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Cost estimate of multi-pollutant abatement from the power sector in the Yangtze River Delta region of China

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HIGHLIGHTS

- Multi-pollutant emission data with various control measure information are provided.
- We use LP algorithm to optimize the cost estimate of multi-pollutant abatements.
- High reduction percent will raise the cost exponentially for different regions.
- For different regions, the cost for the same removal percentage can vary dramatically.

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ABSTRACT

Coal-fired power plants in China have emitted multiple pollutants including sulfur dioxide, nitrogen oxides and fine particulates, contributing to serious environmental impairments and human health issues. To meet ambient air quality standards, the installation of effective pollution control technologies are required and consequently, the cost of installing or retrofitting control technologies is an important economic and political concern. A multi-pollutant control cost model, CoST CE, is developed to calculate the cost of multi-pollutant control strategies in the Yangtze River Delta region (YRD) of China, adopting an LP algorithm to optimize the sorting of control technology costs and quickly obtain a solution. The output shows that total costs will increase along with emission abatement. Meanwhile, the slope becomes steeper as greater emission reductions are pursued, due to the need to install highly effective, but expensive, technologies like SCR and FF. Moreover, it is evident that the cost curve shapes, maximum abatement potential and total cost for the three provinces in the YRD region are quite different due to differences in power plant type and technologies, current emission levels and existing pollution controls. The results from this study can aid policy makers to develop cost-effective control strategies for the power sector.

1. Introduction

Due to rapid urbanization and economic development, China's Gross Domestic Product (GDP) has grown at a high annual rate of greater than 9% between 1978 and 2009 (Zhang and Yang, 2013). Concomitantly, China's energy consumption increased exponentially during this period of time. Among the various forms of energy, coal is the dominant resource for generating electricity and heat in China. According to the China Statistical Yearbook 2012 (National Bureau of Statistics, 2013), total primary energy consumption reached 3.48 billion tons of standard coal equivalent in 2012, representing 68.4% of the total primary energy consumption. Compared to the statistics in 2000, total energy consumption had increased by 185.3% and total coal consumption had risen by 190.8% (National Bureau of Statistics, 2001; 2013). Of total coal consumption, 48.4% was consumed in coal-fired power plants in 2011 to generate electricity (National Bureau of Statistics, 2013). Due to the usage of low quality coal with relatively high sulfur, nitrogen and ash content, coal combustion releases large amounts of gaseous pollutants such as sulfur dioxide (SO_2) and nitrogen oxides (NO_X),

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and particulate matter, including fine particulate matter with diameters less than or equal to 2.5 μm ($PM_{2.5}$). In the ambient atmosphere, SO_2 and NO_X, together with their secondary pollutants, can have serious impacts on the environment and human health (Lu et al., 2010; Du et al., 2012; Chen et al., 2012). $PM_{2.5}$ is a major contributor to the regional haze (i.e., visibility reduction) and has considerable effects on respiratory diseases and global climate change (Yang et al., 2013). Human mortality caused by particle pollution could reach 1.4 million people each year in China (Florig, 1997). In 2011, the World Health Organization (WHO) investigated air pollution in 1100 cities around the world. In the Yangtze River Delta (YRD) region of China, Nanjing, Hangzhou, and Shanghai are unfortunately among the 110 most polluted cities in the world (2011, available from http://www.who.int/phe/health_topics/outdoorair/databases/en/). Meanwhile, the serious regional haze in Shanghai in January 2013 and over more than 25 provinces, including YRD region, in December 2013 raised the public's awareness of the importance of reducing emissions that lead to primary and secondary particulate patter.

