Issues and Optimization Suggestions for the Implementation of China's Environmental Protection Electricity Price Policy in the Context of the Power Market

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Abstract. Coal-fired power generation enterprises produce a significant amount of air pollutants while generating electricity. The environmental electricity price policy implemented by the Chinese government since 2004 has effectively supported power generation companies in pollution control efforts. However, since the initiation of electricity market reforms in 2015, the environmental electricity price policy has lost external conditions, posing risks of potential non-compliance. This article first introduces the history and key content of the environmental electricity price policy, highlighting the challenges it faces in the context of electricity market reform. Based on the principal-agent theory framework, the article designs policy mechanisms on how the government can incentivize power generation companies to effectively implement pollution control measures and provides corresponding policy recommendations.

Keywords: Electricity Price, Environment Protection, Power Market Reform

1 Introduction

Environmental electricity price refers to the environmental surcharge policy implemented by the pricing authority on the electricity generated by newly built or modified coal-fired generating units equipped with environmental facilities such as desulfurization, denitrification, and dust removal. After passing the inspection by the environmental regulatory authorities, this policy is enforced by the pricing authority to encourage pollution control by coal-fired power generation companies. The main objective is to incentivize these companies to treat the pollutants they emit, meet national emission standards, and receive reasonable compensation for the corresponding pollution control costs.

Existing literature on environmental electricity prices is relatively limited. It is widely accepted that high electricity price could help to curb pollution in China and Europe [1-3]. Some scholars have broadly reviewed the content, issues, and improvement strategies of the overall green and environmental electricity price policy system, including renewable energy prices[4-5]. Other scholars have conducted surveys to collect the costs of desulfurization, denitrification, and dust removal for coal-fired power generation companies. They argue that the current uniform environmental electricity price cannot fully compensate the high environmental costs

MSEA 2024, May 24-26, Jinan, People's Republic of China
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DOI 10.4108/eai.24-5-2024.2350030

incurred by some enterprises, suggesting the implementation of differentiated subsidies [6-7]. Some scholars also point out that due to technical constraints, coal-fired power generation companies may exceed emission limits during certain periods of their annual operation. Imposing administrative penalties on these companies could bring additional negative impacts [8-9]. However, none of these studies have addressed the issues of implementing environmental electricity prices under the background of electricity marketization reform.

When the environmental electricity price policy was introduced, China's electricity industry had not fully established a market-oriented trading mechanism. The benchmark on-grid electricity price for coal-fired power generation enterprises was approved by the government. Therefore, there were no implementation issues regarding the environmental surcharge. However, under the backdrop of electricity marketization reform, where on-grid electricity prices are no longer determined by the government but are formed through market transactions, ensuring the effective implementation of the environmental electricity price policy has become a current challenge.

2 Overview of Environmental Electricity Price Policy

Depending on the achieved emission standards, environmental electricity prices can be further categorized into desulfurization, denitrification, dust removal, and ultra-low emission prices. The initial exploration of environmental electricity prices took the form of desulfurization prices. Starting from 2004, the National Development and Reform Commission (NDRC) implemented measures such as adding 1.5 cents per kilowatt-hour to the on-grid electricity price for newly constructed coal-fired power plants with desulfurization facilities. The NDRC, in conjunction with the Ministry of Ecology and Environment, issued the "Measures for the Management of Desulfurization Electricity Prices and the Operation of Desulfurization Facilities for Coal-fired Power Units (Trial)" (NDRC Price [2007] No. 1176), expanding the implementation scope of desulfurization electricity prices further (as shown in Table 1). In the first year of the trial implementation of the desulfurization electricity price policy, the national sulfur dioxide emissions saw their first decline since the Eleventh Five-Year Plan period [7].

