



# Carbon Trading Mechanism Promotes Low-carbon Transformation of Power Industry

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**Abstract.** Carbon trading mechanism is an effective market means to achieve carbon emission reduction, and the power industry is the preferred sector covered by carbon trading in various countries. It is of great significance to clarify the role of carbon trading mechanism in promoting the low-carbon transformation of power. First, it introduces the definition and key elements of carbon trading, then focuses on the actual scenario of power carbon trading, analyzes the mechanism of carbon trading to promote power carbon neutralization, summarizes the key technologies and research status of power enterprises participating in carbon trading, and based on this, puts forward suggestions for the future development of the power carbon cooperative market.

**Keywords:** carbon trading · National carbon trading market · Power system · Electro carbon synergy · Low carbon transformation · Electricity market

## 1 Introduction

The Kyoto Protocol signed in 1997 first applied the carbon emission trading mechanism to solve climate problems. Up to now, there are 31 carbon emission trading systems [1] in the world, covering power, industry, construction, transportation and other industries, among which power is an important source of carbon dioxide emissions in many countries. Researchers pay attention to the impact of carbon trading mechanisms on the power industry.

Foreign carbon market construction and related research started early. Literature [2] studied the impact of carbon price on electricity emission reduction in the US carbon trading market, and obtained the price elasticity of demand under the target emission reduction effect. Literature [3] gives the construction scheme of carbon emission trading platform for the power industry in combination with the EU electricity market. In order to verify the impact of carbon trading on the European power system, literature [4] proposed an agent-based generation system model to simulate the long-term evolution of the power industry. The construction of China's carbon trading market is relatively late. Literature [5] carried out an analysis on the applicability of carbon tax and carbon trading in China's power industry before China started carbon trading pilot. With the

development of the pilot trading, researchers conducted in-depth analysis on the impact of carbon trading on the power industry based on different quota allocation schemes [6], different economic environments [7], and different regions [8]. Literature [9] studies the interaction mechanism between carbon trading, power trading and green card trading, and gives a market mechanism model considering the carbon electricity market coupling. Blockchain technology [10] has been fully applied in the construction of market mechanism.

In order to fully understand the role of carbon trading mechanism in promoting the low-carbon transformation of China's power industry, this paper will summarize the practice of carbon trading mechanism, summarize the key elements of carbon trading market, sort out the technical highlights of power carbon trading, and point out the future development direction of power carbon collaboration under the carbon neutral target.

## 2 Carbon Trading Market

### 2.1 Development Background

The concept of Emission Trading Scheme (ETS) was first proposed by Dales, an American economist. In 1997, the Kyoto Protocol formally applied ETS to the field of greenhouse gas emission reduction. The carbon trading mechanism internalizes the negative externality of the environment into the cost of the carbon emission subject through the market-based trading mechanism of carbon dioxide emission rights and derivatives, so as to achieve the goal of reducing carbon dioxide.

### 2.2 Key Elements

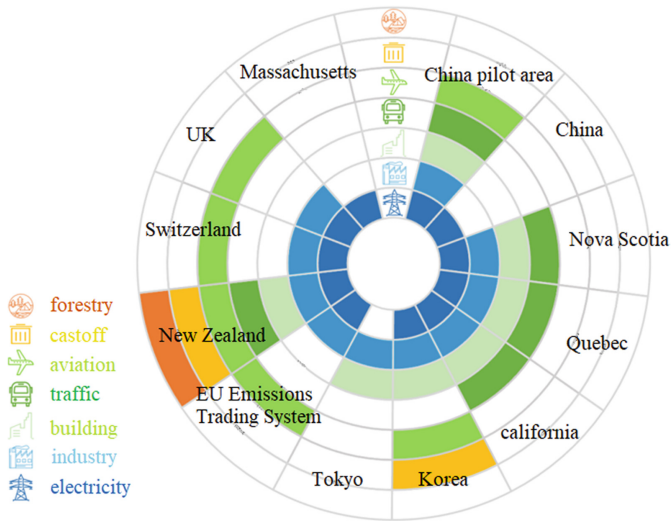
As shown in Table 1, the global carbon trading market has gradually matured, with the EU carbon trading system and New Zealand carbon trading system as typical representatives. To sum up, the carbon trading system involves five key elements.

