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Mitigation Potential of Mercury Emissions from Coal-Fired Power Plants in China

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ABSTRACT: With the rapid increase of coal consumption in China, the mercury emissions from coal-fired power plants have drawn global attention. In this study, a literature review on the mercury content of coal in China and the mercury removal efficiencies of particulate matter, SO_2, and NO_x control devices was conducted thoroughly. A probabilistic emission factor model was established to develop the mercury emission inventory for coal-fired power plants in China. The best estimate for total mercury emissions from coal-fired power plants in China was 96.5 tons (P50) in 2008, with the confidence interval from 57.3 tons (P10) to 183.0 tons (P90). The synergetic mercury removal benefit from the SO_2 control measures during 2005−2008 was 33.9 tons. Two energy scenarios and three pollution control scenarios were developed to forecast the future trend of mercury emissions in China. The change of the energy structure and energy saving will play an important role in the mercury emission reduction in the next 2 decades. Under the current energy consumption pattern and air pollution control policies, the mercury emissions would increase to 196 tons in 2020. The installation of selective catalytic reduction (SCR) will result in 75 tons of mercury emission reduction during 2008−2020. Under the current energy consumption pattern and extended emission controls, the mercury emission in 2030 is 47% lower than that in 2020, because of the widespread application of SCR and the application of fabric filter (FF) and mercury-specific control technologies. Further reduction can be contributed by the enhancement of mercury-specific control technologies. Through the implementation of energy policies with accelerated control technologies, the mercury emission in 2030 can be decreased by 71% from the level of 2008, which shows the significant mitigation potential of mercury emissions from coal-fired power plants in China in the future.

INTRODUCTION

Mercury is a hazardous pollutant, damaging human health and the environment, and can be found in the environment all over the globe, even in the regions far away from any emission source. The United National Environment Programme (UNEP) has regarded mercury as a global pollutant.[1] Combustion of coal to produce electricity and heat is the largest source of anthropogenic mercury emissions in Europe, North America, Asia, and Russia. Coal-fired power plants (CFPPs) are estimated to account for 26% of global anthropogenic mercury emission to the atmosphere.[2] China, with its more than 2000 coal-fired power plants, is the largest single emitter of atmospheric mercury worldwide. Stationary combustion, primarily coal combustion, accounts for 47% of the total mercury emissions in China in 2005.[3]

The coal consumption for the power sector in China has been growing rapidly since 2000. From 2000 to 2008, the total coal consumption has grown by 150%, with an annual growth rate of 12%.[4,5] By the end of 2008, the total installed capacity had increased to over 600 GW and the electricity generation had grown up to 2.8 billion MWh. The provinces with large installed capacity and high coal consumptions were mostly located in north, northeast, and east China. In China, the particulate matter (PM) emission control has been emphasized since the 1990s. By the end of 2008, over 96% of the CFPPs in China have installed electrostatic precipitators (ESPs) and the other 3% have installed fabric filters (FFs). Control of SO_2 emissions from CFPPs is one of the priorities of air pollution control in China from 2005 to 2010 (China's 11th 5-year plan). The ratio of installed capacity with flue gas desulfurization (FGD) had increased from 14% in 2005 to 60% in 2008. Of all of the units with FGD installation, over 90% used limestone−gypsum wet FGD technology. As for NO_x control, low NO_x burners (LNB) have been widely used, owing to its low capital and operation costs. Nearly all units built after 2003 use the advanced LNB technology. In 2008, the total capacity of the operating units with flue gas denitration systems was about 20 GW, of which only 1.5 GW applied selective noncatalytic reduction (SNCR), while the majority installed selective catalytic reduction (SCR).

The air pollution control devices (APCDs) in CFPPs have co-benefit on mercury removal. The United States Environmental Protection Agency (U.S. EPA) reported that ESP has an average mercury removal efficiency of 36%, while FF can remove as high as 90% of the total mercury.[6] The combination of ESP and wet FGD can remove 74% of the total mercury. Besides the existing APCDs, there are some specific mercury control technologies, such as activated carbon injection and bromide injection into the furnace, that can significantly improve the mercury removal efficiency, up to over 95%.

The intention of this paper is to develop both the current mercury emission inventory and the future mercury emission

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estimates for China's power sector, to identify the mitigation potential of mercury emissions from CFPPs in China.

■ METHODOLOGY

Previous mercury emission inventories were usually developed using a conventional deterministic emission factor method.[7] However, the mercury content of coal and the mercury removal efficiencies vary over a large range, which cannot be addressed by the deterministic emission factor model. In this study, a detailed probabilistic emission factor model was established to assess the mercury emission from CFPPs in China.

Information on the mercury content of coal by province, consumption of raw coal and washed coal by province, mercury removal efficiencies by single APCD or technology combinations, and the application of certain APCD combinations were collected from the literature. Probability-based distribution functions were built into the model to address the uncertainties or variations of the key parameters. The model uses Monte Carlo simulations to take into account the probability distributions of key input parameters and gives the mercury emission results in the form of a statistical distribution. All of the results are presented as distribution curves or confidence intervals instead of single points.