To mitigate the severe impact of anthropogenic emissions from power plants on human health and the environment, it is necessary for the Chinese government to implement control strategies to reduce SO_2, NO_X and $PM_{2.5}$ emissions. Governments at the national, provincial, and municipal level in China have already implemented several control strategies over past few years. Since 2006, installation of Flue-Gas Desulfurization (FGD) devices at coal-fired power plants were mandated through China's 11th Five-Year Plan (2006–2010) policies and the China Ministry of Environmental Protection's (MEP's) efforts to reduce SO_2 emissions by 10% relative to 2005 levels (Lu et al., 2011). During the 11th Five-Year Plan period, SO_2 emission reductions exceeded the target, falling 14% from 2005 levels and this success was due in large part to improved policy design that established accountability, focused on performance, and prioritized incentives, and political support to implement and enforce the policies (Schreifels et al., 2012). In the 12th Five-Year Plan (2011–2015), the government has established new goals to further reduce SO_2 emissions by 8% and NO_X emissions by 10% relative to the 2010 emission levels (available at: http://english.sepa.gov.cn/News_service/infocus/201202/t20120207_223194.htm). While significant progress has been made to reduce SO_2 emissions from the power sector, achieving the NO_X reduction goal will require effective pollution control devices such as Selective Catalytic Reduction (SCR), Selective Non-Catalytic Reduction (SNCR), and Low-NO_X Burners (LNB) at coal-fired power plants. For reducing particulate matter, efforts have been underway for many years. China's first ambient air quality standards, published in 1982, prescribed limits for daily average total suspended particulates (TSP) and PM_{10} levels (Florig et al., 2002). According to current inventories, all coal-fired power plants built before 2010 in the YRD region are installed with PM abatement technologies like cyclones (CYC), wet scrubbers (WET) or electrostatic precipitators (ESP). Although there is not currently an absolute target for direct $PM_{2.5}$ emissions, which are finer and have a greater impact on human health, China's State Council promulgated a new ambient air quality standard for $PM_{2.5}$ in 2012 (GB 3095–2012) and the action plan for air pollution prevention and control in September 2013 (available from: http://english.mep.gov.cn/News_service/infocus/201309/t20130924_260707.htm?COLLCC=1069211751&). To meet the new standards, coal-fired power plants may have to install additional or replace existing particulate controls with high-efficiency pollution controls, such as Fabric Filters (FF).

If coal-fired power plants will have to install and operate a number of control technologies to meet these standards, it raises a crucial question: how much money will the government or industry need to invest in the installation and operation of pollution control devices to reduce SO_2, NO_X and $PM_{2.5}$ emissions? Gipson et al. (1975) developed a least-cost evaluation of regional strategies for control of SO_2 and TSP in 1973 for the United States. They formulated an integer programming problem by considering availability of fuel and control devices. Different methods of solving this problem were evaluated and a Linear Programming (LP) round-off plus heuristic technique was recommended as the most promising approach to find the regional least-cost solution. In 1981, Cass and McRae (1981) summarized past work to develop least-cost solutions and pointed out future areas of research and potential barriers for practical application of models, such as data resources (spatially and temporally resolved data on pollutant concentrations, wind speed, wind direction, inversion base height, terrain height and solar radiation), technology transfer and time limits (waiting for administrative review and approval, and training inexperienced personnel). Harley et al. (1989) conducted a least-cost study based on a receptor-oriented model. In their work each air monitoring site was treated as a receptor. They adopted a simplex algorithm for LP coupled with subroutines that implemented a branch and bound algorithm for integer programming. Recently, Fu et al. (2006) conducted research to identify cost-effective control strategies for ozone based on Emission Least Cost (ELC) and Ambient Least Cost (ALC) approaches. They adopted a heuristic method using only a small number of simple air quality model simulations and then refined with a complex air quality model, which might reduce the number of complex model runs. Elliston et al. (2013) used a generic algorithm to identify the least cost for a 100% renewable electricity scenario in the Australian national electricity market. The scenario proved to be cheaper on an annual basis than the replacement scenario for addressing climate change. Vijay et al. (2010) applied a bottom-up method to develop NO_X Marginal Abatement Cost Curves (MACCs) for coal-fired utility boilers in the United States. This method was based on the technical details associated with specific boiler configurations and retrofit technologies, which should have a high resolution. Nevertheless, a shortcoming of their work was that it did not take the pre-existing control technologies into account and could not be interpreted as a policy prescription. It also failed to provide detailed information for each power plant under a specified emissions reduction standard, which was of significant value to the assessment by modelers and policy analysts.

Hence, to bridge the methodological gap above and consider the fact that few studies have been done to investigate the cost issue in China, a multi-pollutant cost model for the YRD region in China was developed to calculate the cost of achieving emission reductions. This model calculates not only the installation cost of new control measures at power plants, but also retrofit cost from existed devices to new and more effective technologies. In addition, it can specify the detailed control strategy for each power plant and show them directly in the cost model. Section 2 describes the cost model methodology in more detail. Section 3 presents the results from the cost model and related discussion. Section 4 highlights our conclusion, policy implications and future work.

2. Material and methods

2.1. Governing equations

Assuming there are N power plants and M types of control technologies for pollutant j, the mathematical formulation for emission control can be written as:

$$R_{j,k} = E_{j,k}\left(1 - \sum_{i=1}^{M}(EFF_{i,j}x_{i,k})\right) \tag{1}$$