How Do China's Electricity and Carbon Markets Interact?

Luyao Wang[1], Zishuo Xu[1], Xiangtao Long[1], Ruoqi Zhang[1], Yuwei Cao[2], Qing Yang[1,2,*], Jianjun Xiao[4], Wenchuan Meng[4], Zaimin Yang[4,5]

[1]China-EU Institute for Clean and Renewable Energy, Huazhong University of Science and Technology, Wuhan, 430074, China

[2] School of Energy and Power Engineering, Huazhong University of Science and Technology, Wuhan, 430074, China.

[3]College of Chemistry and Chemical Engineering, Hubei University, Wuhan ,430062, PR China

[4]Energy Development Research Institute, China Southern Power Grid, Guangzhou, Guangdong, China

[5]College of Electrical Engineering, Zhejiang University, Zhejiang, China

*Corresponding author's e-mail: qyang@hust.edu.cn

Abstract. Under China's dual strategic goals of " carbon peak in 2030 and carbon neutral in 2060 ", the carbon market and electricity market play important roles. The national carbon emission allowance (CEA) market has been launched, and the road map for the development of a unified national electricity market has been clarified. This has a profound impact on the energy and electricity industry, and there is an urgent need for in-depth research on the coupling mechanism and coordinated development of the electricity market and carbon market. This article adopts the system dynamics (SD) method to design and simulate the coupling mechanism between two markets, and analyzes the market coupling effect and performance under different carbon emission levels and carbon reduction policy intensities. The results show that (1) the carbon market affects the profitability of power generation enterprises through the cost of carbon emission reduction, and the carbon price signal can be effectively transmitted to the electricity market. (2) The electricity market is not as sensitive to the intensity of carbon reduction policies as the CEA market. (3) The higher the intensity of carbon reduction policies, the lower the final level of carbon prices. Therefore, it is recommended to implement a time of use electricity pricing mechanism according to local conditions, guide electricity prices to tilt towards the cost of power generation, and moderately enhance the profitability of power enterprises. In addition, the intensity of implementing carbon emission control policies should match the development of the industry and should not be too aggressive.

Keywords: Electricity market, Carbon market, System Dynamics

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1 Introduction

The power sector is an important source of carbon dioxide emissions, accounting for over one-third of the global CO2 emissions from fossil fuel combustion and over 40% of China's CO2 emissions.[1] Against the backdrop of peaking carbon emissions and achieving carbon neutrality, China is shifting from "dual control" of energy consumption to "dual control" of carbon emissions. The national "14th Five Year Plan" proposes to "improve the dual control system of total energy consumption and intensity, and implement a system mainly based on carbon emission intensity control and supplemented by carbon emission total control". [2]The carbon market and the electricity market play important roles as market mechanisms, with close connections and mutual influence. The integration of the carbon market and the electricity market is mainly reflected in cost characteristics, price formation, and mechanism design.[3]

The CO2 emission factor (CEf) of electricity is an important basic parameter for calculating the CO2 emissions of electricity consumption. [4]It is an important measure to implement the "coordinated promotion of emission factor calculation" requirement in the "Implementation Plan for Accelerating the Establishment of a Unified and Standardized Carbon Emission Statistical Accounting System" and provide basic data support for carbon emission accounting, which can be used as a reference for different entities to calculate the CO2 emissions of electricity consumption.[5]

Therefore, this article establishes a SD model that couples China's electricity market and carbon market, and discusses and analyzes whether the market mechanism can operate effectively based on simulation results. In addition, the contribution of this article lies in analyzing the performance of coupled markets under different levels of carbon emissions, conducting sensitivity analysis on the intensity of carbon reduction policies, and further revealing the impact of policy intensity on synergistic effects. Finally, this article provides corresponding policy recommendations for the construction of a coupled electricity market and carbon market.

2 Modeling and Simulation

2.1 SD Model

SD is a simulation technique primarily used to study complex systems. This method focuses on studying the causal relationships between variables, constructing a SD model by establishing flows and determining mathematical equations between variables, analyzing the internal operating mechanism, and studying complex systems with high-order, nonlinear, and multiple feedback. The effectiveness of the model is verified through the operating results. [6][7]The interactive model between the electricity market and the carbon emission all market is a dynamic multiple feedback system that involves the interaction of numerous influencing factors, including market supply and demand, electricity prices, carbon prices, installed capacity, and a series of related factors. Based on the above, this article uses SD to simulate the synergistic effects between the electricity market and the carbon market.[8][9]

2.2 Framework Analysis

The logical framework diagram of the research is shown in Figure 1.