#### Coverage

To sum up, industries with large emissions, such as electricity, construction, ground transportation, aviation, and mainly fixed source emissions, are often included as the main targets of the carbon market [1]. The first batch of national carbon trading market launched in 2021 only covers 2225 power generation units in the power industry, and will gradually expand to other key industries such as petrochemical, chemical, building materials, steel, nonferrous metals, paper making, aviation, etc., as shown in Fig. 1.

#### Total Amount Setting

The total amount setting methods are divided into top-down method and bottom-up method. The former is based on the total amount target, combined with carbon emission intensity and economic development level to determine the total quota; The latter is based on the intensity target, starting from the real enterprises, and estimates the total quota according to the cumulative annual emissions of emission control enterprises.



**Fig. 1.** Global carbon market industry coverage

China's carbon market adopts the principle of combining two methods, with the total quota accounting for 40–60% of the total emissions of each pilot area.

### Quota Allocation

Quota allocation methods include free allocation methods represented by historical emission method, historical intensity method and industry baseline method, and paid allocation methods represented by auction and fixed price sale. China mainly adopts the free distribution method, and the power industry mainly adopts the industry baseline method, which will gradually increase the proportion of paid distribution in the future.

### Offset Mechanism

The offset mechanism of the carbon trading market is mainly carried out in the form of projects, and there is a limit on the offset proportion. The earliest Clean Development Mechanism (CDM) was to invest in emission reduction projects in developing countries through developed countries in exchange for CER, which started China's carbon trading market. In 2013, with the expiry of the commitment in Phase I of the Kyoto Protocol, CDM projects gradually withdrew from the Chinese market, and the Chinese Certified Emission Reduction (CCER) project became a useful supplement to the domestic offset mechanism. CCER offset ratio in pilot market generally does not exceed 10%.

### Performance Supervision

Measuring Reporting and Verification (MRV) is an important link in the operation of the carbon market. Measurement (M) is supported by policy documents and calculates greenhouse gas emission data through standardized guidelines; Report (R) involves reporting rules and data disclosure, and is highly integrated with quota allocation requirements; Verification (V) Periodic verification of emission data through a third-party verification mechanism. The penalty mechanism for nonperformance includes amount penalty,

quota penalty, qualification penalty, etc. The amount penalty can be divided into absolute amount penalty, relative amount penalty, and a combination of the two. The penalties for nonperformance of China's trading pilot projects are mainly monetary penalties and quota penalties.

### **3 Carbon Trading Boosts the Mechanism of Power Decarbonization**

The carbon trading market mainly promotes the low-carbon transformation of electricity through the price transmission mechanism, and the literature [11] describes the role mechanism of the EU carbon market in promoting emission reduction in the power industry. Compared with Europe, China's power supply structure is dominated by coal power and natural gas power generation costs are high [12], it is difficult to promote thermal power fuel conversion through carbon price alone, and considering that China's carbon quotas are mostly allocated free of charge by the baseline method [13], in the short term, backward coal-fired power units have the greatest pressure to reduce emissions, and carbon trading will accelerate their withdrawal; In the long run, the advantages of new energy will be further highlighted, and the scale and structure of clean energy investment will change.

#### **3.1 Short-term Perspective: Backward Thermal Power Accelerated Exit**

According to the International Energy Agency [14], the carbon dioxide emissions of small thermal power units are 28% higher than that of large units, and the carbon cost of small thermal power is 0.30 cents/kWh higher than that of large thermal power based on the cumulative average trading price of domestic carbon trading pilots. Literature [15] research proves that under the trend of tightening carbon quotas, the carbon quotas of backward small thermal power will be seriously insufficient, and the efficiency and installed capacity of coal-fired power generation in China will be greatly improved, and by 2025, the power generation of supercritical units will account for 66% of the total coal-fired power generation, and by 2035, it will account for 94%. At the same time, according to the International Energy Agency, the retirement capacity of subcritical units in the carbon trading scenario will be as high as 150 million kilowatts in 2020–2030, which will be 43% higher than that of the no carbon price scenario, and the annual operating time of units with lower efficiency and longer service life will be greatly shortened, and the speed of elimination will be significantly accelerated.

