World Scientific Research Journal (WSRJ) ISSN: 2472-3703
www.wsr-j.org

Development of China's Electric Power Industry under Low Carbon Economy

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Abstract: Based on the low carbon economy, an in-depth study on the economy of China's power industry and the sustainable development of power, energy, social and economic and environmental coordination is carried out. Moreover, a forecasting model for electric energy demand and pollutant emission is established. In view of the current situation of the unreasonable power supply structure in China, the power demand and pollutant emission is studied from the perspective of low carbon and different scenarios, and the future power demand and pollutant emission of China under low carbon economy is predicted. Empirical analysis is conducted to explore the interrelationship between China's electric energy demand and pollutant emissions and the optimization of China's power energy structure. Based on the data envelopment analysis (DEA) model, the effectiveness of the investment efficiency of China's nuclear power industry is analyzed, and the effectiveness evaluation index system for the coordinated development of power, economy and environment is established to optimize the power energy structure of China.

Keywords: low carbon economy, electric energy, economic development, environmental protection, sustainable development

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1. INTRODUCTION

At present, the energy and economic model of high carbon development in China is not sustainable. As the strategic center of energy development, the power industry plays a leading and important role in the development of the national economy. Electricity is the center of energy development. Low carbon economy calls for speeding up the optimization of electric energy structure and realization of the development of low carbon electricity. Therefore, the adjustment and optimization of power energy structure, and the establishment of power generation rights and emission trading market mechanism will play an important role in the sustainable development of power, economy and environment in China.

Energy and environmental problems are important problems that restrict the world economy and the sustainable development of society. Green development and development and utilization of new energy has become the economic development strategy of all countries in the world. Combined with the actual work in the power industry, how to achieve sustainable development of electric energy under low carbon economy is discussed. At present, China's power energy structure is dominated by carbon-based energy. The emission of pollutants in China's power industry accounts for the largest total emission of the country, and the development of low carbon power is the pillar to promote the development of low carbon energy in China and the key to promote the sustainable development of low carbon economy. Enterprises should improve the efficiency of power energy utilization in China, establish a linkage trading mechanism between power generation rights and emission trading market, thus reducing greenhouse gas emissions to cope with global climate change. Reducing greenhouse gas emissions involves double considerations of environmental protection and economic development. The clean production of electric energy is the key link of low carbon economy, and the recycling of electric energy is an important way to promote low-carbon economy and establish a coordinated development mechanism of electric energy, economy and environment. Therefore, in the low carbon economic development model, it is very important to systematically discuss and analyze the coordinated development of the power industry and the economy and the environment in China, and to promote the sustainable development of China's power industry.

2. LITERATURE REVIEW

The development of social economy promotes the increase of energy consumption. The increase of energy consumption will inevitably increase the emission of pollutants. It is the focus of recent research to integrate energy consumption, economic development and environmental pollution into a unified framework analysis.

Li and Li studied the Grainger causality from long-term consideration of economic growth, energy consumption and carbon dioxide emissions. Carbon dioxide emissions are the Grainger causes of energy consumption for a long time, and otherwise the causality is not established (Li and Li, 2015). The lack of long-term causality of Turkey's income and carbon dioxide emissions may mean that it can also reduce carbon dioxide emissions under the condition of not giving up economic growth.

Yan et al. made an empirical study of Central American countries (Yan, Bin, Chen, Zhong, Dezhi, & Jiang, 2015). It shows that in the short term, there is a one-way causality from energy consumption and economic growth to environmental pollution, there is a short and two-way causality between energy consumption and economic growth, and there is a two-way causality between energy consumption and carbon dioxide pollution in the long term.

Shaoyun and so on included the study of environmental pollution, energy consumption and economic growth in China in a unified analysis framework. On the premise of lack of carbon dioxide emissions, it is considered that there is no long-term Grainger causality between energy consumption and economic growth (Shaoyun, Wang, Zhiying, and Liu, 2015). Energy conservation policy or energy shortage has little impact on the actual growth of the country's economy in the long time.

Zhao et al. applied the time series data of 1949-2014 years and calculated that there is a two-way causality between energy consumption and economic growth, and between economic growth and environmental pollution in the long and short term (Zhao, Chen, and Liu, 2015).

Newbery analyzed the influence of property right on the external from the angle of property right. The free transaction of property rights makes the pollution amount to Pareto optimal, and the effectiveness is irrelevant to the initial configuration state (Newbery, 2016). The transaction cost is zero under the precondition of the clear property right, so as to realize the optimal allocation of resources. It does not affect the original environmental resources allocated to the polluter or distributed to the victims of pollution.

Krishnan and Mccalley, on the basis of controlling the variable of capital and labor, constructed a multivariable VAR model to study the dynamic causality between China and the sub-region in environmental pollution, energy consumption and economic growth from 1989-2009 (Krishnan and Mccalley, 2016). There is three unidirectional causality existing from environmental pollution to economic growth, from environmental pollution to energy consumption, and from energy consumption to economic growth.