Thermal power enterprises participate in both the carbon market and the electricity market, and the two markets are coupled through a common market entity. Thermal power enterprises are important entities in two markets. As providers of carbon quotas, they occupy a major share in the carbon market. By linking the two markets through their power generation behavior and trading decisions, thermal power enterprises comprehensively consider the supply and demand, price trends, carbon emission levels, and quota allocation of the two markets, and make optimal decisions in the two markets.

Under the total carbon emission control, thermal power enterprises need to submit carbon emission quotas equal to their actual power generation carbon emissions, and the shortfall can be purchased from the carbon market. The allocation quantity and method of carbon emission quotas for thermal power enterprises will affect their power generation behavior. According to the baseline method for quota allocation, efficient and low emission units will receive more quotas and can choose to generate more electricity or sell quotas, while inefficient and high emission units will receive relatively fewer quotas and can choose to purchase quotas or generate less electricity and transfer power generation rights.

China is accelerating the planning and construction of a new energy system, promoting the green and low-carbon transformation of energy, and making every effort to promote the development of renewable energy. The electricity trading market is regarded as an effective way to enhance local consumption capacity and optimize the allocation of renewable energy power resources. By expanding the trading of renewable energy markets, it promotes the installation of renewable energy capacity.

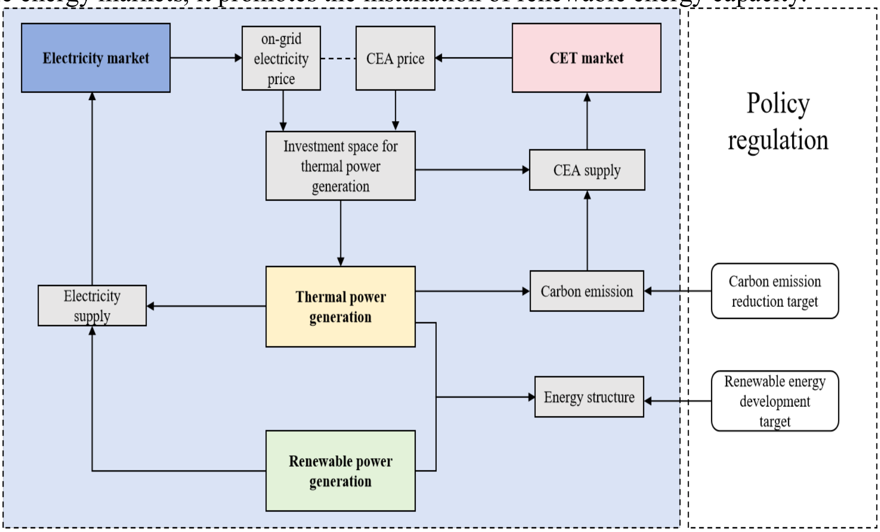

Fig. 1. The logical framework of this paper.

2.3 Model Design

2.3.1 Assumptions.

Due to the fact that the model cannot simulate all the details of real-life situations, it is necessary to make reasonable assumptions about the model. The assumptions made for the model are as follows:

1. Electricity producers are divided into thermal power generators and renewable energy generators
2. The trading of carbon market and electricity market is independent, that is, electricity trading is not tied to carbon trading.
3. Set upper and lower price limits based on the trading situation in the real market.
4. Selling electricity from grid operators to purchasing power plants or end-users, without considering the transaction method of direct electricity purchase

2.3.2 Causal Relationship of SD Model.

Figure 2. shows the causal relationship between the electricity market and the carbon market.

The electricity market and carbon market are two negative feedbacks respectively. When carbon prices rise, carbon quota holders hope to increase sales in order to gain profits. However, when the supply of CEA exceeds demand in the market, it leads to a decrease in CEA prices. The market situation of CEA will affect the profits of the seller's thermal power plants, and then affect the new installed capacity of traditional thermal power through investment. After the total installed capacity increases, the amount of thermal power generation will also increase, and the supply and demand level of CEA in the market fluctuates. Through the above negative feedback loop, the price reaches a relatively balanced state.

The electricity price signal in the spot market can fully reflect the electricity supply and demand levels at different times and locations. The main supply in the electricity market comes from thermal power plants and renewable energy power plants, and the fluctuation of electricity prices is determined by market supply and demand. The electricity price and carbon price jointly affect the profit of coal-fired power generation, which in turn causes changes in the newly added conversion capacity of coal-fired power generation, ultimately affecting the amount of electricity generated. This feedback is also negative.

