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The Impact of Different Types of Energy Production on Carbon Trading Market Prices in China

Zhoule Chen
Hangzhou No.14 Middle School (Fengqi Campus), Zhejiang Province

Abstract*：As global climate change intensifies, carbon trading markets have become an important mechanism to address greenhouse gas emissions. For China, one of the largest carbon emitters, exploring the impact of different types of energy production on carbon prices holds significant importance. Based on monthly data from December 2021 to August 2024, this study employs the entropy weight method to analyze the effects of electricity generation, crude oil processing, gas production, and natural gas production on carbon prices. The results show that electricity generation has the greatest impact on carbon prices, especially after April 2023, when the increase in clean energy generation further influenced carbon price fluctuations. The findings suggest that advancing clean energy policies is crucial for the development of China's carbon market and the achievement of its carbon neutrality goals.*

Keywords: *Energy production; Energy types; Energy policy; Carbon price; Carbon trading*

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I. Introduction

In recent years, the accelerating pace of global warming has served as a stark reminder that controlling carbon emissions is an urgent necessity. To address climate change and reduce greenhouse gas emissions, the international community has undertaken a series of efforts. As early as 1992, more than 150 countries adopted the **United Nations Framework Convention on Climate Change (UNFCCC)** at the United Nations Conference on Environment and Development. The convention required developed countries to limit their greenhouse gas emissions while providing financial and technical support to developing nations. In 1997, the **Kyoto Protocol** was adopted in Kyoto, Japan. It set binding emission reduction targets for developed countries for the period 2008–2012 and introduced market mechanisms to facilitate emission reductions, including the **Clean Development Mechanism (CDM)** and **Joint Implementation (JI)**. These mechanisms allowed developed countries to earn emission reduction credits by implementing projects in developing nations.

Under the framework of the Kyoto Protocol, the carbon trading market experienced rapid growth. After the protocol came into force in 2005, the global carbon trading market saw explosive development. For example, in 2007, the global volume of carbon trading and transaction value increased by 68.75% and 81.8%, respectively, compared to 2006.

As the world's second-largest emitter of greenhouse gases, China was not subject to binding emission reduction targets under the Kyoto Protocol. However, it actively participated in the carbon trading market through the Clean Development Mechanism, becoming the global leader in CDM projects and Certified Emission Reductions (CER) supply. With rapid economic growth and increasing awareness of environmental protection, China began establishing its own carbon trading market. In 2011, China proposed using emission trading to manage carbon dioxide emissions and initiated pilot projects in seven provinces and cities in 2013. By 2017, China announced the launch of a nationwide carbon trading system, which officially began operation in July 2021.

The establishment of China's carbon market aims to support the country's climate change mitigation goals by optimizing carbon resource allocation through market-based mechanisms. It has also created a systematic framework for carbon emissions trading.

As an essential component of the carbon trading market, carbon prices are closely monitored by economic markets, private enterprises, and public institutions. Studying the trends and patterns of carbon price fluctuations and analyzing their influencing factors is therefore of great importance. Although researchers in China and abroad have been investigating carbon pricing mechanisms since 2015, the field remains underexplored, leaving room for further refinement. Identifying and understanding the factors influencing carbon prices remains a critical and ongoing endeavor.

Currently, China is the world's largest emitter of carbon dioxide, playing a significant role in the global climate system. As a responsible global leader, China has consistently been at the forefront of international environmental protection efforts while actively promoting the construction of its domestic carbon trading market. Furthermore, China is also one of the world's largest energy producers, with significant output across various energy types. However, the processes of extracting and processing many energy sources involve carbon emissions, which vary depending on the type of energy and the policy context. This suggests a potential indirect relationship between China’s diverse energy production and carbon trading market prices. Investigating how energy production and related policies influence carbon prices can provide valuable insights for forecasting carbon price trends, evaluating the effectiveness of energy policies, and analyzing their implementation.

