Integrated assessment of environmental performance-based contracting for sulfur dioxide emission control in Chinese coal power plants

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Abstract
Performance-based contracting (PBC) is applied to Chinese industry for cleaner production, which is characterized by the payment made on measurable environmental outcome. Policy, technology, market, and capital are four elements that co-shape PBC where the synthesized effects are hard for intuition to tell. This study introduced an original interdisciplinary assessment model of PBC for SO2 emission control in Chinese coal power plants that involves key environmental policies including command-and-control regulations, market-based approaches, and administrative measures, as well as technology, market, and capital variables. The evaluation showed that in key regions, both pollution levy programs 8 and 10 CNY/kg SO2 (with the only penalty of concentration) could drive total emission amount close to regulatory targets. Interest expenses seem less relevant to SO2 abatement cost in terms of the whole contract period; however, it can raise the SO2 abatement cost similar to the service premium in the first few years.

Fluctuation of power market is a business risk to PBC. As unitization hours of generator sets decrease from 4760 to 4115 h/y, the proportion of profits in the income decreased from 12.12 to 4.16%. Since payment is made on the basis of emission verification, economic benefits can represent both environmental and economic benefits. Profits and financial chain of the contractor depending on the synthesized effects of technology, capital, market, and tax policy. Sensitivity analysis quantitatively indicates technical factor as crucial; however, the buyer’s business fluctuation is the real key to operational sustainability. The method was proved useful to integrated policy assessment at project level and PBC managerial decision-making.

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1. Introduction

In order to improve cleaner production, China is now developing a system of third-party governance of industrial pollution. In this reform, performance-based contracting (PBC) is adopted as a vital model, in which payment is made on the basis of specific and measurable levels of performance outcome defined by the customer and agreed upon by the contracting parties. This is in contrast to traditional action-based approach; wherein payment is related to the completion of milestones and project deliveries. If measuring performance is practical and information asymmetry exists between the buyer and provider, PBC is an effective alternative to improve the outcomes. In past decades, PBC is reshaping service supply chains in capital-intensive industries such as aerospace and defense (Kim et al., 2007), energy services (Larsen et al., 2012; Steinberger et al., 2009), ecosystem services (Banerjee et al., 2013; Derissen and Quaas, 2013), and water services (Kanakoudis and Tsitsiﬁli, 2012). In the past decade, PBC was tried in Chinese coal-fired power sector for SO2 emission control.

The power sector is the focus of SO2 emissions control in China, which contributed 41.7–51.6% to Chinese industrial SO2 emission...
power plants signed contracts with environmental companies introduced a franchising mechanism in 2007. Under this policy, the power plants signed contracts with environmental companies which will operate, and if necessary, finance and construct the SO2 cleanup facilities. As long as SO2 scrubber operation is satisfactory and the SO2 emission performance is verified and confirmed by the government, the contractor, in return, is given access to a price premium of desulfurization electricity, 15CNY/MWh. As the service provider’s income depends on SO2 emission performance, this is a type of PBC. It has realized great environmental and economic outcomes: Chinese power sector achieved a significant decline in SO2 emission although with continually increasing pollution pressure caused by rapid economic development (Klimont et al., 2013); meanwhile, companies specialized in flue gas pollution control made great progress, with 27 listed on the 2016 stock market that was few before 2010.