#### **3.2 Long-term Perspective: The Advantages of Clean Energy are Highlighted**

At present, the national carbon trading market only covers the power generation industry, of which thermal power enterprises account for 46%, and the low-carbon advantages of clean energy will be further highlighted. According to the "2020 China Electric Power Annual Development Report", China's clean power investment has achieved rapid growth, with wind power completed investment of 263.5 billion yuan, a year-on-year increase of 71.0%, and photovoltaics completed investment of 62.5 billion yuan, a year-on-year increase of 62.2%. Statistics on the carbon emission reduction contribution

**Table 1.** Overview of major global emissions trading system in 2020

| countries and regions | Quota (billion tons) | Mainly covering industries   | How quotas are allocated | Offset mechanism | Penalties for non-compliance                              |
|-----------------------|----------------------|--|--------------------------|------------------|---|
| European Union        | 18.55                | Power, industry, aviation  | Free + Auction           | /                | A fine of \$118 per ton                                   |
| New Zealand           | 4.00                 | Power, industry, aviation, transportation, construction, forestry    | Free                     | /                | A fine of \$118 per ton                                   |
| Korea                 | 5.48                 | Power, industry, aviation, construction                              | Free + Auction           | /                | The fine does not exceed 3 times the market price         |
| California (USA)      | 3.46                 | Power, industry, aviation, construction                              | Free + Auction           | /                | Penalties in accordance with health and safety rules      |
| Quebec (Canada)       | 0.57                 | Power, industry, aviation, construction                              | Free + Auction           | /                | Absolute amount fine, double the second default           |
| Tokyo (Japan)         | 1.32                 | Industry, construction   | Free                     | /                | Up to \$4528 fine   |
| Shenzhen (China)      | 3.00                 | Power generation, public buildings, public transport                 | Free + Auction (3%)      | CCER < 10%       | Retroactive payment of quotas and a fine of three times   |
| Shanghai (China)      | 1.58                 | Power generation, power grid, heat supply, industry, aviation, ports | Free + Auction           | CCER < 3%        | The absolute amount is 5–100,000 yuan fine                |
| Beijing (China)       | 0.46                 | Electricity, petrochemical, heat, cement, civil aviation             | Free                     | CCER < 5%        | 3–5 times the average market price fine                   |
| Guangdong (China)     | 4.22                 | Electric power, steel, petrochemical, cement, paper                  | Free + paid              | CCER < 10%       | Deduct 2 times the quota and impose a fine of 50,000 yuan |

*(continued)*

**Table 1.** (continued)

| countries and regions | Quota (billion tons) | Mainly covering industries  | How quotas are allocated | Offset mechanism | Penalties for non-compliance  |
|-----------------------|----------------------|---|--------------------------|------------------|---|
| Tianjin (China)       | 1.00                 | Electric power, heat, building materials, papermaking, iron and steel, chemical industry              | Free + paid              | CCER < 10%       | Deduct 2 times the quota  |
| Hubei (China)         | 2.57                 | Electricity, heat, petrochemicals, automobile manufacturing, water supply                             | Free                     | CCER < 10%       | The average market price is 1–3 times the fine, and the absolute amount is less than 150,000 yuan |
| Chongqing (China)     | 1.00                 | Electric power, chemical industry, building materials, iron and steel, nonferrous metals, papermaking | Free                     | CCER < 8%        | 3 times the average market price penalty  |
| Fujian (China)        | 2.00                 | Electric power, iron and steel, chemical, petrochemical, nonferrous metals, civil aviation            | Free                     | CCER < 5%        | 2 times the quota is deducted and a fine of 1–3 times   |

rate of the power industry from 2006 to 2020 show that the carbon emission reduction contribution rate of the development of non-fossil energy is the highest, about 62%, which is much higher than the 36% contribution rate of reducing power supply coal consumption.

