Energy Policy 106 (2017) 579–587

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Economic evaluation of health benefits of mercury emission controls for China and the neighboring countries in East Asia

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ARTICLE INFO

Keywords:
Mercury
Policy analysis
Economic benefits
Health impact
Scenario analysis

ABSTRACT

Globally, coal-fired power plant (CFPP) is a major source of mercury. China is developing its first National Implementation Plan on Mercury Control, which priorities the control of emissions from CFPPs. While social benefits play an important role in designing environmental policies in China, the benefits associated with mercury control are not yet understood, mainly due to the scientific challenges to trace mercury's emissions-to-impacts path. This study evaluates the benefits of mercury reductions in China's CFPPs for China and its three neighboring countries in East Asia. Four policy scenarios are analyzed following the policies-to-impacts path, which links a global atmospheric model to health benefit analysis models to estimate the economic gains from avoided mercury-related adverse health outcomes under each scenario, and take into account key uncertainties in the path. Under the most stringent scenario, the benefits of mercury reduction by 2030 are projected to be \$432 billion (95% CI: \$166–941 billion), with the benefits for China and the neighboring countries accounting for 96% and 4% of the total benefits, respectively. Policy scenario analysis indicates that coal washing generates the greatest benefits in the near term, whereas upgrading air pollution control devices maximizes health benefits in the long term.

1. Introduction

Mercury and its compounds are highly toxic substances for humans. On the Agency for Toxic Substances and Disease Registry's priority list, mercury is ranked third after arsenic and lead (ATSDR, 2015). Exposure to organic mercury has been linked to neurologic and mental disorders as well as effects on the cardiovascular system (Roman et al., 2011). Mercury is released into the environment from both natural and anthropogenic emissions. The natural sources include primary natural emissions (such as volcanic eruptions, geothermal sources and topsoil enriched in mercury) and reemission processes of historically deposited mercury over land and sea surfaces (Streets et al., 2009). The anthropogenic sources consist of a large number of industrial sources, including fossil-fuels combustion, ferrous and non-ferrous metals smelting, ore processing, waste incineration, cement and chemicals production and others (Streets et al., 2009). Current global emission inventories indicate that China is the largest contributor of anthropogenic mercury emissions to the atmosphere, contributing approximately one third to the global total (Streets et al., 2009; UNEP, 2013).

Control of the mercury emissions has achieved global attention, and the Minamata Convention on Mercury, a legally binding international treaty, was signed by 140 countries in 2013. Under the Minamata Convention, China is developing its National Implementation Plan on Mercury Control in order to fulfill its commitment to mercury control and reduction (World Bank, 2016). According to the most recent inventory, coal combustion is the predominant mercury emission source in China, contributing 47% to the anthropogenic mercury emissions in China in 2010 (Zhang et al., 2015). The coal combustion sector mainly includes coal-fired power plants (CFPPs) and coal-fired industrial boilers (CFIBs), and these sources are also listed as the top priorities of mercury emission control in the Minamata Convention. UNEP estimated that the mercury emission from global coal combustion is 474 t in 2010, of which 66% are attributed to CFPPs (UNEP, 2013). In China, compared with CFIBs, CFPPs are more preferred to be the target for actions on mercury control because they are key point sources and account for 42% of the coal combustion emissions (Zhao et al., 2015).

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http://dx.doi.org/10.1016/j.enpol.2017.04.010
Received 17 November 2016; Received in revised form 31 March 2017; Accepted 5 April 2017
0301-4215/

Mercury control in CFPPs is often achieved in co-benefit strategies aiming at conventional pollutants reductions. The recent National Air Pollution Prevention and Control Action Plan (2013–2017) has potential co-beneficial effects on mercury control for CFPPs in China (CSC, 2013). In addition, increasing efforts on direct actions have been taken for CFPPs. In 2011, the Ministry of Environmental Protection initiated a pilot project on mercury monitoring and control for large CFPPs in China. The newly revised Emission Standard of Air Pollutants for Thermal Power Plants, for the first time in China, stipulates the mercury emission limit of 30 μg/m^3 for thermal power plants (MEP, 2011). Although the design of environmental policies in China mostly considers socioeconomic impacts (Cao, 2010), the quantification of these impacts is often challenging. These challenges are especially serious for pollutants such as mercury, which may transport between multiple environmental media, and result in cross-boundary issues (Giang and Selin, 2016; You, 2015).

Mercury emission control on CFPPs has been extensively studied (Wang et al., 2012; Tian et al., 2012; Wu et al., 2011; Rallo et al., 2012; Pavlish et al., 2003). However, these studies have limitations in considering the pathway from mercury emissions to human impacts. Many do not explicitly consider trans-boundary issues related to mercury emissions, and do not link emissions to exposure changes (Bellanger et al., 2013; Pacyna et al., 2010; Rice et al., 2010). Few studies have explicitly considered health endpoints such as cardiovascular effects (Rice et al., 2010). Most recently, Giang and Selin (2016) reported the potential benefits to the United States of the Minamata Convention and domestic policies. While studies have been conducted to investigate the public health and economic benefits of mercury control in western developed countries (Giang and Selin, 2016; Bellanger et al., 2013; Pacyna et al., 2010; Rice et al., 2010), the potential benefits of the Minamata Convention on Asian countries are not yet well understood.