A quantitative and profound analysis of PBC for SO2 emission control is needed now. Optimization of SO2 emission control strategy was well studied using cost-effectiveness analysis (Dong et al., 2015; Zhang et al., 2015, 2017), where SO2 abatement cost was often set as general and static. A few studies zoomed into coal power plant and collected comprehensive data to examine the critical factors and their impacts on PBC (Li et al., 2016; Xu, 2011). However, at least the following characteristics of PBC have not yet been well considered: 1) cost of PBC varies with the operational status and environmental policy; 2) income of PBC varies with the buyer’s business fluctuations and the realized emission performance; 3) indeed, policy, technology, market, and capital are four elements co-shaping environmental PBC. Uncertainty is a challenge that PBC schemes have to tackle (Derissen and Quas, 2013); with regard to PBC for SO2 emission control, it is the changing policy and market context. Chinese environmental regulation framework on power sector not only is complex but also is increasingly stringent (Li et al., 2011; Schreifels et al., 2012). While central government adopted the top-down strategy for SO2 control, the local government issued regional-specific policies to adapt to regional disparity and inequity (Dong et al., 2015; Hao et al., 2015; Xie et al., 2016). In addition, the buyer’s business fluctuations, such as the declining of average utilization of power generation units because of over-capacity in power industry poses a negative impact on the profit of service provider, especially on those who financed and invested SO2 scrubbers. Thus, PBC properties arise from the interacting parts in complex and changing circumstances where intuition is likely to fail. A quantitative decision tool will be helpful for policy makers to predict the impacts of policy on the project level along with other factors, and also helpful for the service provider to make decision by estimating the effects of external changes and internal response timely.

To this end, this study aimed at: 1) developing an interdisciplinary assessment model of PBC for SO2 emission control. This model combines policy factors including command-and-control regulations, market-based approaches, and administrative measures, as well as technology, market, and capital factors, accounting for the characteristics of environmental PBC. 2) Conducting a profound analysis of a basic case. That was done from several aspects, such as the effect of incentive policy, the influence of financial cost, and the risk of buyer’s business fluctuations, and the comparison between the influences of the four elements on PBC outcome. The proposed approach provided meaningful findings, adding a new perspective to the current state of research on environmental performance-based contracting.

2. Materials and methods

After shutting down small, less-efficient power plants in the past years (Price et al., 2011), 600 MW power generator has been the main set in Chinese coal power industry (Deng et al., 2015). In addition, wet limestone gypsum FGD (WFGD) is the most popular technology deployed for SO2 control. Thus, parameters and equations of the assessment model are collected by taking WFGD for two 600 MW generating sets as the object. An overview of the model parameters is provided in the Nomenclature. The model parameters and equations are split into four sections that are discussed separately:

- Environmental policies (Table S1 in supporting information, SI);
- Cost estimation of WFGD (SI Table S2);
- Calculation of SO2 production and emission performance (SI Table S3);
- Contract and financing (SI Table S4).

2.1. Environmental policies

2.1.1. Command-and-control regulations

(1) Emission amount control. In China, the total amount of SO2 discharged from thermal power generator unit should be lower than TEC limit, which is calculated as (MEP, 2014):

\[ Q_{cap} = (E_{cap} \times 5500 + D/1000) \times Q_{ep.L} \times 10^{-3} \]  

where 5500 is average utilization duration of generating units in principle, h/year; \( Q_{ep.L} \) means emission performance limit, equivalent to 0.7, 0.35, and 0.175 g SO2/kWh for high-sulfur coal, general areas, and key regions, respectively.

(2) Emission concentration standard. The current Emission Standard of Air Pollutants for Thermal Power Plant of China has come into effect since Jan 1, 2012 (MEP and QS, 2011). It specifies the requirement of SO2 emission concentration not exceeding 100 mg SO2/m3 in general, and 50 mg SO2/m3 for key regions that is called specific emission standard. In 2013, MEP announced the list of 47 key cities that should mandatorily implement the specific emission standard (MEP, 2013).

2.1.2. Market-based approaches

(1) Pollution levy. Under the current Pollutants Discharge Price policy, 1.26CNY/kg SO2 is required for SO2 emission, which will double if the concentration exceeds the emission standard known as the penalty of concentration, or if emission amount exceeds TEC limit that is called the penalty of amounts. Moreover, this charge will be tripled if the two circumstances coexist (NDRC et al., 2014). Most provinces such as Inner Mongolia implement this standard (Inner Mongolia PDRC et al., 2015), while local governments in the key regions issued high local standards. For example, Shanghai Municipality raises the pollutant discharge fees to 4, 7, and 8CNY/kg SO2 that was or will be effective since Jan 1/2015, Jan/1/2017, Jan/1/2019, respectively (Shanghai PDRC...
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