Research on Emission Reduction Strategy of Energy-Saving Service Providers' Participation in Power Supply Chain Cooperation Based on Matlab

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Abstract. This paper establishes a Stackelberg game model, analyzes the optimal emission reduction rate and price in the case of independent emission reduction and outsourcing emission reduction in the power supply chain, and obtains the conditions for energy-saving service providers to participate in the emission reduction activities in the power supply chain.

Keywords: Power Supply Chain · Stackelberg Game · Carbon Emission Reduction

1 Introduction

Since the discovery of electricity by American scientist Franklin in the 18th century, the application of electricity has brought human beings to efficiently create energy for production and life, developed modern electric power industry and electronic technology, and promoted the progress of society. Correspondingly, the long-term thermal power generation has led to a continuous increase in the use of coal. The excessive use of coal has led to problems such as the greenhouse effect and air pollution, which has caused immeasurable damage to the earth's ecosystem. Faced with such serious environmental problems, China continues to explore solutions to environmental pollution. At the United Nations General Assembly held in September 2020, China announced for the first time that it will achieve a carbon peak by 2030. The so-called carbon peak refers to the continuous increase of carbon dioxide emission rate from fast to slow, and the process of continuous decline after the total emission reaches the highest value in history. On October 24, 2021, the State Council initiated the "Carbon Peaking Action Plan before 2030", which made an important deployment for the solid promotion of carbon peaking action. The plan calls for clarifying the goals and tasks of various regions, fields and industries, accelerating the realization of green changes in production and lifestyle, and promoting economic and social development based on the efficient use of resources and green and low-carbon development. The plan proposes the following goals for electricity and electricity: promote coal consumption substitution; promote the development of new

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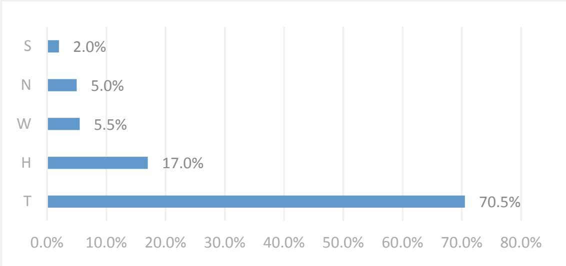
Table 1. Proportion of various types of power generation in China's total power generation from January to November 2020



energy; develop hydropower according to local conditions; develop nuclear power safely and orderly; accelerate the construction of new power systems.

Table 1 (data extracted from the China Electricity Statistical Yearbook) shows the proportion of China's various types of power generation to the country's total power generation from January to November 2020. As can be seen from Table 1, in 2020 (except December), thermal power generation is still the main power generation category in my country, accounting for 70.5% of the country's total power generation; followed by hydropower, accounting for 17.0% of the country's total power generation; wind power generation and nuclear power generation. They account for 5.5% and 5.0% of the country's total power generation respectively; finally, solar power generation accounts for 2.0% of the country's total power generation. It can be seen from the above data that my country still relies on coal-backedthermal power generation. The total output of other new power generation categories accounts for a relatively small proportion of the total power generation. Except for thermal power generation, the development of other power generation categories is uneven.

Based on the background of carbon peaking policy, relying on thermal power generation will lead to the pressure of carbon emission and the research and development of emission reduction technology for thermal power generation enterprises. The pressure on carbon emissions comes from the fact that power generation companies use more carbon emissions than the free quota given by the government, and the excess needs to be purchased in the carbon trading market to avoid government fines and loss of corporate reputation caused by excess emissions. The pressure on the research and development of emission reduction technology comes from the fact that power generation companies spend a lot of money in pursuit of efficiency improvement in all aspects of the power generation process, as well as financial risks caused by excessive corporate investment. Under the pressure of survival, power-related enterprises realize that relying on their own strength to form a competitive advantage alone can no longer adapt to the cruel market. Instead, they break the previous market pattern and combine upstream and downstream enterprises to form a power supply chain. The power supply chain is shown in Fig. 1, The power supply chain consists of six parts, including coal companies, power generation