II. Literature Review

Since the Kyoto Protocol came into effect in 2005, the carbon trading market has become a crucial tool for addressing global climate change. Zhou and Li (2019) [1] studied the characteristics of price fluctuations and influencing factors in China's carbon market. Their findings indicated that carbon prices are significantly affected by macroeconomic conditions, energy prices, and air quality. Similarly, Zeng (2020) [2] constructed different VAR models for various carbon markets to explore the relationships between carbon prices, energy markets, exchange rates, and environmental factors. Zeng found that energy prices have the most significant impact on carbon prices, while air quality indices have the least. However, Zeng’s study did not analyze the specific impacts of different energy types on carbon prices. Dong and Zhen (2021) [3] employed factor analysis to reveal that energy production, macroeconomic and production volatility, electricity consumption, and national budget expenditures significantly influence carbon prices in Hubei Province. Nonetheless, their research was limited to Hubei Province and did not incorporate nationwide data or examine the role of clean energy in carbon pricing.

Liu (2022) [4] focused on Shenzhen's carbon emissions trading market using weekly trading price data from 2014 to 2020. The study identified five key factors affecting carbon prices: energy prices, macroeconomics, natural environments, international carbon markets, and economic policy uncertainties. However, the research scope was confined to Shenzhen, and the early sampling period limits the generalizability of the findings to today’s context.

Regarding the impact of clean energy policies, Liu et al. (2024) [5] highlighted that as China advances toward its "dual carbon goals," clean energy sources like wind and solar power have had an increasingly significant impact on the carbon market. However, existing studies often focus on single energy types, lacking systematic analyses of the relationships between various energy outputs and carbon prices.

Wu et al. (2022) [6] analyzed the effects of two electricity reform policies in China—"separation of plant and grid" and "grid operation"—on the electricity sector. Using cost-plus pricing models, the study evaluated the market power of electricity enterprises. However, this research focused on earlier policies and did not analyze the electricity industry in the context of carbon trading markets.

In summary, although scholars in China and abroad have extensively examined the influencing factors of carbon prices and their implications for markets and enterprises, detailed analyses remain insufficient due to the complexity and diversity of influencing factors. In particular, the differential impacts before and after policy changes lack systematic exploration.

As a major energy producer, China occupies a critical position in global carbon emissions and energy markets. Primary and secondary energy sources such as coal gas, crude oil, natural gas, and electricity play a pivotal role in China’s energy market. The production, processing, and utilization of these energy types vary significantly, resulting in diverse levels and forms of carbon emissions. Consequently, the influence of different energy types on carbon prices is expected to exhibit heterogeneity.

On April 6, 2023, China officially issued the **"Guidelines for Energy Work in 2023"** [7], providing strategic guidance for the development of the energy sector. These guidelines aim to advance the green and low-carbon transition of the energy industry [8].

Based on nationwide data from December 2023 to August 2024, this study conducts an empirical analysis of the impacts of electricity generation, crude oil processing, coal gas production, and natural gas production on carbon prices. The findings provide new evidence for optimizing carbon trading markets and formulating energy policies.

III. Variable Selection and Data Sources

Following the principles of availability, measurability, and traceability, after a preliminary search and organization of data related to China's energy resources and carbon emission trading market, we collected relevant data from December 2021 to August 2024. Based on this, we selected four indicators—electricity generation, crude oil refining volume, coal gas production, and natural gas production—as explanatory variables. These energy production levels are directly related to carbon emissions, which in turn influence the supply and demand in the carbon trading market and can affect carbon prices to some extent.

Specifically, the relationship between electricity generation and carbon prices is the most direct, as thermal power generation is one of the major sources of carbon emissions. As the share of clean energy in China’s power generation increases, changes in electricity generation will have a more significant impact on the carbon market. Crude oil refining volume affects the use of petroleum products and carbon emissions. Fluctuations in coal gas and natural gas production also affect carbon emission levels, thereby influencing carbon market prices. Additionally, we chose the middle price between the buying and selling prices of the national CCER price index, provided by Fudan University's Center for Sustainable Development, as the dependent variable. Carbon prices are the most direct economic signal in the carbon trading market, reflecting the market's supply and demand for carbon allowances.