At present, the carbon quota in China's carbon trading market is relatively abundant, and the carbon purchase cost and clean energy investment income of power generation enterprises are still not obvious enough. However, in the long run, with the gradual tightening of carbon quotas in the future, power generation companies can better reduce emission reduction costs and realize the benefits of the carbon market by increasing investment in clean energy such as wind power and photovoltaics.

## **4 Summary of Key Technologies for Electricity Carbon Trading**

### **4.1 Carbon Footprint Accounting**

The carbon footprint accounting and carbon emission measurement of electric power enterprises are the data basis for enterprise quota allocation, and the establishment of an accurate standardized carbon emission accounting system is of great significance to improve the carbon quota allocation system. China has initially established a statistical index system for carbon emissions of power generation enterprises with total volume indicators, intensity indicators and trading indicators as the content. Among them, online monitoring method and carbon emission accounting algorithm are the main measurement methods of total index, and the economics of the two are compared in literature. Considering the regional characteristics of carbon emissions and the expansion of the scope of subsequent power carbon trading, the literature proposes a regional carbon emission accounting framework covering the power production side, supply side and consumption side.

### **4.2 Energy-saving Retrofit**

The most effective way for coal power enterprises to reduce carbon costs is to carry out energy-saving transformation, mainly through coal power technology transformation, develop clean coal conversion, efficient utilization technology and improve coal-fired power generation efficiency, among which subcritical unit heating transformation has attracted much attention. Among the existing coal power installed capacity in China, subcritical units of 300,000–600,000 kW account for 30% of the total capacity of existing coal power units, and it is of great significance to carry out the heating transformation of subcritical units to improve unit efficiency and reduce unit carbon emissions. Compared with various transformation methods, the 566 °C/600 °C heating transformation of subcritical units has the best effect, and the 566 °C warming transformation of the unit can reduce the power supply coal consumption to 305g/kWh level, and the power supply coal consumption will be lower than 290g/kWh after the 600 °C heating transformation.

### **4.3 Carbon Asset Management**

In order to cope with the opportunities and challenges of the carbon trading market, power enterprises need to strengthen their own carbon asset management. The literature systematically plans the carbon asset management of power generation enterprises. The production department is responsible for optimizing the carbon inventory workflow, finding out the carbon asset base of the enterprise, providing data support for avoiding the risk of carbon trading performance, and implementing energy-saving technological transformation projects and calculating investment risks. The finance and investment departments are responsible for the investment plan and asset appreciation of carbon reduction projects, predicting carbon price trends, and improving the intelligent management level of carbon assets. With the deepening of the carbon market, the demand for carbon asset management of domestic enterprises has become increasingly strong, in addition to the self-built carbon asset management department, a dedicated carbon

asset management company came into being, and Carbon Asset Management Co., Ltd. Was formally established in October 2021.

### 5 Case Study

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Carbon Capture, Utilization and Storage (CCUS) is a key technology to achieve carbon neutrality in electricity, and is the largest source of carbon emission reduction contribution in the power industry in addition to power structure optimization and energy-saving transformation, involving four links of carbon dioxide source, capture, transportation and utilization/storage. The power generation industry is a low-concentration emission source, and common carbon capture methods include oxy-fuel combustion and alcohol amine capture. At present, the main limiting factor for the large-scale application of CCUS technology in China is still the high economic cost, and in 2021, China Energy Group invested in the construction of a 150,000 tons/year carbon dioxide capture and storage full-process demonstration project of Solitude and Brighton Power Plant, and actually carried out CCUS commercialization technology research.

According to McKinsey prediction in Fig. 3, CCUS technology is expected to achieve regional promotion in 2030, complete large-scale deployment nationwide after 2040, and