Table 1. Implementation Time and Surcharge Standards for Different Types of Environmental Protection Electricity Prices

Electricity Price Type	Document Number	Implementation Start Year	Implementation Scope	Surcharge Standard (Unit: cents/kilowatt-hour)
Desulfurization Electricity Price		2004	New Coal-fired Power Plants	1.5
	NDRC Price Adjustment [2007] No.1176	2007	New (Expanded) Coal-fired Units and Existing Coal-fired Units requiring desulfurization upgrades according to the "Eleventh Five-Year Plan for	1.5

			Desulfurization of Existing Coal-fired Power Plants"	
Denitrification Electricity Price	NDRC Price Adjustment [2011] No.2618	2011	Coal-fired power generation companies in 14 provinces as denitrification	0.8
	NDRC Price Adjustment [2012] No.4095	2012	All coal-fired power generation units nationwide	0.8
	NDRC Price Adjustment [2013] No.1651	2013	All coal-fired power generation units nationwide	1
Dust Removal Electricity Price	NDRC Price Adjustment [2013] No.1651	2013	All coal-fired power generation units nationwide	0.2

In response, the NDRC initiated denitrification electricity price pilot projects in 14 provinces (autonomous regions, municipalities) in 2011, setting a temporary denitrification price increase standard of 0.8 cents per kilowatt-hour. In 2012, the denitrification electricity price pilot projects expanded to all coal-fired power units nationwide. In 2013, the NDRC raised the denitrification electricity price increase standard to 1 cent per kilowatt-hour and implemented a dust removal price increase standard of 0.2 cents per kilowatt-hour for coal-fired power enterprises meeting particulate emission standards.

In 2014, the NDRC and the Ministry of Ecology and Environment jointly issued the "Measures for the Supervision of Environmental Electricity Prices and the Operation of Environmental Facilities for Coal-fired Power Units" (NDRC Price [2014] No. 536, hereinafter referred to as Document 536), consolidating desulfurization, denitrification, and dust removal electricity prices into environmental electricity prices. Regulatory measures originally applicable to desulfurization electricity prices were extended to denitrification and dust removal electricity prices. Article 5 of Document 536 stipulates that newly constructed coal-fired power units should simultaneously build environmental facilities according to environmental regulations, and existing coal-fired power units must complete environmental facility upgrades according to the schedule determined by relevant governments. Article 15 outlines penalty measures for emissions exceeding standards during the operation of environmental facilities. When the average hourly concentrations of sulfur dioxide, nitrogen oxides, and particulate matter exceed the limits, the government pricing authority confiscates the environmental electricity price funds for the excess period. For emissions exceeding 1 time or more, fines are imposed, not exceeding 5 times the environmental electricity price funds for the excess period.

3 Challenges in the Implementation of Environmental Electricity Price Policy under the Background of Electricity Market Reform

In March 2015, the Central Committee of the Communist Party of China and the State Council issued the "Opinions on Further Deepening the Reform of the Electric Power System"

(Document No. 9 of 2015, hereinafter referred to as Document No. 9), initiating a new round of electric power system reform. In October 2021, the National Development and Reform Commission (NDRC) issued the "Notice of the National Development and Reform Commission on Further Deepening the Market-oriented Reform of On-grid Electricity Prices for Coal-fired Power Generation" (NDRC Price [2021] No. 1439), orderly opening up the on-grid electricity prices for all coal-fired power generation, and essentially bringing all coal-fired power generation into the electricity market. Through market transactions, on-grid electricity prices are formed within the "benchmark price + fluctuation" range. The introduction of these policies changed the external conditions for the execution of the environmental electricity price policy, introducing risks that make the original environmental electricity price difficult to implement.

Firstly, market-traded electricity prices may not necessarily include the environmental electricity price surcharge. If the power industry undergoes complete market-oriented reform, where prices are no longer regulated by the government but determined by market transactions, electricity consumers, not being the direct beneficiaries of emission reduction, may opt for cheaper electricity in the market to reduce electricity costs. In a scenario with two coal-fired power companies in the market – one with environmental facilities, meeting emission standards but having higher generation costs and correspondingly higher market quotations, and the other without environmental facilities, having lower market quotations but not meeting emission standards – electricity users may lean towards purchasing electricity from the non-compliant coal-fired power company, leading to the adverse consequence of inferior quality driving out superior quality.

