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Impact Of Carbon Price On The Cost Of Thermal Power Generation

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Abstract: The carbon market and electricity market play a decisive role in the optimal allocation of market resources, bringing challenges to the operation and development of power generation companies (especially thermal power). Based on the operation mechanism of the national carbon market, this paper constructs a cost assessment model for thermal power generation units in the context of carbon trading, with the aim of studying the impact of the carbon prices on the cost of thermal power generation both in the near and long term. The calculation results of the model show that the carbon price will have a small impact on the cost of electricity for thermal power companies and the electricity market in the near term. However, in the long term, as the carbon quota is tightened and the carbon price is raised, the carbon market will affect the quotation strategies of market players and market clearing price.

Keywords: Carbon Market; Electricity Market; Carbon Price; Cost of electricity; Empirical analyses

1. Introduction

As the world's largest carbon emitter, China is dedicated to actively addressing climate change. The carbon market, as an effective market mechanism, is an effective policy tool to promote the transformation of supply-side structure to a green and low-carbon one [1].

The power industry is one of the largest carbon emitting industries in China. Under the goal of "carbon peaking and carbon neutrality" and the vision of building a new power system, carbon emission reduction in the power industry is imperative, and the carbon market and power market will play an important role as market mechanisms [2].

Existing studies have focused on the coupling and coordinated development of power market and carbon market, the principles and methods of allocating carbon emission allowances, and the cost of carbon for thermal power units. In terms of the synergy between power market and carbon market, Liu et al. [3] studied the problem of unclear coupling mechanism of the electricity market and carbon market by modeling the equilibrium situation of the two markets. Li et al. [4] developed an economic dispatch model to study the combined effect of electricity market reform and carbon pricing strategy in reducing CO2 emissions in power system operation. In terms of initial carbon emission allowance allocation. Zhang et al. [5] established a CGE model to analyze the impact of different ETS quota allocation scheme on the power industry. Chi et al. [6] developed a system dynamics model to simulate and evaluate different methods of allocating carbon quotas in the context of electricity system reform. In terms of carbon cost for thermal power units, Yu et al. [7] proposed a carbon abatement cost estimation model. By applying the proposed model, the abatement costs of four coal-fired generating units were estimated under six combinations of scenarios.

In summary, there is a lack of research that empirically analyzes the impact of carbon prices on thermal power costs both in the near and long term. To fill this gap, this paper builds a model to access the impact of the economics of thermal power units based on the carbon market trading mechanism. Using an empirical analysis, the impact of carbon markets at different stages of development on the cost of thermal power generation is analyzed, and relevant policy recommendations are put forward based on the research results.

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2. Model formulation

2.1 Measurement model for thermal power industry

The annual power generation capacity (Q) of the thermal power industry can be calculated by:

$$Q = V_c \times T_c \#(1)$$

where V_c denotes the installed capacity and T_c the average utilization hours of thermal power units.

The annual carbon emissions (E) of the thermal power industry can be calculated by:

$$E = Q \times \varepsilon \#(2)$$

where ε denotes the carbon emission factor of thermal power.

The increase in the average unit cost (C_z) of electricity from thermal power caused by the carbon price can be expressed as:

$$C_z = \frac{\delta \times P_c \times E}{Q} \#(3)$$

where P_c denotes the carbon price and δ denotes the proportion of total carbon quota shortfall.

According to Eq. (2), the value of C_z can be calculated by:

$$C_z = \frac{\delta \times P_c \times Q \times \varepsilon}{Q} = \delta \times P_c \times \varepsilon \#(4)$$

2.2 Measurement model for thermal power units

According to the studies conducted by [11-12], the annual carbon emissions (E_i) from thermal power unit i can be calculated by:

$$E_i = b_{e,i} \times \sigma \times Q_{e,i} + b_{h,i} \times \sigma \times Q_{h,i} \#(5)$$

For each thermal power unit i, $b_{e,i}$ is the standard coal consumption of power generation; $Q_{e,i}$ is the power supply capacity; $b_{h,i}$ is the standard coal consumption for heating; $Q_{h,i}$ is the heat supply; and σ is the coal-fired equivalent carbon emission factor.

