Quantitative Analysis of the Impact of National Carbon Market on Electricity Market

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Abstract. China's electricity market and national carbon market are both under construction. The core link between the carbon market and the electricity market is price. As the carbon quota tightens and the carbon price rises, the national carbon market will affect the bidding strategy of market participants, and then have an impact on market structure, transaction price, cross-provincial trade, etc., and promote the further improvement of auxiliary service market, capacity market, green electricity trading and other mechanisms in the electricity market. Based on a mixed integer linear programming model, this paper quantifies the impact of the national carbon market on the electricity market and promotes the coordination between the electricity market and the national carbon market.

Keywords: electricity market, carbon market, market coordination, quantitative analysis

1 Introduction

Carbon trading is an important policy tool for controlling and reducing greenhouse gas emissions by using market mechanisms, with the main functions of carbon emission control and carbon emission pricing. In 2021, China's national carbon market was launched, becoming the world's largest carbon market. From the international experience, the electricity market and the carbon market are two independent markets, connected by the common market participants of thermal power enterprises. The foreign electricity market and carbon market are relatively mature, coordinated, and smooth, and the carbon price can be effectively transmitted through the electricity price, without coordination problems. Different from foreign countries, thermal power still accounts for a large proportion in China, and the electricity market is still in the stage of coexistence of planning and market, so the electricity market and carbon market in China have a high degree of mutual influence and are very closely linked [1-4].

B. K. Kandel et al. (eds.), *Proceedings of the 2023 3rd International Conference on Business Administration and Data Science (BADS 2023)*, Atlantis Highlights in Computer Sciences 19,
https://doi.org/10.2991/978-94-6463-326-9_47

This paper constructs a carbon-electricity market operation model, and quantitatively studies the impact of the carbon market on the bidding strategy of market participants based on a mixed integer linear programming method, and then analyses the impact of the carbon market on the market structure, transaction price, cross-provincial trade, etc. of the electricity market [5-6].

2 Impact of carbon price on electricity Market price

2.1 Impact on Bidding Behaviour for Market Participants

The core link between the carbon market and the electricity market is price. In the initial stage, the carbon price has a small impact on the incremental cost of electricity for thermal power enterprises and has little impact on the electricity market; in the long term, as the carbon quota tightens and the carbon price rises, the extra carbon emission reduction cost of thermal power will be guided in the electricity market, and the carbon market will affect the bidding strategy of market participants, as is shown in the Figure 1.

For coal-fired power generation enterprises, according to the profit and loss analysis theory, their basic profit formula is as follows: coal-fired power enterprise profit = total revenue - total cost. When the total revenue of coal-fired power enterprises is greater than the total cost, there is operating profit. The carbon market adds extra carbon emission reduction cost to coal-fired power[7-10].

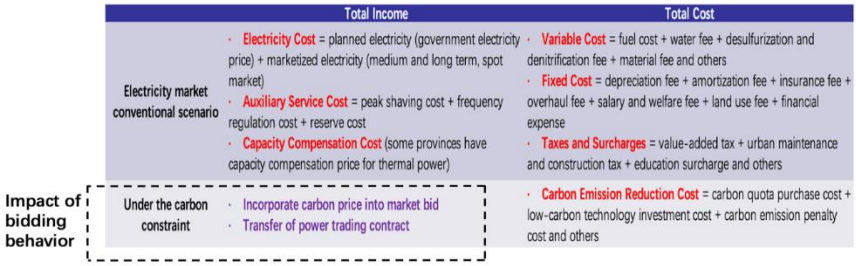

Fig. 1. Schematic diagram of cost and revenue of thermal power enterprises.

2.2 Impact on Market Transaction Clearing Price

2.2.1. Model Idea.

Using PLEXOS, an Australian electricity market simulation commercial software, to model and simulate the impact of the carbon market on the electricity market transaction clearing. The mixed integer linear programming method is used for optimization calculation, as is shown in the Figure 2.

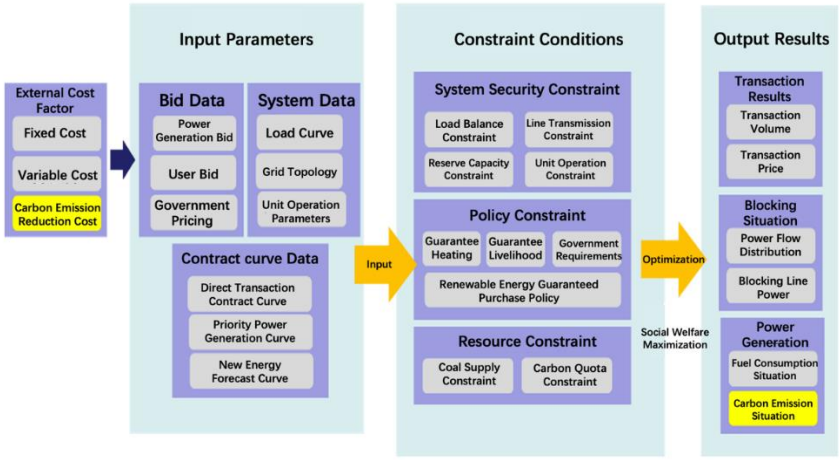

Fig. 2. Schematic diagram of electricity market transaction model under carbon constraint

Simulation idea: Incorporate the corresponding carbon emission cost of each type of thermal power unit into the market bid and optimize the clearing centrally.