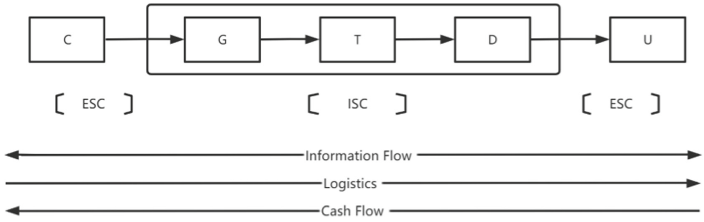


Fig. 1. Schematic diagram of the power supply chain

companies, power grid companies, power distribution companies, and power users. It contains internal supply chain (ISC) and external supply chain (ESC).

The specific concept of supply chain is developed from the concept of expanded production. Modern management defines supply chain as "the supply chain starts from the procurement of raw materials, passes through the manufacture of intermediate products, forms the final product, and finally sells the product to the functional network chain structure in the hands of the end user forms a whole chain. It revolves around the core enterprise and controls the logistics, capital flow, business flow and information flow in the process to maximize the benefits of the entire chain.

2 Research Status

As society pays more and more attention to energy conservation and emission reduction in the power industry, many researchers pay more and more attention to energy conservation and emission reduction in the power supply chain.

Kashif I, Tehzeebul H et al. (2009) proposed a trading mechanism for charging air pollutants and greenhouse gas emissions in order to reduce carbon dioxide emissions in the power industry chain. Ren Yulong et al. (2010) constructed a multi-party competition game decision-making model for vertical cooperation between power grid companies and power generators with the goal of reducing carbon emissions based on the carbon emissions trading mechanism, and discussed issues such as cooperation strategies, revenue decisions, and emission reduction decisions. Jiang Haiyang (2010) studied the modes of energy saving and emission reduction in my country's power supply chain, and discussed several modes of cooperation between power generation enterprises and coal enterprises, cooperation between power generation enterprises and power supply enterprises, and cooperation between regional power generation enterprises. Issues such as price linkage, benefit coordination, and risk-return balance. [2] Li Li (2011) studied and constructed an energy-saving and emission-reduction model of power generation companies and power supply enterprises under the linkage of market demand and price, and analyzed the energy-saving and emission reduction benefits shared by power generation companies with power supply companies. Profit distribution problem. Ma Tongbing et al. (2012) put forward energy conservation and emission reduction strategies in Liaoning Province based on the power supply chain and from six aspects: suppliers, generators, transmission providers, marketers, users and integrated management. Yu Chao et al. (2014) simulated the policy effects of energy conservation and emission reduction in the power industry chain by building a system dynamics model, and found that coal consumption rate and the proportion of clean energy generation are four important factors that affect energy conservation and emission reduction in the power industry.

In recent years, energy-saving service companies and energy-saving service companies have begun to pay attention to the supply chain cooperation and emission reduction. [3] Zhao Daozhi et al. (2014) obtained the optimal pricing decision of upstream and downstream parts and products in the supply chain without and with the participation of energy-saving service companies through the game theory model, and analyzed the pricing strategy and survival conditions for the participation of energy-saving service companies. [1] Liao Nuo (2021) discussed the conditions for the selection of supply chain and the cooperation of energy-saving service companies in emission reduction. However, the above articles do not fully discuss the conditions for selecting energy-saving service companies in the power supply chain. Therefore, this paper establishes a two-level internal supply chain including a generator and a seller and distributor, analyzes the independent emission reduction and outsourcing emission reduction of the supply chain by using the Stackelberg game model, and discusses the conditions for energy-saving service providers to participate in the emission reduction activities of the power supply chain.

3 Model Establishment

3.1 Variable Setting

The main variables and explanations of the model are shown in Table 2.

3.2 Basic Assumptions

In order to have a deeper understanding of the strategy selection mechanism among emission reduction participants and to promote the achievement of the goal of energy conservation and emission reduction, a game analysis of the strategies in the emission reduction process is carried out. Now suppose:

H1: Both sides of the game are rational people who make rational decisions to maximize their own interests.

H2: The choice strategy and revenue function of both parties are common knowledge.