Mckenna et al. studied and analyzed that there are three unidirectional causalities between environmental pollution, power consumption and economic growth, which are one-way causality from environmental pollution to economic growth and power consumption, as well as one-way causality from power consumption to economic growth. As far as the sub-region is concerned, there is a one-way causality between the economic growth and electricity consumption in the eastern coastal areas. In the central region, there is a one-way causality from power consumption to economic growth, and it shows two-way causality relationship between environmental pollution and economic growth, and the two-way causality from environmental pollution to power consumption (Mckenna, Hofmann, Merkel, Fichtner, and Strachan, 2016).

Lou et al. established the quantitative expression of the coordination degree of the 3E system, and proved that the model can be quantified to express the coordinated development of the 3E system. Moreover, the effective evaluation model of the coordination degree of the 3E system is established on the basis of the system development (Lou, Zhang, Wu, and Wang, 2017).

Koelbl et al. studied that, in the case of no new policy, the target of carbon emission reduction in 2030 is difficult to achieve. Using the different combinations of existing power generation technology, a certain emission reduction target is achieved. It would be better if the power cost increase does not exceed 20% of the total cost. They also analyzed the feasibility of applying mixed integer linear programming model to analyze the intermittency in the capacity expansion scheme in western North America and the development of renewable energy resources (Koelbl, Broek, Wilting, Sanders, Bulavskaya, and Wood, 2016).

To sum up, the current research is basically the study of the coordination degree of energy, economy and environment. This paper will focus on the coordination degree of power energy - economy - environment of its subsystems.

3. RESEARCH METHOD

3.1 Emission trading theory

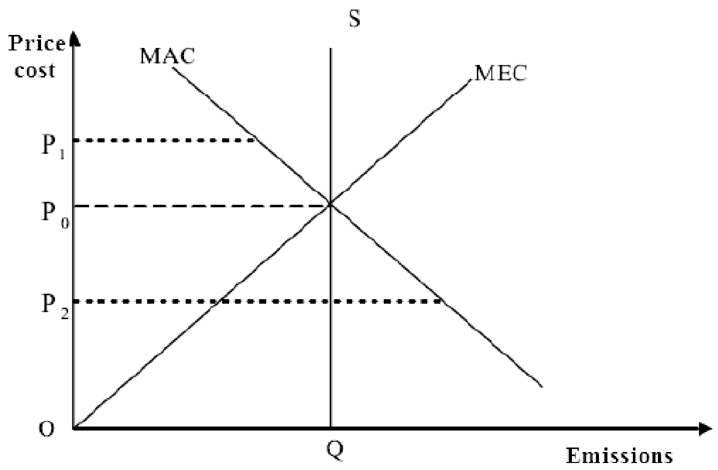

Figure 1. Emission trading under the supervision of the government

In Figure 1, it is the emission right transactions under government supervision, marginal control cost is expressed in MAC, and MEC represents marginal external cost. The maximum allowable discharge Q of the pollutant is determined by the environmental quality target that the government departments should reach. The supply curve of the total amount of pollutant emission is a vertical line that is not affected by the change of price. Government departments can use auction, pricing sale and free distribution in the initial market supply of emission permits. The emission right ends when it is sold to Q. some pollutant discharge enterprises can reduce the emission of pollution and increase the amount of emission rights of enterprises by installing sewage equipment and improving the technical level and utilization of sewage equipment. Enterprises can also increase the emission rights through the emission trading market to make profits.

3.2 Power demand forecasting model

This paper only aims at the impact of energy policies, such as GDP level, population growth and power energy structure adjustment, on the demand for power energy in different scenarios under low carbon economy.

The prediction method is based on the data of the meteorological survey resources and the range of prediction and evaluation and the parameters of the pollution sources. The grid is set by selecting the coordinate origin with the 210m high chimney as benchmark, 30Km x 30Km is used as the calculation grid range and the grid spacing is 500m. The hour, the daily average concentration and the annual mean concentration of the 4 evaluation points on the 61 x 61 grid nodes are calculated.