Optimization objective: Minimum cost of power generation side.

Declaration price: The market participant's bid considers the carbon cost price, that is: declaration price = original price + carbon price.

Main constraints: (1) Power balance constraint; (2) Unit operation constraint; (3) System security reserve constraint.

2.2.2. Model principle.

This paper us the same clearing program as the current spot pilot clearing principle in Shanxi, Gansu and other places, and the objective function is to minimize the total power purchase cost, as follows:

$$\min \sum_{i=1}^{N} \sum_{t=1}^{T} (C_{i,t}(P_{i,t})) \tag{1}$$

Where, T represents the total number of periods considered,M represents the number of users who participate in the day-ahead spot market bid, N represents the number of units, $P_{i,t}$ represents the output of unit i in period t, $C_{i,t}(P_{i,t})$ represents the unit segmented bid curve, and the bid curve of new energy and self-scheduling units can be set to zero to achieve priority clearing.

The constraints include unit operation constraints, system power balance constraints, reserve constraints, network constraints, etc., as follows:

(1) Unit operation constraint

Generator output limit constraint

$$I_{i,t} \cdot P_{i,t}^{\min} \le P_{i,t} \le I_{i,t} \cdot P_{i,t}^{\max} \quad , \ t = 1,2,\ldots..,T \tag{2}$$

The output result of unit i in period t is $\{P_{i,t}\}_{i=1\ldots N;t=1\ldots T_T}$. When the unit is in the output state, the upper and lower limits of the unit's output are mainly determined by the upper and lower limits of the unit's output at time t.

(2) Power balance constraint

$$\sum_{j \in NG} I_{i,t} \cdot P_{t,j} = D_t \ , t=1,2,...,T \tag{3}$$

The total active load of the system D_t in period t , that is, the sum of the output of the units that are on in each period must meet the load of that period.

(3) System capacity reserve constraint

$$\sum_{i \in NG} I_{i,t} \cdot P_{i,t}^{\max} \ge D_t \cdot (1+R_{Ut})$$

$$\sum_{i \in NG} I_{i,t} \cdot P_{i,t}^{\min} \le D_t \cdot (1-R_{Dt})$$

$$t=1,2,...,T \tag{4}$$

The output of the units that are on in each period must meet the positive and negative reserve constraints of the system according to a certain reserve ratio. Where NG is all the units in the whole system.

(4) Network constraint

Branch power flow constraint

Line and transformer capacity limit, section transmission limit constraint, etc.

$$\left|X_{t,j}\right| \le X_{\max,j}, \qquad t=1,2,...,T, \ j \in NL \tag{5}$$

$$X_{t,j} = \sum_{i=1}^{N} G_{j-i} P_{i,t} \tag{6}$$

Where, N is the total number of units. The transmission capacity of lines, sections and transformers can be abstracted as the transmission capacity constraint of lines. That is, the line transmission power in each period cannot exceed the positive and negative capacity of the line. In practical application, there is usually a certain margin for the positive and negative capacity of the line, that is, $X_{\max,j}$ multiplied by a certain ratio as the transmission limit of the line.

2.2.3. Simulation Results.

Based on the simulation results, it is found that: as the carbon market price increases, the average clearing marginal price of the electricity spot market will rise, and the thermal power winning volume will shift from high-carbon units to low-carbon units. A simulation of a day-ahead market for a spot pilot was conducted, with 140 thermal power units as bidding participants. Considering typical daily load curve, unit bid curve, system security constraints and other conditions, three scenarios were set: no carbon price, carbon price 50 yuan/ton, carbon price 90 yuan/ton, as is shown in the Figure 3.

In terms of transaction volume, as the carbon price increases, the daily total winning volume of high-carbon units (below 200M) gradually decreases, and the low-carbon units (600MW and above) gradually increase.

In terms of transaction price, as the carbon price increases, the weighted average clearing price of the power generation side rises. Compared with the scenario without carbon price, the average increase is about 1.2% when the carbon price is 50 yuan/ton, and about 7% when the carbon price is 90 yuan/ton, as is shown in the Figure 4.