Secondly, non-compliant coal-fired power companies lack authoritative entities to impose economic penalties. Before the electricity marketization reform, government pricing authorities would take corresponding punitive measures against coal-fired power companies that did not meet emission standards. However, after marketization reform, government pricing authorities should no longer directly intervene in on-grid electricity prices, making it inconvenient to directly confiscate the environmental electricity price added to the benchmark on-grid electricity price. Despite the existing electricity market rules specifying that environmental electricity prices should be included in market-traded electricity prices, electricity users, after paying the market-traded electricity price inclusive of the environmental electricity price, lack the motivation to encourage coal-fired power companies to meet emission standards and the means to economically penalize non-compliant coal-fired power companies.

Therefore, the originally well-executed environmental electricity price policy under government-regulated electricity prices might face challenges in smooth execution under the new electricity market background, necessitating the establishment of new execution mechanisms adapted to market transactions.

4 Designing an Environmental Electricity Price Execution Mechanism Adapted to the Electricity Market Background

As the electricity marketization reform advances, there has been a subtle change in the external conditions for the execution of the environmental electricity price policy. In a purely market-traded environment, both power generation companies and electricity users, as trading parties, have motivations to avoid the surcharge of the environmental electricity price, benefiting from reduced transaction prices. However, with power generation companies losing the subsidy from the surcharge of the environmental electricity price, there is naturally no incentive for them to achieve compliant emissions. Meanwhile, as the representative of the overall societal interest, the government wishes for power generation companies to achieve compliant emissions. Yet, the efforts made by power generation companies to achieve compliant emissions are private information that cannot be fully observed by the government. Therefore, in the context of the electricity market, when there is information asymmetry between the government and power generation companies regarding the efforts made for compliant emissions, designing relevant environmental electricity price policies to meet the requirements of electricity market transactions becomes an urgent problem.

In the following sections, this paper will establish a model under the principal-agent theory framework to address this issue.

This paper assumes that power generation companies play the role of agents in the principal-agent theory framework. After reaching transactions with electricity users, they choose the level of effort in reducing pollutant emissions, denoted as e . For simplicity, this paper sets e as a binary variable, taking values in the range of 0 or 1. When $e=0$ it signifies that the power generation company does not make any efforts in reducing pollutant emissions, and when $e=1$, it represents that the company has implemented efforts in reducing pollutant emissions. The cost function for the effort in pollutant reduction by the power generation company is denoted as $x(e)$. Furthermore, it is assumed that when the effort level for pollutant reduction is 0, the company incurs no cost, and when the effort level is 1, the cost of emissions abated is x , hence $x(0)=0, x(1)=x$.

The government acts as the principal and compensates the power generation company for implementing pollutant reduction efforts based on the payment t it makes. This paper assumes that the profit function for the power generation company is $U=u(t)-x(e)$, where the function $u(\bullet)$ is monotonically increasing and globally concave.

The actual level of pollutant emissions by the power generation company is subject to randomness. In other words, even though the company makes efforts and incurs corresponding costs in pollutant emission control, the actual emissions may not necessarily meet national standards. It depends on external factors beyond the control of the power generation company. For example, rapid changes in output according to grid dispatch instructions may lead to deviations in the operation of desulfurization and denitrification facilities from the rated conditions, resulting in increased pollutant emissions. Therefore, the assumption in this paper regarding the stochastic nature of actual pollutant emissions is realistic. It is assumed that the pollutant emission level by the power generation company is $\tilde{q}$, with values in the range of $\tilde{q}$ in $\{\underline{q}, \overline{q}\}$, and there exists an indicator $\underline{q}$ such that $\overline{q}-\underline{q}=\Delta q>0$ signifies compliant emissions. The effort level of pollutant reduction by the power generation company influences the probability of achieving compliant emissions. This is mathematically expressed as

$\Pr\left(\tilde{q}=\underline{q} \mid e=0\right)=\pi_0, \Pr\left(\tilde{q}=\underline{q} \mid e=1\right)=\pi_1$, and it holds that $\pi_1>\pi_0$. This indicates that after the power generation company makes efforts in pollutant reduction, the likelihood of achieving compliant emissions is higher. The difference between these two probabilities is denoted as $\Delta\pi=\pi_1-\pi_0$.

