout of new coal power supply points is determined according to the regional environmental impact assessment results.
Optimize development zone	Beijing, Hebei, Shanxi, Liaoning, Jilin, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu and Ningxia	There is still a certain environmental capacity in such areas, but the overall distribution is uneven. The supporting coal-fired thermal power supply mainly used in this area can be moderately increased. The focus should be on constructing large capacity and high parameter ultra-supercritical units with a single unit of 600MW or above. The emission stress of air pollutants from new power plants must be regulated to meet the standard of gas-fired power plants. The layout of new coal power supply points should be determined strictly

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		according to the regional EIA results.
Restricted development zone	Shanghai, Chongqing and Tianjin	In such areas, air pollution is serious, and there is basically no environmental capacity. New coal-fired power sources are no longer planned, and new coal-fired power units are prohibited. According to the regional environmental impact assessment results, the existing site should be used for reconstruction and expansion, and the coal should be replaced by an equal or reduced amount. The replaced coal should include non-electric coal consumption, and the self-provided coal-fired power plants should be phased out. The air pollutant emissions of the existing 300000 kW units and the reconstruction and expansion units must meet the standards of gas-fired power plants.