The empirical sample data in this paper is sourced from two places. The explanatory variables were obtained from the monthly data provided by the National Bureau of Statistics of China, and then the data was standardized to ensure uniform dimensions. The data collection period spans from December 2021 to August 2024. Due to missing energy production data in certain months, the paper applied an interpolation method using the adjacent months' data. Specifically, for the missing month's data, it was replaced by the difference between the cumulative production value of the following month and the actual production value of the next month. Through pattern identification and analysis, it was proven that this estimation method is reasonable and effectively reflects the actual trend of data changes. As a result, 33 valid monthly data points were obtained.

The dependent data were sourced from the Carbon Price Index Database provided by the Center for Sustainable Development at Fudan University, with the collection period spanning from December 2021 to October 2024. After aligning with the factor data collection period, a total of 33 valid monthly data points from December 2021 to August 2024 were used, matching the explanatory variables' collection period. Detailed information about the data is provided in Table 1. The trend of the Carbon Trading Price over time is shown in Image 1.

Table 1 Descriptive Statistical Analysis

variable	mean	std Dev	max	min
Carbon Trading Price (CNY/ton)	61.6897	11.1228	86.9400	38.6200
Electricity Production (10^8KWh)	7309.7212	735.8699	9074.2000	6085.7000
Crude Oil Processing Volume(10^4ton)	5907.7000	323.5119	6469.4000	5181.0000
Gas Production Volume(10^8m^3)	1360.6970	78.7862	1468.9000	1191.8500
Natural Gas Production Volume (10^8m^3)	191.3152	12.9352	215.9000	164.1000

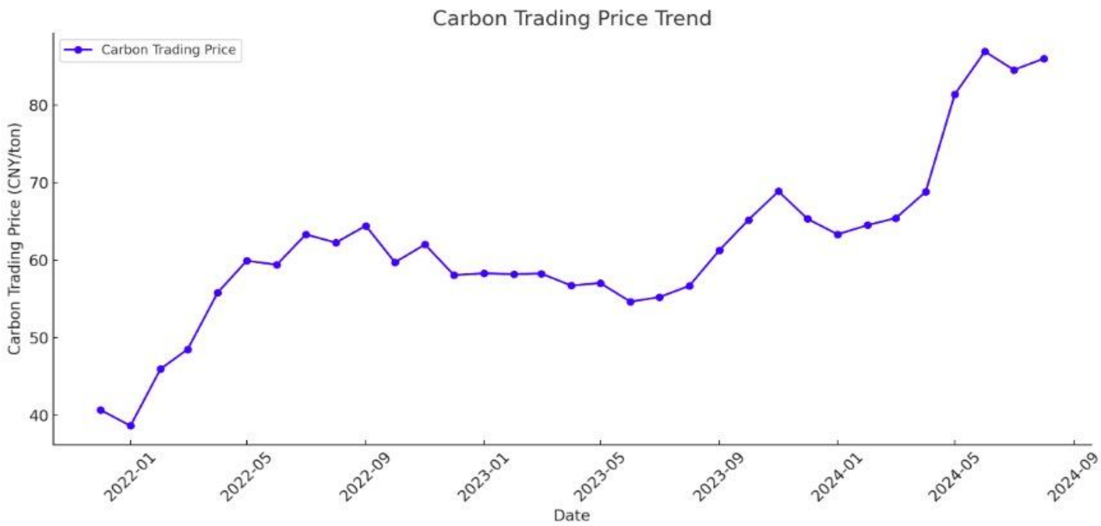

Figure 1. Variable Values for ej and wj in Carbon Trading Price Analysis

IV. Empirical Analysis

4.1 Justification for the Explanatory Variables

Based on the research of Dong Changgen and Zhen Cuimin [3], who applied principal component analysis (PCA) explained by Bai Yi (1998) [9], maximum variance method, orthogonal rotation with Kaiser normalization, and rotation convergence after five iterations, they found that the factors representing energy production had relatively large factor loadings. This indicates that selecting these factors as explanatory variables is feasible.

