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Evaluation of costs associated with atmospheric mercury emission reductions from coal combustion in China in 2010 and projections for 2020☆

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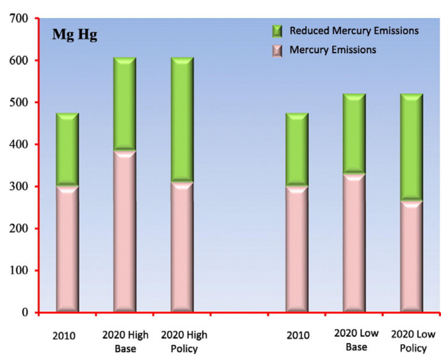
HIGHLIGHTS

- Mercury abatement costs for coal combustion in China for 2010 were estimated.
- Four scenarios were used to project mercury abatement costs for 2020.
- Decrease in unit abatement costs in 2020 suggests viable of various scenarios.

GRAPHICAL ABSTRACT



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ABSTRACT

Coal combustion is the most significant anthropogenic mercury emission source in China. In 2013, China signed the *Minamata Convention* affirming that mercury emissions should be controlled more strictly. Therefore, an evaluation of the costs associated with atmospheric mercury emission reductions from China's coal combustion is essential. In this study, we estimated mercury abatement costs for coal combustion in China for 2010, based on a provincial technology-based mercury emission inventory. In addition, four scenarios were used to project abatement costs for 2020. Our results indicate that actual mercury emission related to coal combustion in 2010 was 300.8 Mg, indicating a reduction amount of 174.7 Mg. Under a policy-controlled scenario for 2020, approximately 49% of this mercury could be removed using air pollution control devices, making mercury emissions in 2020 equal to or lower than in 2010. The total abatement cost associated with mercury emissions in 2010 was 50.2×10^9 RMB. In contrast, the total abatement costs for 2020 under baseline versus policy-controlled scenarios, having high-energy and low-energy consumption, would be 32.0×10^9 versus 51.2×10^9, and 27.4×10^9 versus 43.9×10^9 RMB, respectively. The main expense is associated with flue gas desulfurization. The unit abatement cost of mercury emissions in 2010 was 288×10^3 RMB/(kg Hg). The unit abatement costs projected for 2020 under a baseline, a policy-controlled, and an United Nations Environmental Programme scenario would be 143×10^3, 172×10^3 and 1066×10^3 RMB/(kg Hg), respectively. These results are much lower than other international ones. However, the relative costs to China in terms of GPD are

☆ Capsule: Mercury abatement costs for coal combustion in China was estimated and projected, which accounted for 0.14% of GDP in 2010, and 0.03%–0.06% in 2020.

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higher than in most developed countries. We calculated that abatement costs related to mercury emissions accounted for about 0.14% of the GDP of China in 2010, but would be between 0.03% and 0.06% in 2020. This decrease in abatement costs in terms of GDP suggests that various policy-controlled scenarios would be viable.

1. Introduction

Mercury is a persistent environmental pollutant. It causes global concern because of its long-range transport and high toxicity (Schroeder and Munthe, 1998; Streets et al., 2005; Pirrone and Mason, 2009). Previous studies showed that China's mercury emissions from anthropogenic sources have reached 600 Mg/y (Streets et al., 2005; Pirrone and Mason, 2009; A. Wu et al., 2006; Y. Wu et al., 2006; E.G. Pacyna et al., 2010a; J.M. Pacyna et al., 2010b), accounting for approximately 28–40% of global emissions (Pacyna et al., 2006; Pirrone and Mason, 2009). E.G. Pacyna et al. (2010a) and J.M. Pacyna et al. (2010b) estimated that the 635 Mg emissions in China in 2005 would decrease to between 380 Mg (under the Extended Emissions Control scenario) and 290 Mg (under the Maximum Feasible Technology Reduction scenario) in 2020. This last estimate assumes that all Chinese power plants will be equipped with improved emission control installations by 2020. If improvement is 50% lower than this estimate, then under various scenarios, China's emissions will increase rather than decrease by 2020, related to its ongoing economic development.

Coal combustion is believed to be the largest anthropogenic mercury emission source, producing approximately 24–66% of global emissions, with coal being consumed mainly in power plants and industrial boilers (Pacyna et al., 2006; United Nations Environment Programme (UNEP), 2002, 2013a, b). Pacyna and Pacyna (2002) estimated that China's mercury emissions from coal burning contributed to more than 25% of the total global emissions. Furthermore, A. Wu et al. (2006) and Y. Wu et al. (2006) showed that mercury emissions from coal combustion in China increased from 202 Mg in 1995 to 257 Mg in 2003, with an annual growth rate of 3.0%. Zhang et al. (2015) estimated that mercury emissions from coal combustion in China reached 254 Mg in 2010, accounting for approximately 47% of the national total emissions.