The government as the principal is more concerned about the pollutant emissions of power generation companies. Therefore, for the government, it is more desirable for power generation companies to make efforts to reduce pollutants, thus increasing the probability of achieving compliant emissions. Let the utility function of the government be $v(\bullet)$, a monotonically increasing function. The expected utility of the government when the power generation company makes efforts to reduce pollutants is given by:

$$\begin{aligned}&\pi_1 v(\underline{q})+(1-\pi_1)v(\overline{q})\\&=\pi_0 v(\underline{q})+(1-\pi_0)v(\overline{q})+\Delta\pi\left(v(\underline{q})-v(\overline{q})\right)\end{aligned} \tag{1}$$

And when the power generation company does not make efforts to reduce pollutants, the expected utility of the government is:

$$\pi_0 v(\underline{q})+(1-\pi_0)v(\overline{q}) \tag{2}$$

Obviously, equation (1) is greater than equation (2) , so the government strictly prefers power generation companies to engage in pollutant control. However, due to the lack of a strict one-to-one correspondence between the actual level of pollutant emissions and the efforts of power generation companies in pollutant control, there is a certain degree of randomness. It is possible for a power generation company to make efforts and incur related costs, but the actual pollutants may not meet the standard. Since the government cannot directly observe the efforts of power generation companies in pollutant control, it can only observe whether the actual pollutant emissions of power generation companies meet the standard. In this situation of information asymmetry, the government can design incentive contracts based on observable pollutant emissions to motivate power generation companies to make efforts in pollutant control. When the pollutant emission level of the power generation company is the standard emission level $\underline{q}$, the government's transfer payment to the company is $\overline{t}$; when the pollutant emission level is the excessive emission level $\overline{q}$, the government's transfer payment is $\underline{t}$. Here, $\overline{t}>\underline{t}$ indicates that the government's transfer payment for compliant emissions is higher. Assuming the government is risk-neutral, when the power generation company makes efforts in pollutant reduction, the government's expected utility is:

$$V_1=\pi_1\left(S(\overline{q})-\underline{t}\right)+\left(1-\pi_1\right)\left(S(\underline{q})-\overline{t}\right) \tag{3}$$

When the power generation company does not make efforts in pollutant reduction, the government's expected utility is:

$$V_0=\pi_0\left(S(\overline{q})-\underline{t}\right)+\left(1-\pi_0\right)\left(S(\underline{q})-\overline{t}\right) \tag{4}$$

According to the principal-agent theory, the incentive contract signed between the government and power generation companies needs to satisfy the participation constraint and incentive compatibility constraint. Assuming the power generation company's external reservation utility is zero, the participation constraint for this power generation company can be expressed as:

$$\pi_1 u(\overline{t}) + (1-\pi_1)u(\underline{t}) - x \geq 0 \tag{5}$$

Equation (5) indicates that if the power generation company makes efforts to control pollutant emissions, the profit level it obtains will not be lower than its external profit level, ensuring that the power generation company will sign this incentive contract with the government. The incentive compatibility constraint for the power generation company is:

$$\pi_1 u(\overline{t}) + (1-\pi_1)u(\underline{t}) - x \geq \pi_0 u(\overline{t}) + (1-\pi_0)u(\underline{t}) \tag{6}$$

Equation (6) indicates that after the power generation company makes efforts to reduce pollutant emissions, the profit level obtained from the incentive contract must be higher than the profit level when no efforts are made. Therefore, under the incentive compatibility constraint, a rational power generation company will choose to engage in pollutant reduction.