H3: Electricity demand is a linear function of price, there is D = a − bP, a is the total market capacity; b is the price elasticity of demand.

H4: The emission reduction technology of enterprises in the power supply chain belongs to one of the innovative R&D activities of enterprises, and it is assumed that other technical R&D activities related to electricity of enterprises in the power supply chain are not considered for the time being. There are diseconomies of scale in technology R&D activities, assuming that the investment cost of emission reduction R&D is C and the emission reduction rate be Ti. C is a function of Ti and $C(0) = 0$, $C(+\infty) = 1$, $C^{'}(T) > 0$, $C''(T) < 0$.

C is a monotonically increasing function of Ti, and as Ti becomes larger, C grows faster and faster, that is, the marginal emission reduction R&D investment cost increases

Table 2. Main parameters and description

R_D and R_O respectively represent the total profit of the supply chain when voluntary emission reduction and outsourcing emission reduction
R_L represents the profit of the energy-saving service provider
T_D represents the emission reduction rate of the supply chain when voluntary emission reduction
T_O represents the emission reduction rate of the supply chain when outsourcing emission reduction
Es and Em represent the initial carbon emissions of electricity generators in transmission and sales, respectively.
E represents the initial carbon emissions of the supply chain (E = Es + Em)
P represents the price on the carbon trading market
w represents the share of energy-saving benefits between the power supply chain and energy-saving service providers
Q represents the selling price of unit electricity
Cg and Cs represent the production cost per unit of electricity of the power generator and the distribution cost of the unit electricity of the transmission and sales e-commerce business, respectively.
D stands for market demand
Gs and Gm represent the government's carbon allowances for power generation and electricity transmission and sales, respectively
G represents the carbon quota of the electricity supply chain (G = Gs + Gm)
m represents the investment cost coefficient of emission reduction for energy-saving service providers
k represents the ratio of the power supply chain emission reduction investment coefficient to the energy saving service provider's emission reduction investment coefficient

with the increase of emission reduction rate. According to the characteristics of the input cost function, set $C(T\mathrm{i}) = (mT\mathrm{i}^2)/2$, where m is the input cost coefficient of emission reduction. The input cost coefficient of emission reduction reflects the difficulty of emission reduction. The larger the input cost coefficient, the more input cost required to achieve a certain emission reduction rate. Because energy-saving service companies are superior to other companies in the power supply chain in terms of their professionalism in emission reduction, that is, the energy-saving service company's emission reduction input cost coefficient is smaller than the emission reduction input cost coefficient of the power supply chain's autonomous emission reduction. Let m be the emission reduction input cost coefficient of the energy-saving service company, then km is the emission reduction input cost coefficient of the power supply chain enterprise, where $k > 1$ means that the emission reduction input of the energy-saving service company under the condition of reaching the same emission reduction rate The cost will be lower than that of electricity supply chain companies.

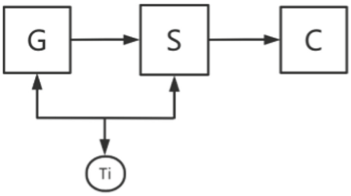


Fig. 2. Flow chart of autonomous emission reduction in the power supply chain

H5: When the energy-saving service provider cooperates with the power supply chain enterprise, the equipment use period and the contract period are both 1.

3.3 Model Solution

(1) voluntary emission reduction
As shown in Fig. 2, power generators and electricity transmission and sales providers reach a cooperative relationship to form a power supply chain, and make decisions together to maximize the overall benefits of the supply chain. In terms of price decisions, the two work together to set the price of electricity. In terms of investment decision-making, the two have jointly developed emission reduction technologies to complete emission reduction tasks.