In the national carbon market, free quotas are allocated using the benchmark method. The free quotas ($A_{free,i}$) obtained by thermal power unit i in the primary market can be calculated by:

$$A_{free,i} = (1 - \alpha) \times \left(B_{e,i} f_i Q_{e,i} + B_{h,i} Q_{h,i}\right) \#(6)$$

where α is the quota auction ratio; $B_{e,i}$ is the baseline carbon emissions from electricity supply; f_i is the correction factor related to cooling method, load rate and heating ratio; $B_{h,i}$ is the baseline value of carbon emissions for heating supply. The $B_{e,i}$ and $B_{h,i}$ values for different types of thermal power units are confirmed in Table 3.1.

Table 3.1 Carbon emission baseline in the national carbon emission market

Type	Electricity supply (t·CO2/MWh)	Heating supply (t·CO2/TJ)
Conventional coal-fired units (≥300 MW)	0.877	126
Conventional coal-fired units (< 300MW)	0.979	126
Non-conventional coal-fired units	1.146	126
Gas-fired units	0.392	59

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Table 3.2 Short-term results of the measurement model for thermal power units

Unit capacity	Type	Carbon emission baseline (g/ kWh)	Maximum carbon emission intensity (g/ kWh)	Increase in the average unit cost of electricity (10^{-3}Yuan/kWh)
< 200MW	Sub-critical	979	1039	3.00
≥ 200MW	Sub-critical	979	833	-4.07
≥ 300MW	Supercritical	979	833	-4.07
	Sub-critical	979	1005	1.32
≥ 600MW	Ultra-supercritical	877	837	-2.00
	Supercritical	877	920	2.14
	Sub-critical	877	907	1.53
≥ 1000MW	Ultra-supercritical	877	848	-1.45
	Supercritical	877	754	-6.15

Table 3.3 Long-term results of the measurement model for thermal power units

Unit capacity	Type	Carbon emission baseline (g/ kWh)	Maximum carbon emission intensity (g/ kWh)	Increase in the average unit cost of electricity (10^{-3}Yuan/kWh)
≥ 300MW	Supercritical	793	806	1.9
	Sub-critical	793	827	2.2
≥ 600MW	Ultra-supercritical	793	759	-0.4
	Supercritical	793	780	-0.2
	Sub-critical	793	819	2.1
≥ 1000MW	Ultra-supercritical	793	705	-1.0
	Supercritical	793	720	-0.9

Based on the operating rules of the national carbon market, emission-controlled enterprises shall pay to the competent authorities a compliance fee of not less than their annual carbon emission allowances. The value of δ is calculated by:

$$\delta = \frac{E_i - A_{free,i}}{A_{free,i}} \#(7)$$

The increase in the average unit cost (C_i) of thermal power unit i caused by the carbon price can be calculated by:

$$C_i = (\alpha + \delta) \times A_{free,i} \times P_c \#(8)$$

The cost ($C_{carbon,i}$) of carbon in the carbon market for thermal power unit i can be calculated by:

$$C_{carbon,i} = \frac{(E_i - A_{free,i}) \times P_c}{Q_{e,I}} \#(9)$$

Finally, the revenue (R_i) generated per unit of electricity for thermal power unit i can be calculated by:

$$R_i = G_i - C_i - C_{carbon,i} \#(10)$$

where G_i is the clearance tariff.

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3. Empirical Analysis

3.1 Analysis of short-term results

Taking the national electricity market in 2020 as an example, the total shortage of carbon quotas is set at around 5%, the carbon price level is 50 Yuan/ton, and carbon quotas are still allocated in the form of free (α=0). According to the National Bureau of Statistics, the total thermal power generation capacity in 2020 is 1246.24 million kWh, the average utilization hours of thermal power is 4154h,and the thermal power carbon emission factor is 832 g/kWh.

Based on the measurement model for thermal power industry, the average unit cost of thermal power generation will increase by about 0.00208 yuan/kWh. Moreover, the increases in the average unit cost of different types of thermal power units, calculated using Eqs. (5) – (8), are shown in Table 3.2.