The diffusion mode is a point source with wind (U10≥1.5m/s), and the following wind direction is the ground concentration C (mg/m^3) of any point (X, Y) on the X axis, and the ground position of the exhaust cylinder is the original point, which are calculated by the following formula.

$$C = \left(\frac{Q}{2\pi\lambda\sigma_y\sigma_s} \right) \exp - \left(\frac{Y^2}{2\sigma_y^2} \right) \cdot F \tag{1}$$

The maximum ground concentration C_{max} (mg/m^3) and the distance from the exhaust cylinder X_{max} (m) of the sampling time of the exhaust wind (30min) are calculated:

$$C_{\max} = \frac{2Q}{e \cdot \pi \cdot U \cdot H_e^2 \cdot p_1} \tag{2}$$

The daily mean concentration prediction model. The average concentration of the pollutants is calculated by selecting the meteorological parameters such as wind direction, wind speed and atmospheric stability on the representative day of observation, and then the average concentration is added to get the average daily concentration. The calculation formula is as follows:

$$\overline{C} = \frac{1}{n} \sum_{j=1}^{n} C_{ik} \tag{3}$$

The annual mean concentration of any point of acceptance (X, Y) in the evaluation area coordinate system is:

$$C(X,Y) = \sum_i \sum_j \sum_k \left(\sum_r C_{rijk} f_{ijk} + \sum_r C_{Lrijk} f_{Lijk} \right) \tag{4}$$

4. Empirical study on pollutant emission from coal-fired power plants with carbon based energy

4.1 Changes of pollutant emission before and after desulfurization in coal-fired power plants

According to the calculation, the reduction effect of the desulphurization facilities of coal-fired power plants on pollutants is obtained, as shown in Table 1.

Table 1. Change of pollutant emission before and after desulphurization

Classification	Item	Unit	Before desulphurization	After desulphurization	Change situation
Smoke	Emission	t/h	0.08	0.063	-0.017
	Emission concentration	mg/m3	30	31	+1
SO4	Emission	t/h	4.77	0.533	-4.237

	Emission concentration	mg/m3	2041	267.8	-1774.2
NO2	Emission	t/h	1.81	0.90	-0.91
	Emission concentration	mg/m3	777	452	325

Data source: calculated and collated.

From the above table, we can see that smoke, SO_2, NO_2 emissions and emission concentrations after desulphurization obviously decrease, which will obviously improve the quality of atmospheric environment.

4.2 Prediction results of hourly concentration in thermal power plant

Table 2. Maximum ground concentration and distance under various meteorological conditions in a coal-fired power plant under windy conditions

Classification	Stability	Maximum hourly concentration (mg/m3)	Wind speed (m/s)	Occurrence distance (m)
SO2	B	0.0236	2.5	5340
	C	0.0193	5.0	7340
	D	0.0121	6.0	12240
	E	0.0158	2.0	37580
	F	0.0095	2.0	65260
	Absolute maximum	0.0236	2.5	5340
	B	0.0280	2.5	5340
	C	0.0229	5.0	7340
NO2	D	0.0143	6.0	12240
	E	0.0187	2.0	37580
	F	0.0113	2.0	65260
	Absolute maximum	0.0280	2.5	5340

Table 2 is the maximum and absolute maximum landing concentration and the range of occurrence distance under typical meteorological conditions. The maximum landing concentration of SO_2 and NO_2 hours at all levels in the wind power plant are 0.0236mg/m^3 and 0.0280mg/m^3, respectively. They are 4.72% and 11.67% respectively of the second-level standard limit values in GB3095-1996, which are not exceeding the standard, and are the largest under the class of B stability.

The maximum concentration of SO_2 and NO_2 in static wind and small wind is below 0.0987mg/m^3 and 0.1170mg/m^3 (E class stability and static wind), respectively, which are 19.76% and 48.75% of the second-level standard limit values, respectively. When the wind is small, the diffusion of pollutants is slow, the landing concentration is relatively large, and the maximum landing concentration is closer to the source. Even in this kind of small wind weather which is not conducive to diffusion, the concentration of SO_2 and NO_2 axis is not exceeding the standard.

4.3 4.3. Prediction results of hourly concentration in thermal power plant

The meteorological data and the historical data of the meteorological station can be used to determine the typical day and calculate the typical day meteorological parameters, and the daily mean concentration of the evaluation area and the evaluation points can be calculated.

Table 3. Daily mean concentration contribution of NO2 in coal-fired power plants (mg/m3)

Typical day of evaluation points	1#	2#	3#	4#	Evaluation area	
					Maximum concentration	Distance (km)
2017.08.07	0.0158				0.0260	3.8
2017.11.29		0.0122			0.0220	5.0
2017.06.04			0.0175		0.0210	3.0
2017.12.22				0.0117	0.0260	3.5

Data sources: collated according to the evaluation point data.

According to the NO_2 daily average concentration distribution of typical days, the maximum daily average concentration of NO_2 in the evaluation area and the evaluation points is as shown in Table 3. The maximum daily average concentrations of NO_2 in the evaluation area and the evaluation points are 0.0260 and 0.0175mg/m^3, respectively, accounting for 21.67% and 14.58% of the standard limits, respectively, neither exceeding the standard.