As one of the major mercury emitters, China signed the *Minamata Convention* in 2013, affirming that mercury emissions from coal-fired power plants and industrial boilers should be strictly controlled. Therefore, an evaluation of costs associated with atmospheric mercury emission reductions from China's coal combustion is essential. It would also support development of mercury-related environmental policies.

Several studies on abatement costs of mercury emissions, conducted in Europe and North America, showed a marked decrease in emissions since 2000 (Pirrone et al., 2001; USEPA, 2002; Visschedijk et al., 2006; E.G. Pacyna et al., 2010a; J.M. Pacyna et al., 2010b). However, few studies have been carried out in China. Wu et al. (2011) calculated the mercury abatement costs of air pollution control devices (APCDs) in China's power plants based on other pollutants' reduction costs. The cost data used in a number of studies originated from developed countries. Because of the differences in economic development levels among countries, the costs for China may differ significantly from other developed countries. Furthermore, large uncertainties are associated with previous estimations for China, because they did not consider detailed mercury emission inventories.

In this study, mercury abatement costs for coal combustion in China in 2010 were estimated, based on a provincial mercury emission inventories. Different types of coal, industries, and APCDs are considered in this estimation. Using updated installation and operation costs for APCDs, both total and unit abatement costs were calculated. In addition, two scenarios, namely a baseline and a policy-controlled scenario were proposed to describe mercury control policies for 2020. Two other scenarios, namely a high-energy and a low-energy consumption scenario were developed to describe energy consumption in 2020. Based on these scenarios, abatement costs for 2020 were estimated. Results of these estimations were compared with other reported costs (United Nations Environment Programme (UNEP), 2013a, b; E.G. Pacyna et al., 2010a; J.M. Pacyna et al., 2010b; Wu et al., 2011).

2. Data sources and methodology

2.1. Installation rate and removal efficiency of air pollution control devices

As environmental regulations in China becoming increasingly stringent, the installation rate of APCDs in power plants and other industries has grown rapidly, especially in the last few years. Currently, widely used APCDs in China include electrostatic precipitators (ESPs), fabric filters (FFs), and flue gas desulfurization (FGD). Only a few sites have selective catalytic reduction (SCR), while none use activated carbon injection (USEPA, 1997; UNEP, 2002; E.G. Pacyna et al., 2010a; J.M. Pacyna et al., 2010b; United Nations Environment Programme (UNEP), 2013a, b).

In some previous studies, the installation rate of APCDs in coal-fired industries was recognized to be equivalent to that in coal-fired power plants (United Nations Environment Programme (UNEP), 2013a, b). However, given the high installation and operation costs for large numbers of industrial boilers, the actual installation rate of APCDs in coal-fired industries is much lower than for power plants (NBSDE, 2011). Zhang et al. (2015) showed that only some large-capacity boilers in China have adopted a combination of FFs & FGD. Clearly, mercury emissions from coal-fired industries have been underestimated. The overall installation rate and removal efficiency of the whole coal-fired industry is lower than that in the power plants. In this study, we used real data for APCDs installation rates and estimated future development to carry out our scenario analysis.

Mercury removal efficiencies for different APCDs vary significantly (Wu et al., 2010; Wang et al., 2010; Zhang et al., 2012; United Nations Environment Programme (UNEP), 2013a, b). Detailed studies have been carried out on the combustion efficiencies of different devices, such as the capture of mercury in particulate control devices by unburned carbon (Hower et al., 2010; Chen et al., 2007). In our study, the information of removal efficiencies came from previous studies, and the removal efficiencies of the individual techniques have been considered in their calculations.

The detailed installation rate and mercury removal efficiency of each combination of APCDs in 2010 are listed in Table S1. We calculated the weighted equivalent (average) removal efficiencies for each industry, which are about 60.22% and 4.30% for coal-fired power plants and industry boilers, respectively. Since it is difficult to obtain detailed emission and control information of different coal types, and the production volume of some coal types such as lignite is not high, we assumed that the type of coal used had no significant impact on mercury removal (Zhang et al., 2012).

2.2. Emission and reduction factors

Typically, the mercury concentration of raw coal is used as the primary emission factor (EF) in calculating mercury emissions from coal combustion. In our study, mercury concentrations of raw coal were obtained at a provincial level from Streets et al. (2005) (Table S2). According to previous research, not all the mercury in the fired-coal is released