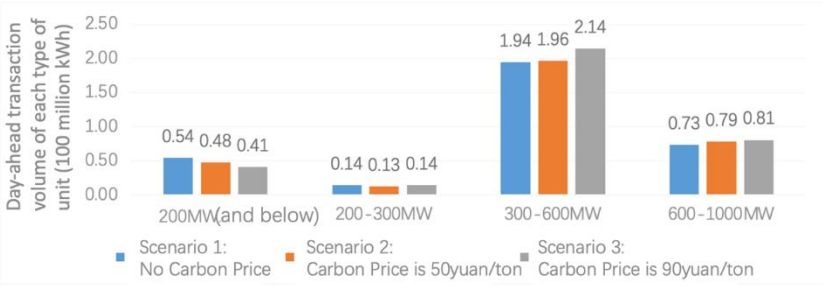

Fig. 3. Schematic diagram of electricity market transaction model under carbon constraint.

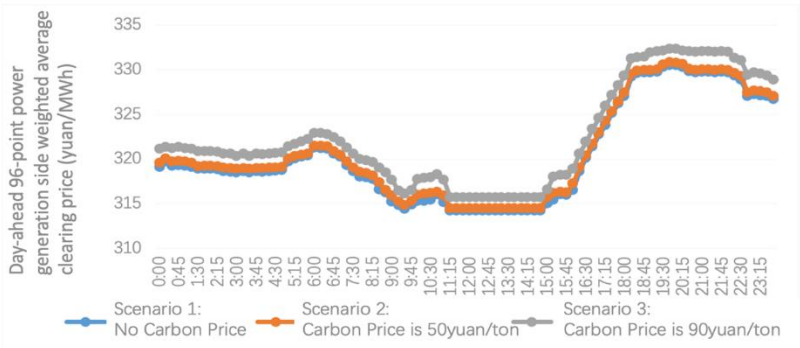

Fig. 4. Schematic diagram of electricity market transaction model under carbon constraint.

3 Other Impact on Electricity Market

3.1 Impact of New Energy Participation in the Market

The carbon market promotes the development of new energy, promotes new energy to become the main market competitor, and promotes new energy to enter the market. At present, most of China's clean energy belongs to priority power generation and does not participate in the market; thermal power is the main competitor for the marketized electricity space. The carbon market is conducive to increasing the proportion of clean energy power generation, and some clean energy will gradually enter the "market" from "priority power generation" and be absorbed by competition.

3.2 Impact of Cross-Provincial Trading

For the receiving provinces with a large proportion of imported thermal power, when the carbon price is high, it will raise the landing power price and affect cross-provincial trade. Due to the different proportions of thermal power installed capacity and coal consumption rate in each province, and the impact of carbon price on the cost of electricity per unit are different in each province. If the carbon price of each province is included in cross-provincial trade, the transaction volume, clearing price, etc. of each province may change. It will affect the inter-provincial trade distribution pattern. Some inter-provincial transmission lines with a lot of transactions before may not be busy anymore. The electricity price of receiving provinces, inter-provincial trade volume and other indicators will be changed too.

3.3 Impact on Auxiliary Services and Capacity Market

With the increase of thermal power carbon cost, thermal power enterprises' demand for improving auxiliary service market and establishing capacity market will increase. Under the trend of energy transition and tightening carbon emission constraints, the utilization hours of coal-fired units decrease year by year, coupled with the rise of coal price and carbon price impact, coal-fired enterprises face operational difficulties and hope to obtain benefits by participating in auxiliary services and capacity market.

3.4 Impact on Green Electricity Trading

The carbon market further promotes green electricity trading, especially after high-energy-consuming industries enter the carbon market, the demand becomes more intense, and then accelerates the improvement of green electricity trading mechanism. In the future, high-energy-consuming industries such as petrochemicals, steel, cement, electrolytic aluminium, etc. will enter the carbon market, and electricity carbon emissions will also be accounted for. Further stimulate users' strong demand for buying green electricity trading and put higher requirements on the trading organization of different power sources, including possibly further promoting cross-provincial "point-to-point" green electricity trading.

4 Conclusion

The carbon market mainly affects the electricity market through price, and the carbon price affects the bidding strategy of market participants, and then has a certain impact on market structure, transaction price, cross-provincial trade, market mechanism construction, etc. For receiving provinces with a large proportion of imported thermal power, when the carbon price is high, it will raise the landing power price and affect cross-provincial trade. With the increase of thermal power carbon cost, thermal power enterprises' demand for improving auxiliary service market and establishing capacity market will increase. The carbon market accelerates users' direct purchase of green electricity and green certification needs, thereby promoting renewable energy to enter the electricity market and users' direct purchase of green electricity.

Acknowledgement

This paper is supported by Science and Technology Project of State Grid Corporation of China (Research on Key Mechanism of National Carbon Market Construction, Operation Simulation and Evaluation Technology of Carbon Reduction Contribution of Power Grid under "3060" Goal. Project number:1300-202157360A-0-0-00).

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