Table 4. Daily mean concentration contribution of SO2 in coal-fired power plants (mg/m3)

Typical day of evaluation points	1#	2#	3#	4#	Evaluation area	
					Maximum concentration	Distance (km)
2017.08.07	0.0135				0.0220	3.8
2017.11029		0.0105			0.0180	5.0
2017.06.04			0.0150		0.0180	3.0
2017.12.22				0.0105	0.0220	3.5

Data sources: collated according to the evaluation point data.

In accordance with the daily average concentration distribution of SO_2, the maximum daily average concentration of SO_2 in the evaluation area and the evaluation points is shown in Table 4. The maximum daily average concentrations of SO_2 in the evaluation area and the evaluation points are 0.0220 and 0.0150mg/m^3, respectively, accounting for 14.67% and 10% of the standard limits, respectively, neither exceeding the standard.

5. EVALUATION OF CHINA'S POWER, ECONOMIC AND ENVIRONMENTAL SYSTEMS BASED ON DEA

The system layer is composed of three subsystems: coal-fired power generation system, economy and environment; the development of coal-fired power generation, environmental investment, and the level of economic development level are used as the middle element layer;

and the capacity of coal-fired power generation, power generation, coal consumption, environmental input, per capita GDP, sulfur dioxide emission and concentration are used as indicator layer. The carbon based power generation development system is taken as an input index and the social economic development and the environmental system as the output index. The development level of China's power, social economy and environmental system is analyzed and studied, and the effect of the power energy as an input factor on the economic growth and the environment is discussed from the angle of relative efficiency evaluation. From the point of view of input-output, the DEA analysis model containing the preference of decision-makers is utilized. The carbon based energy coal-fired power generation, new coal-fired power generation, desulfurization unit, environmental input and other data from 2013-2017 are used as examples, as shown in Table 5.

Table 5. Carbon based energy coal-fired power generation system in China

Year	Thermal power installed capacity (ten thousand kilowatts)	Thermal power generation (100 million kwh)	Coal consumption of power generation (g standard coal / degree)	Desulphurization unit capacity (ten thousand kilowatts)	Per capita (GDP yuan / person)
2013	60282	27072	356	39786	23708
2014	65114	29827	340	44277	25605
2015	68726	33319	333	49108	29748
2016	76547	38337	330	54348	33989
2017	78667	37866	326	56640	38354

Data source: power energy statistics yearbook.

The power consumption of China increases with the increase of per capita GDP. Especially in the period of 2013-2017 years of great economic development in China, the capacity of coal-fired generator assembly machine is greatly improved, and the capacity of desulfurization unit in China is increasing year by year because of increasing environmental protection. At the same time, the newly added units are basically large capacity units. The consumption of electric coal is declining year by year. The results of the preliminary calculation are shown in Table 6 as follows.

Table 6. Carbon based energy coal-fired power generation system in China

Year	CO2 emissions (billions of tons / year)	SO2 emissions (billions of tons / year)	Average SO2 concentration (mg/m3)
2013	87146773	23213000	2495
2014	2973826675	22143677	2381
2015	3321932216	21851496	2349
2016	3822199897	22179081	2385
2017	3775330927	21176319	2277

Data source: collated.

It can be seen from the above table that, with the increase of thermal power installed capacity in 2013-2017 years, the emission of CO_2 pollutants increased year by year. However, due to the increasing requirements of the desulfurization unit and the decrease of SO_2 emissions from the new installed large capacity units, the increase of environmental investment and the upgrading of the generator set can reduce the discharge of pollutants, and promote the coordinated development of China's electric energy, economy and environment. It explains the contradiction between China's electric energy production and environmental protection. From the perspective of future emission prediction of power energy production in China, the discharge equipment and operation efficiency of the power industry in China will not meet the requirements of environmental protection, and the contradiction between power production and environmental protection is remarkable. The enterprises should improve the control standards of pollutant emission. Through the promotion of science and technology and mechanism innovation, the quantity of large capacity units and the installation of sewage equipment as well as utilization efficiency of the coal-fired power plant will be improved so as to effectively control the impact of the emission of energy pollutants in China on the environment.

6. CONCLUSION

First of all, the power demand and pollutant emission in China are predicted. Then, the DEA model is used to evaluate the effectiveness of China's nuclear power investment, and the coordinated development of China's power, economy and environment system is evaluated and discussed. The DEA model is used to make a quantitative study on the investment effectiveness of nuclear power industry and the evaluation of China's power, economy and environment system. Under the conditions of low carbon economy, the structural adjustment of power energy and the emission of pollutants will provide a reference for the coordinated development of power energy, economy and environment in China.

To sum up, under the condition of low carbon economy, nuclear power should be developed vigorously, and the power generation capacity and efficiency of carbon based coal-fired generating units are supposed to be improved. In addition, the utilization rate of the pollutant discharge equipment should be improved, the adjustment of power energy structure in China is promoted, and the power energy is coordinated with the economy and the environment.

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