Most of the ultra-supercritical and supercritical units will have a surplus of carbon quotas, which can be sold in the carbon market for profit. In particular, ultra-supercritical units (1000MW) can make a profit of 0.00615 Yuan/kWh. On the other hand, subcritical units have insufficient carbon quotas and need to purchase quotas from the carbon market or reduce emissions on their own, resulting in higher costs for power generation. For example, the cost of electricity for sub-critical units (<200MW) will increase by 0.003 Yuan/kWh.

The above results show that the allocation of carbon quotas for thermal power units is relatively generous in the short term, and the carbon price has a small impact on the average cost of thermal power generation.

3.2 Analysis of long-term results

Based on the measurement model for thermal power industry, the carbon quota shortage is considered at 5%. If the long-term carbon price rises to 90 – 160 Yuan/ton in 2030, the average unit cost of thermal power generation will increase by 0.0037 – 0.0067 Yuan/kWh. Moreover, if 20% of carbon quotas are allocated by auction, the average unit cost of thermal power generation will increase by 0.0019 – 0.0033 yuan/kWh. Further, If all quotas are auctioned, the cost will increase to 0.0074 – 0.0133 Yuan/kWh.

Based on the measurement model for thermal power units, the increase in the electricity cost of different types of thermal power units in the long term are shown in Table 3.3. if we consider the carbon emission benchmark value of 793g/kWh, there will be a surplus of carbon quotas for 1000MW units and a shortage for 300MW units. Most supercritical and ultra-supercritical units have surplus quotas: To be specific, 600MW ultra-supercritical units can realize a profit of 0.004 Yuan/kWh. When the unit capacity is the same, the average unit cost of for ultra-supercritical units is generally lower than that for supercritical units. For example, when the unit capacity is 1000MW, the profit of ultra-supercritical units is 0.001 Yuan/kWh, while the profit of supercritical units profit is 0.0009 Yuan/kWh. Besides, if the carbon price is 90 yuan/ton, the average unit cost will increase by 0.0019 – 0.0021 Yuan/kWh.

The above results show that with the tightening of carbon quotas and the introduction of the allocation model, the continued increase in the carbon price will significantly push up the cost of power generation for thermal power units.

4. Conclusion

With the development of carbon market and the improvement of carbon trading related policies, carbon emission accounting and quota allocation will have certain influence on the cost of thermal power enterprises and their behavior in the carbon market. This paper has the following conclusions:

On one hand, carbon price can affect the quoting behavior and trading decisions of market players. In the early stage of the operation of the national carbon market, the relatively rich carbon

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quotas lead to a small impact of carbon price on the cost of electricity for thermal power enterprises. However, with the gradual tightening of carbon quotas in the future, the carbon price will continue to rise, which will directly affect the operation and quoting strategies of thermal power enterprises and push up the cost of power generation. Ultimately, this may accelerate the withdrawal of thermal power, which in turn will have a certain impact on the protection of power supply and the stable operation of the system.

On the other hand, the carbon price raises the price of electricity market transactions. In the short term, the carbon market has minimal impact on the clearing price of power market. In the long term, as carbon quotas are gradually tightened, the impact of the carbon price on the trading price of the power market is becoming more and more significant.

Based on the above findings, this paper proposes the following policy recommendations:

First, the development and improvement of the national carbon market should be accelerated. The purpose is to use the market mechanism to force thermal power enterprises to strengthen their energy-saving renovation efforts, thus reducing carbon emissions and power generation capacity of high-carbon emission units.

Second, in the short term, carbon quotas for the power industry should continue to be allocated free of charge, and a small amount of initial carbon quotas could be auctioned. The initial carbon price should be kept at a stable level, not excessively high.

Last the not the least, in the long term, it is necessary to gradually increase the proportion of quota auctions and raise the carbon price. The purpose is to encourage thermal power enterprises to strengthen the application of low-carbon emission reduction technologies and accelerate the construction of new power systems through the transmission effect of carbon price on electricity price.

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