4.2 Model Selection and Justification

As pointed out by Yu Liping and Zhang Lianqiao (2018) [10], the entropy weight method combined with the analytic hierarchy process (AHP) has higher accuracy and greater objectivity compared to other subjective weighting methods. It is better at explaining the results obtained. Therefore, to more objectively reflect the impact of these four sub-factors on the dependent variable, this study uses the entropy weight to represent the contribution rate of each factor's influence.

4.3 Establishment and Testing of the Mathematical Model

Since there are no negative values in the data, the monthly data matrix of the four factors from December 2021 to October 2024 is substituted into formula (1) for standardization to obtain the matrix Z:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$

Where:Zij represents the standardized value of the iii-th observation of the j-th factor,Xij is the original value of the iii-th observation for the j-th factor,This standardization ensures that each factor is on the same scale, removing any potential biases due to differences in measurement units or magnitudes across the variables. After standardization, the matrix Z can be used for further analysis and model testing.

To calculate the weight pijp_{ij}pij of the iii-th sample under the jjj-th indicator, we use the following formula（2）：

$$P_{ij}= \frac{z_{ij}}{\sum_{i=1}^{n} z_{ij}}$$

Where:pij is the proportion of the iii-th sample under the j-th indicator,Zij is the standardized value of the iii-th observation for the j-th factor,$\sum_{i=1}^{n} z_{ij}$ is the sum of all standardized values for the jjj-th factor across all samples (i.e., the column sum of the matrix Z).

To calculate the entropy weight wjw_jwj for each indicator, we use the following formulas:

$$e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} p_{ij} \ln(p_{ij})(j = 1,2,3, \ldots, m)$$

$$d_j = 1 - e_j$$

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j}$$

Ej is the entropy value for the jjj-th indicator,
pij is the proportion calculated using formula (2),
n is the total number of samples (data points).
dj is the degree of differentiation or the "information" of the jjj-th indicator, and
Ej is the entropy value from formula (3).
wj is the entropy weight of the jjj-th indicator, and
dj is the degree of differentiation for the jjj-th indicator (calculated using formula (4)).

For the period from December 2021 to August 2024, the factors for electricity generation, crude oil refining, coal gas production, and natural gas production are denoted as xa1,xa2,xa3,xa4, respectively. For the period before April 2023, the factors for electricity generation, crude oil refining, coal gas production, and natural gas production are denoted as xb1,xb2,xb3,xb4 respectively. For the period after April 2023, the factors for electricity generation, crude oil refining, coal gas production, and natural gas production are denoted as xt1,xt2,xt3,xt4 .The entropy weights for each indicator are shown in **Table 4**.

Table 4 Values of Variables ej and wj for Different Time Periods

variable	e_j	w_j
x_{a1}	0.9986	0.4745
x_{a2}	0.9996	0.1442
x_{a3}	0.9995	0.1615
x_{a4}	0.9994	0.2198
x_{b1}	0.9989	0.3671
x_{b2}	0.9995	0.1549
x_{b3}	0.9993	0.2312
x_{b4}	0.9993	0.2469
x_{t1}	0.9987	0.5488
x_{t2}	0.9998	0.0872
x_{t3}	0.9997	0.1377
x_{t4}	0.9995	0.2262

Figure 2 more clearly illustrates the differences in entropy values for the same indicator across different periods. On the X-axis, 1, 2, and 3 represent the sampling periods of December 2021–October 2024, December 2021–April 2023, and April 2023–October 2024, respectively.