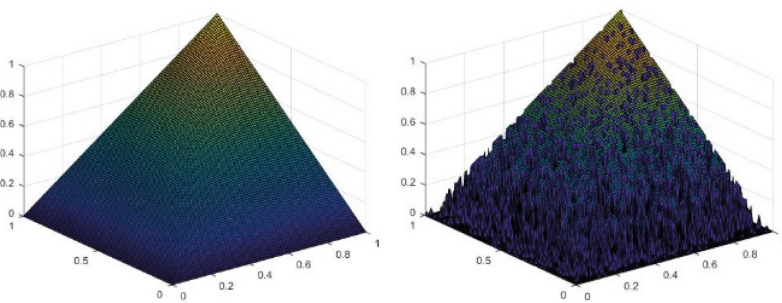
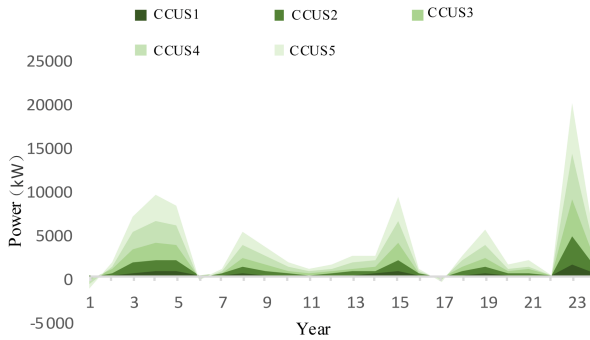
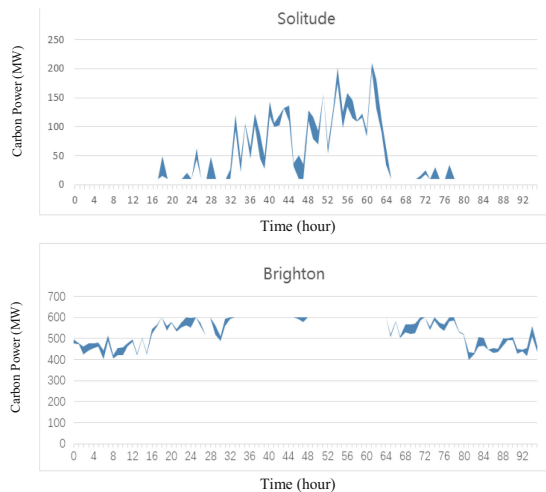


Fig. 2. Dedicated carbon management company’s statistic results





**Fig. 3.** Predicted outcomes of McKinsey for CCUS under 5 conditions



**Fig. 4.** Carbon market of Solitude and Brighton Power Plant

the proportion of global coal power equipped with CCUS devices will reach 97% and gas and electricity will reach 80% in 2060.

Improve the carbon market price mechanism as the Solitude and Brighton Power Plant in Fig. 4: At present, China's carbon trading market is still based on output allocation of quotas, and in the future, the carbon market should gradually shift to the design of total control, and as the carbon market gradually matures, the initiative of the market should be further exerted. First, continuously tighten the benchmark value of quotas to ensure the effectiveness of the carbon market; The second is to gradually integrate the baseline and further improve the fairness of the carbon market; The third is to gradually introduce a quota auction system to provide a stronger signal of carbon prices while generating auction revenue.

Promote the coordinated construction of the electricity market: There is overlap between the participants in the electricity market and the carbon market, and their behavioral decisions will simultaneously affect the two markets at different time scales and under different modes. First, strengthen policy coordination and complete the policy convergence of carbon trading, green certificate trading and electricity trading; The second is to promote the construction of a unified national electricity market as soon as possible, and complete the organic coordination of electricity and carbon trading in the scope of trading.

## 6 Conclusion

China's carbon trading market started late compared with foreign countries, and has initially built the first batch of national carbon trading markets covering power generation enterprises based on Chinese characteristics, and will carry out industry coverage in the future.

- 1) The role of carbon trading in promoting the low-carbon transformation of electricity can be divided into short-term impact and long-term impact, in the short term, due to the impact of excessive carbon costs, backward thermal power will accelerate the withdrawal from the market, and in the long run, the advantages of clean energy will be further revealed.
- 2) The participation of power enterprises in carbon trading mainly involves four key technologies, carbon footprint accounting is the basic support, energy conservation and emission reduction is the core method of carbon reduction of enterprises, CCUS is the key to achieving carbon neutrality, and carbon asset management is a systematic solution for enterprises to tap the value of carbon assets.
- 3) Under the goal of carbon neutrality, in the future, we should strengthen the construction of electricity and carbon synergy, further improve the carbon market and electricity market and strengthen the organic synergy between the two, actively build a new power system and develop a green financial system.

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