In addition, the supply of CEA is affected by carbon emission reduction intensity control policies, and different policy intensities will stimulate the market, leading to a new equilibrium state.

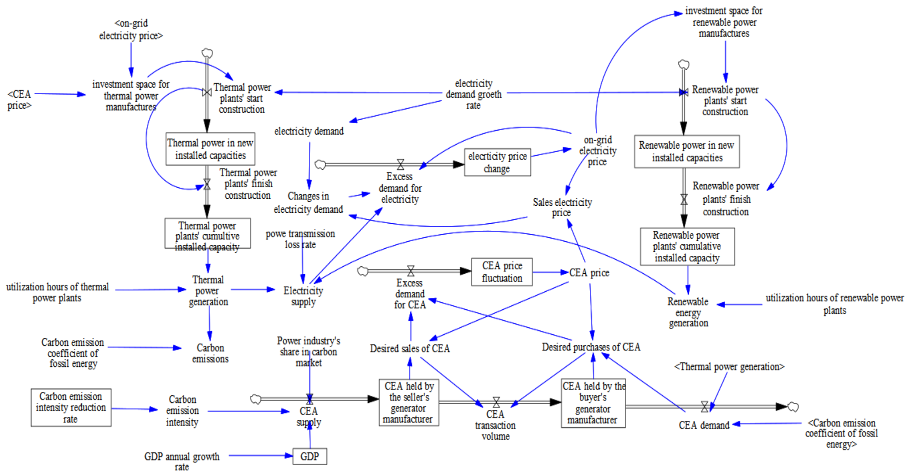

Fig. 2. The SD model of the electricity and carbon market

2.4 Data, Results and Discussion

Based on the constructed SD model, this section conducts simulation and scenario analysis, and simulates the changes in two markets under different carbon intensity policies. The benchmark data used for simulation is the end of the year 2021, with a running time step of one month and a simulation time of 100 months. The installed capacity and power generation data of thermal power and renewable energy in the model mainly come from the National Bureau of Statistics and the National Energy Administration; The policy document cites the White Paper on China's Policies and Actions to Address Climate Change and the Outline of the 14th Five Year Plan for National Economic and Social Development and the Long Range Objectives for 2035 of the People's Republic of China. The initial carbon price is set at 20 yuan/ton, and the price ceiling is set at 200 yuan/ton based on the current carbon market level.

When simulating initial data, the CEf of electricity is the latest published national fossil energy electricity CEf of 0.8426 kgCO_2/kWh, Carbon emission intensity reduction rate is 0.25%.

2.4.1 Simulation Analysis of the Baseline Scenario.

In the benchmark scenario, the trends of carbon prices and electricity prices in the coupled market are shown in the Figure 3. The carbon price increases rapidly in the initial stage, and then decreases at a gentle rate after fluctuating at a high price for a period of time. The benchmark price of electricity is set at 0.38 yuan/kWh and has been steadily increasing to reach the market stable price of 0.75 yuan/kWh. From the perspective of changing trends, due to the need for the electricity market to maintain a generally stable overall level, its volatility is relatively small, while the carbon market responds more strongly to stimuli, resulting in significant fluctuations during price fluctuations.

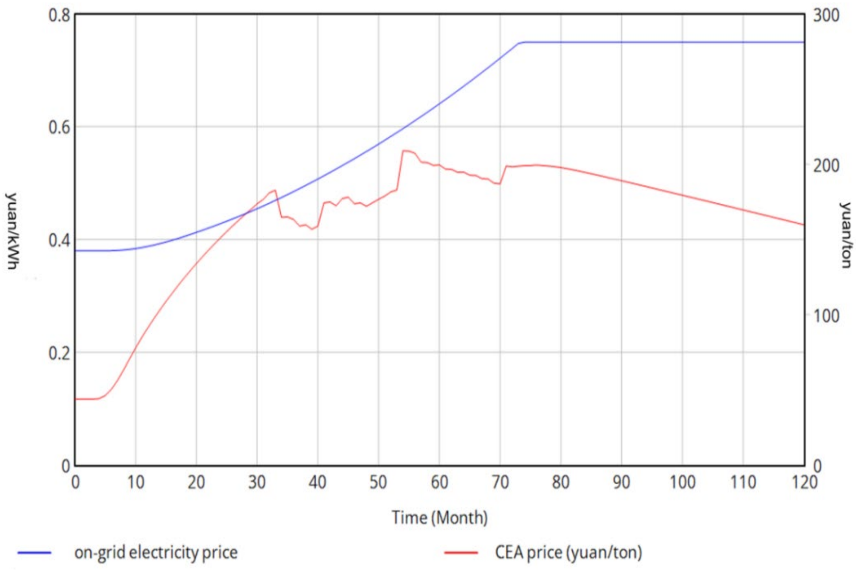

Fig. 3. On-grid electricity price and CEA price

2.4.2 Simulation Analysis of Different Policy Intensities.

This article sets a scenario for the CO2 emission reduction rate per unit of GDP, indicating the intensity of carbon emission reduction policies.The parameter settings refer to existing research, as shown in Table 1.[10] The larger the emission reduction rate, the greater the policy intensity.