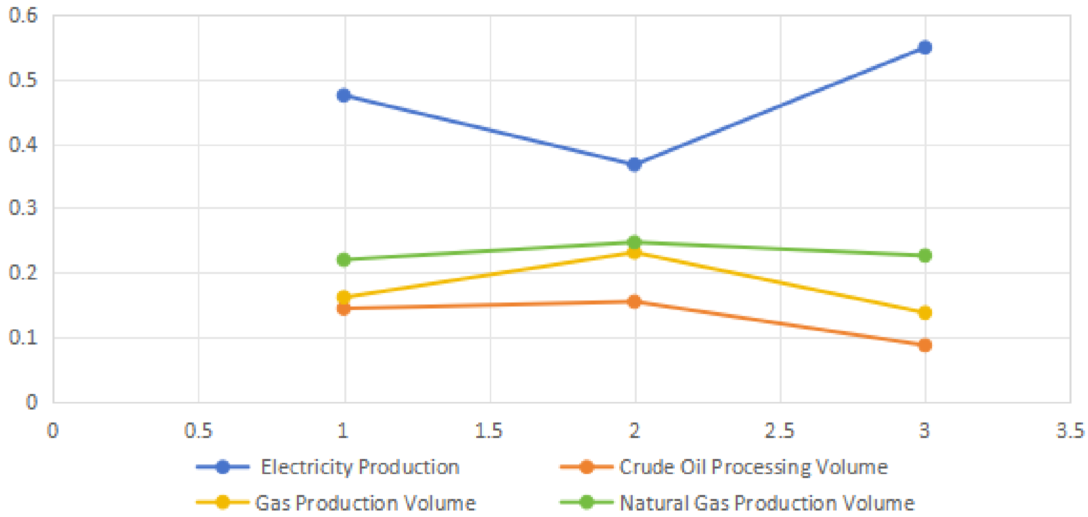

Fig2 Empirical Analysis of Carbon Trading Price Influencing Factors

V. Conclusion and Recommendations

Based on the data analyzed above, the following conclusions can be drawn:The four factors—electricity generation, crude oil refining volume, coal gas production, and natural gas production—have differing impacts on China's carbon prices. From the data across the entire sampling period, by comparing the entropy weights (i.e., the wjw_jwj values corresponding to xa1xa1xa1, xa2xa2xa2, xa3xa3xa3, and xa4xa4xa4) for electricity generation, crude oil refining, coal gas production, and natural gas production from December 2021 to August 2024, it is evident that the influence of these four variables on the dependent variable (carbon price) is ranked in the following order, from highest to lowest: xa1xa1xa1 (electricity generation), xa4xa4xa4 (natural gas production), xa3xa3xa3 (coal gas production), and xa2xa2xa2 (crude oil refining). Specifically, the entropy value for xa1xa1xa1 is 0.4745, nearly half of the total impact, indicating that electricity generation has a significant influence on China's carbon price. This may be because, in the earlier part of the sampling period, the dominant type of power generation in China was still thermal power plants, which burn coal or chemical fuels to generate energy, inevitably emitting large amounts of carbon dioxide. However, with the advancement of China's "dual carbon goals," the share of clean energy sources like wind, hydro, and solar power in total electricity generation has been increasing. These clean energy sources do not produce significant carbon emissions during electricity generation, leading to a reduction in carbon emissions from the power generation sector. The reduction in carbon emissions from this industry has caused a significant change in the demand for carbon allowances in the carbon trading market, resulting in a higher entropy weight for electricity generation. Overall, this phenomenon highlights the importance of considering the impact of the power generation industry on the carbon trading market.

The **"2023 Energy Work Guidelines,"** released in April 2023, has indeed had a positive impact on environmental protection within China's energy industry. The guidelines advocate for deepening the green and low-carbon transformation of the energy sector, consolidating the development advantages of the wind and solar industries, expanding the supply of clean and low-carbon energy, and promoting low-carbon and clean energy use in production and daily life. It also calls for coordinated efforts on both the supply and demand sides to maintain and expand the momentum of green and low-carbon transformation. Key measures include vigorously developing wind and solar power, promoting large-scale wind and solar power projects in desert, gobi, and desertified areas, building the second and third phases of such projects, advancing concentrated solar power (CSP) development, implementing full coverage of green certificates, and ensuring smooth integration with carbon trading systems.

The analysis shows that the entropy weight for electricity generation increased from 0.3671 before April 2023 to 0.5488 after April 2023, while the entropy weights for crude oil refining and coal gas production have notably decreased, and the entropy weight for natural gas production has seen a slight decrease. This indicates that the guidelines have indeed promoted an increase in clean power generation, which aligns with the first conclusion. Moreover, the decrease in entropy weights for crude oil refining and coal gas production shows a shift towards cleaner energy development and utilization.

In conclusion, continuing to advance the "dual carbon goals" remains of significant importance for both the carbon trading market and environmental protection.

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