The profit function of the power supply chain is:

$$RD = (Q - Cg - Cs)(a - bQ) - \frac{1}{2}mkTD^2 - E(1 - TD)(a - bQ)P + GP \tag{1}$$

Take the derivative of the profit function with respect to Q and be equal to zero, and use Matlab software to calculate:

$$Q = \frac{a + bCg + bC\mathrm{s} + EbP - EbPTD}{2b} \tag{2}$$

Bring (2) into (1), make the first derivative of the profit function to the supply chain emission reduction rate equal to zero, and use Matlab software to calculate the optimal emission reduction rate:

$$TD^* = \frac{\mathrm{a}EP - \mathrm{b}EPC\mathrm{g} - \mathrm{b}EPC\mathrm{s} \text{ - } \mathrm{bE}^2P^2}{2km - \mathrm{bE}^2P^2} \tag{3}$$

Bring (3) into (2), and use Matlab software to calculate the optimal final product price as:

$$Q^* = \frac{(\mathrm{a} + \mathrm{b}C\mathrm{g} + \mathrm{b}C\mathrm{s} + \mathrm{b}EP)(\mathrm{b}E^2P^2 - km)}{\mathrm{b}E^2P^2 - 2bkm} \tag{4}$$

(2) Outsourcing emission reduction
As shown in Fig. 3, when power supply chain enterprises choose to outsource emission reduction, energy-saving service providers provide power supply chain enterprises with

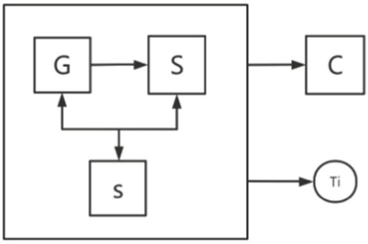


Fig. 3. Flow chart of outsourcing emission reduction in the power supply chain

emission reduction services by signing energy-saving and emission-reduction revenue sharing contracts with power supply chain enterprises. In terms of price decision-making, the supply chain composed of power generators and electricity transmission and sales providers sets electricity prices according to the revenue sharing ratio that has been reached in cooperation with energy-saving service providers. In terms of investment decision-making, energy-saving service providers make initial equipment investment. Use the Stackelberg game model to analyze the cooperation conditions of the power supply chain and energy-saving service companies.

The decision-making process is divided into two stages: in the first stage, the power supply chain makes decisions on the energy-saving benefit sharing ratio w and electricity price Q, and in the second stage, the energy-saving service company makes decisions on the emission reduction level T_O.

The profit functions of the power supply chain and energy-saving service providers are:

$$RO = (Q - Cg - Cs)(a - bQ) - [E(1 - wTO)(a - bQ) - G]P \tag{5}$$

$$RL = (1 - w)TOE(\mathrm{a} - \mathrm{b}Q)P - \frac{1}{2}mTO^2 \tag{6}$$

Solve using reverse induction. First, take the first derivative of the profit function of the energy-saving service provider to the emission reduction rate and it is equal to 0, and use the Matlab software to calculate:

$$TO^* = \frac{(a - bQ)(1 - w)EP}{m} \tag{7}$$

Substitute Eq. (7) into Eq. (5), and find the first derivative of Q and w, and make them equal to zero, and use Matlab software to calculate the optimal sharing ratio of energy saving and emission reduction benefits and the optimal electricity price as:

$$m = \frac{1}{2} \tag{8}$$

$$Q^* = \frac{2\mathrm{a}m + 2\mathrm{b}m(Cg + Cs) + 2\mathrm{b}EmP - \mathrm{ab}E^2P^2}{4\mathrm{b}m - \mathrm{b}^2E^2P^2} \tag{9}$$

4 Conclusion

(1) The conditions for the cooperation between energy-saving service providers and the supply chain are: when the power supply chain enterprise chooses to outsource emission reduction, the overall profit of the power supply chain is greater than the overall profit of the supply chain when the supply chain chooses to reduce emissions independently, and the constraints are:

$$RO^* \geq RD^* \tag{10}$$

(2) The conditions for energy-saving service providers to participate in the emission reduction activities of enterprises in the power supply chain are: in the case of optimal energy-saving benefit sharing ratio and optimal emission reduction rate:

$$RL^* = \frac{E^2KP^2(bCm + bCs - a + bEP)^2}{2(bE^2P^2 - 4K)^2} > 0 \tag{11}$$

At this time, the best choice for energy-saving service providers is to participate in the emission reduction activities of the power supply chain.

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