Table 1. Scenario settings with different policy intensities

	Reduction rate of CO_2 emission
Scenario A	0.25%
Scenario B	0.35%
Scenario C	0.45%

The results in Figure 4. and Figure 5. indicate that the electricity market is not as sensitive to the intensity of carbon reduction policies as the market, and the higher the intensity of carbon reduction policies, the lower the final level of carbon prices.

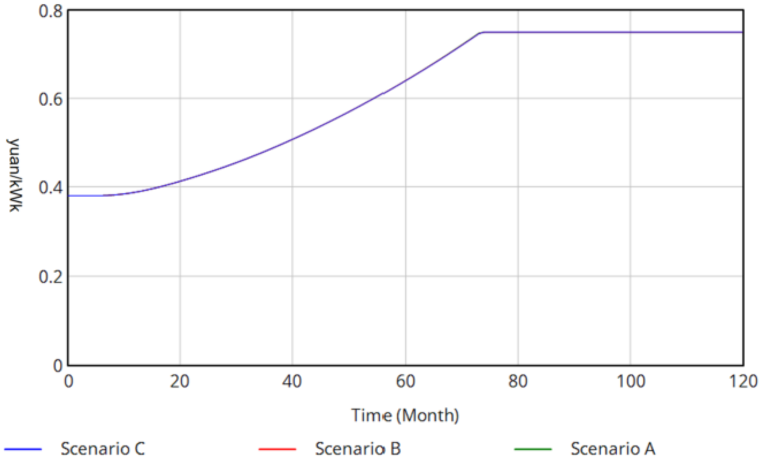

Fig. 4. The simulation results of On-grid electricity price under different policy intensities

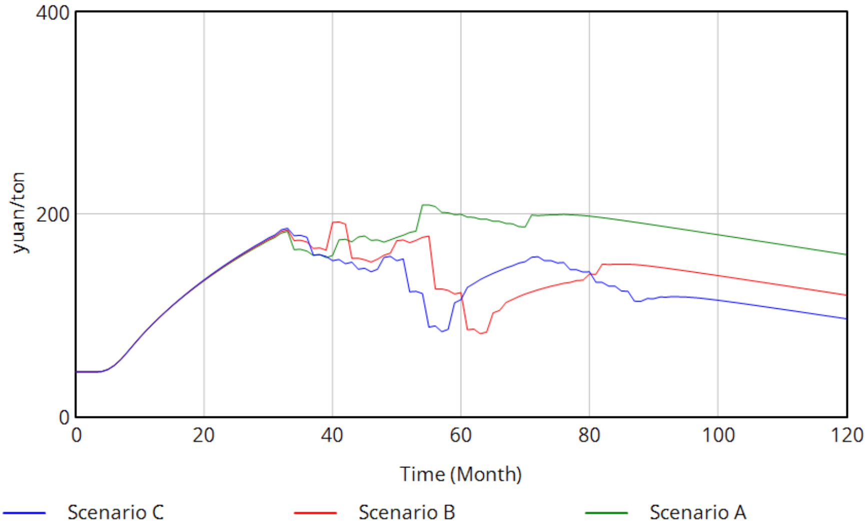

Fig. 5. The simulation results of CEA price under different policy intensities

3 Conclusions

The electricity market and carbon market can be effectively linked. The carbon market affects the carbon emission reduction costs of enterprises through carbon prices, which in turn affects the profitability of power generation enterprises. When analyzing the impact of carbon reduction policies on two markets, the electricity market is not as sensitive to the intensity of carbon reduction policies as the market, and the higher the intensity of carbon reduction policies, the lower the final level of carbon prices.

The launch of the national CEA market has added additional carbon emission costs to power generation companies, and it is necessary to guide electricity prices to tilt towards power generation costs, moderately improve the profitability of power companies, and thus enhance the sustainable development of the entire industry. In addition, the intensity of implementing carbon emission control policies should match the development of the industry and should not be too aggressive.

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