This study uses an integrated framework to trace the policies-to-impacts path to assess the health and economic benefits of different policy scenarios of China's mercury reduction strategies. To our best knowledge, this is the first study to evaluate the national health and economic benefits of mercury control in China and its neighboring countries in East Asia. This study contributes to the understanding of future health and economic benefits associated with mercury control in international context.

2. Methodology

This study follows a policies-to-impacts path, which links a global atmospheric model to health benefit analysis models. Firstly, emission inventories under each policy scenario are calculated and used in the mercury transport model to simulate atmospheric transport and deposition of mercury. Secondly, health benefits are evaluated through the relationship between the reduction of mercury deposition and mercury intake of exposed populations. Thirdly, economic gains from avoided mercury-related adverse health impacts under each scenario are estimated using economic assessment models.

2.1. Emission scenarios and inventories

In recent years, China has issued a series of regulations on air pollution control, including the National Air Pollution Prevention and Control Action Plan (issued on 2013), the Performance Assessment Measures for Air Pollution Prevention and Control Action Plan (issued on 2014), the latest revision of the Atmospheric Pollution Prevention and Control Law of the People's Republic of China (2015 Revision, came into force on January 1, 2016), and the Mercury Pollution Control Technology and Policy (Draft for Comments). Based on these regulations, we summarize the potential policy options for atmospheric mercury emissions control, and develop four scenarios associated with different control policies for the projection of mercury emissions from CFPPs in 2020 and 2030. These representative scenarios have the most relevant and important impacts on the mercury emission control for CFPPs, including: improvement of coal washing (Scenario I), adoption of best available technologies that have both co-benefit and direct impact on mercury reduction (Scenario II), and replacement of coal with new clean energy (Scenario III). A combination of the three policies is considered as a synthetic scenario (Scenario IV). In Scenario IV, the percentage of coal-fired power in primary energy will decrease, at the same time, in coal-fired power plants, the coal washing rate and the application of advanced ACPDs will increase. Therefore, Scenario IV represents the maximum possible reduction of mercury emissions. In order to calculate the benefits of the avoided mercury emissions under each control scenario, a business as usual scenario (Scenario 0) is established, in which the national policy of air pollution control and energy will not change in practice after 2010. For Scenario 0, the mercury emission in 2010 is used as the base inventory, and linearly scaled to 2020 and 2030 using the power generation projected by the International Energy Agency (IEA, 2007, 2014). Rational for these scenarios is presented in Table 1. The detailed explanation of each scenario is provided in the Supplementary Material.

Table 1
Rational of the emission scenarios in 2020 and 2030.

Scenario	2020	2030
Scenario 0	This scenario is the business as usual case, in which the national policy of energy saving and air pollution control is based on the status of 2010 and assuming they remain unchanged in future years. The percentage of coal-fired power in the total power generation is 76% (National Energy Administration (NEA) (NEA) (2011)). The coal washing rate is 2.1% (Wang et al., 2012). The installation of APCDs includes ESP 14.8%, ESP+WFGD 68.8%, FF+WFGD 5.2%, SCR+ESP+WFGD 11.2% (Zhang et al., 2015).	This scenario is the business as usual case, based on the status of mercury control in 2010, and scaled to 2030 using the projected power generation (IEA, 2007, 2014). The percentage of coal-fired power in the total power generation is 76% (National Energy Administration (NEA) (NEA), 2011). The coal washing rate is 2.1% (Wang et al., 2012). The installation of APCDs includes ESP 14.8%, ESP+WFGD 68.8%, FF+WFGD 5.2%, SCR+ESP+WFGD 11.2% (Zhang et al., 2015).
Scenario I	This scenario estimates the emissions under a significant improvement of coal washing rate from 2.1% to 50% (Zhang et al., 2016). Other parameters are consistent with Scenario 0.	In 2030, the coal washing rate is further increased to 70% (Zhang et al., 2016). Other parameters are consistent with Scenario 0.
Scenario II	This scenario is an estimate of emissions under much stricter requirement of APCDs. The installations of ESP, FF, WFGD and SCR will be 80%, 20%, 100% and 95%, respectively.	In 2030, the APCDs are further updated with advanced technologies and high efficiency of mercury control. The installations of ESP, FF, WFGD, SCR, SNCR and SMC will be 65%, 35%, 100%, 95%, 5% and 50%, respectively (Wang et al., 2012).
Scenario III	This scenario simulates the replacement of coal-fired power with more clean energy sources. The percentage of coal-fired power generation is projected to decrease to 60% (IEA, 2014; CSC, 2014).	In 2030, the percentage of coal-fired power generation is further reduced to 50% (IEA, 2007).
Scenario IV	This scenario is considered as the most stringent and ideal option that comprise all the potential policies in the above three scenarios.	This scenario is considered as the most stringent and ideal option that comprise all the potential policies in the above three scenarios.

Note: APCDs: air pollution control devices; ESP: electrostatic precipitator; WFGD: wet flue gas desulfurization; FF: fabric filter; SCR: selective catalytic reduction; SNCR: selective noncatalytic reduction; SMC: specific mercury control technology.