Since the function $u(\bullet)$ is a monotonically increasing function, the parameters $u(\underline{t})$ and $u(\overline{t})$ in Equations (5) and (6) can be denoted as $\underline{t}$ and $\overline{t}$, respectively.

Under the conditions of the participation constraint and incentive compatibility constraint, the government expects that the power generation company will implement pollutant reduction, and its expected utility is as shown in Equation (3). As the principal, the government's optimization problem is to choose the appropriate transfer payment $\{\underline{t}, \overline{t}\}$ to maximize its utility level. Therefore, the government's optimization problem can be expressed as:

$$\begin{aligned} &\max_{\{\overline{t}, \underline{t}\}} \pi_1(\overline{S} - \overline{t}) + (1-\pi_1)(\underline{S} - \underline{t}) \\ &\pi_1 \overline{t} + (1-\pi_1)\underline{t} - x \geq \pi_0 \overline{t} + (1-\pi_0)\underline{t} \\ &\pi_1 \overline{t} + (1-\pi_1)\underline{t} - x \geq 0 \end{aligned} \tag{7}$$

Solving the optimization problem in Equation(7), we get:

$$\underline{t}^* = -\frac{\pi_0}{\Delta\pi} x \tag{8}$$

$$\overline{t}^* = \frac{1-\pi_0}{\Delta\pi} x \tag{9}$$

From Equations (8) and (9), it can be seen that $\underline{t}^* < 0$ and $\overline{t}^* > 0$, corresponding to the government providing a negative transfer payment when it observes excessive pollutant emissions by the power generation company, which also corresponds to *ex post* penalty measures. When the government observes compliant emissions by the power generation company, it provides a positive transfer payment, corresponding to the environmental price markup.

For the power generation company, when facing the transfer payment given by Equation (8), its profit level after making efforts to control pollutant emissions is $-\frac{\pi_1}{\Delta\pi}x$, which is obviously negative. When facing the transfer payment given by Equation (9), its profit level after making efforts to control pollutant emissions is $\frac{1-\pi_1}{\Delta\pi}x$, which is obviously positive. Even if the power generation company makes efforts in pollutant control, there is still a certain probability of being punished. However, by making efforts, the power generation company increases the probability of being punished from π_0 to π_1. The expected benefit of making efforts in pollutant control is derived from Equations (8) and (9) as $\Delta\pi(\overline{t}^* - \underline{t}^*) = x$, which is precisely equal to the cost of his efforts. Therefore, under this incentive contract, power generation companies do not incur any losses. Similarly, the government, acting as the principal, has an expected transfer payment, $\pi_1\overline{t}^* + (1-\pi_1)\underline{t}^* = x$ which precisely compensates for the pollution control efforts made by power generation companies. From a societal perspective, this achieves optimal compensation.

5 Conclusion and Policy Recommendations

This paper provides a historical review of the environmental electricity price policy implemented by the Chinese government and highlights the challenges in effectively executing the policy under the new electricity market context. Consequently, within the framework of the principal-agent theory and considering the information asymmetry regarding efforts by power generation companies to reduce pollutants between the government and these companies, this paper proposes a policy mechanism on how the government can incentivize power generation companies to engage in pollution control.

At the policy level, the paper suggests that, during the market registration phase before entering the market, power generation companies should undergo a strict review by the electricity trading center, guided by relevant government departments, to ensure that environmental facilities are properly installed and have received approval from environmental authorities. Only power generation companies that pass environmental inspections should be allowed to enter the market and engage in market transactions. The market transaction price should inherently include the environmental electricity price to avoid the aftermath of uncollectible fees. However, the funds generated from the environmental electricity price added to the market transaction price should not be settled immediately with power generation companies. Instead, they should be deposited into a dedicated government-regulated account. Only after the government verifies that the power generation company's pollutant emissions meet the standards should the funds be settled with the company. If a power generation company fails to meet the pollutant emission standards during the corresponding trading period, the government should impose appropriate penalties and deduct the environmental electricity price increment. This clear system of rewards and penalties can effectively motivate power generation companies to achieve compliant emissions.

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