The model is described as the following equation:

$$E(x_i, y_{j,k}) = \sum_i \sum_j [M_i(x_i)A_{i,j}(1 - Pw)R_j \times (1 - \sum_k C_{j,k}\eta_{j,k}(y_{j,k}))]$$

where $E(x,y)$ is the probability distribution of the Hg emission, $M(x)$ is the probability distribution of the Hg content of coal as burned, A is the amount of coal consumption, P is the percentage of washed coal used in power plants, w is the mercury removal efficiency of coal washing, R is the release factor of mercury from combustion, C is the application ratio of a certain combination of APCDs, $\eta(y)$ is the mercury removal efficiency of a certain combination of APCDs, i is the province, j is the combustor type, and k is the type of APCD combinations.

The probability distributions in this study were discrete, which is suitable for Monte Carlo simulation. The probability distribution functions of the mercury content of coal and the mercury removal efficiency of combinations of APCDs were analyzed by the statistical software, named Crystal Ball.[8] In Crystal Ball, a mathematical distribution analysis was performed for the two key parameters to describe the characteristics of the data set. The quality or closeness of each fit is determined by the χ^2 and Anderson−Darling tests. To obtain reliable outputs, the sampling number of the Monte Carlo simulation was set to be 10 000. Year 2008 was selected as the base year of this study.

■ RESULTS AND DISCUSSION

The most important factors affecting mercury emissions are the mercury content of coal and the mercury removal efficiency of APCDs.

Mercury Content of Coal. On the basis of the results from our previous study[9] and the U.S. Geological Survey (USGS) database,[10] the mercury content of raw coal in each province was calculated (as shown in Figure 1). It can be seen that the mercury contents of coal in Shaanxi, Guizhou, Inner Mongolia, and Shanxi have large variations. A statistical distribution fit was performed on the provincial data of the mercury content using Crystal Ball. The mercury content for most provinces fit the log-normal distribution. The P10/P50/P90 values mean that there is a probability of 10/50/90% of the actual result that would be equal to or below the P10/P50/P90 values.

The parameter used in the emission model is not the mercury content of coal as mined but as burned in power plants. The interprovincial coal transport is shown in Figure 2. On the basis of the amount of import and export of coal for each province as well as the usual coal transport routes, a coal

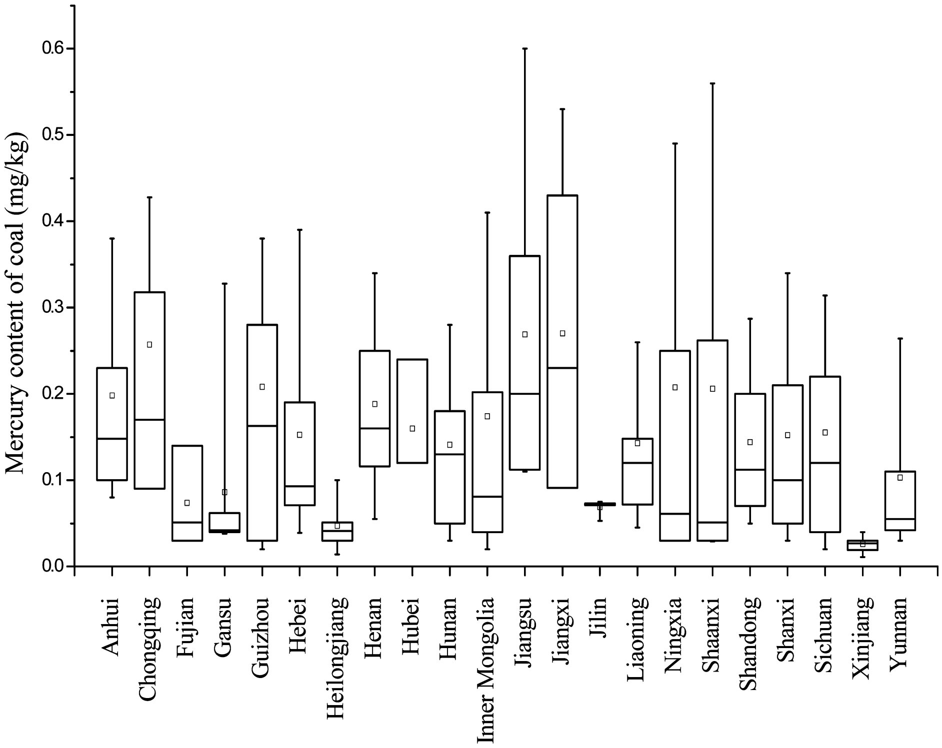

Figure 1. Mercury content of coal as mined in each province (mg/kg). The bottom and top of the box represent the 25th and 75th percentiles (the lower and upper quartiles), respectively. The band near the middle of the box represents the 50th percentile (the median). The ends of the whiskers represent the 10th and 90th percentiles. The hollow dot represents the mean value.

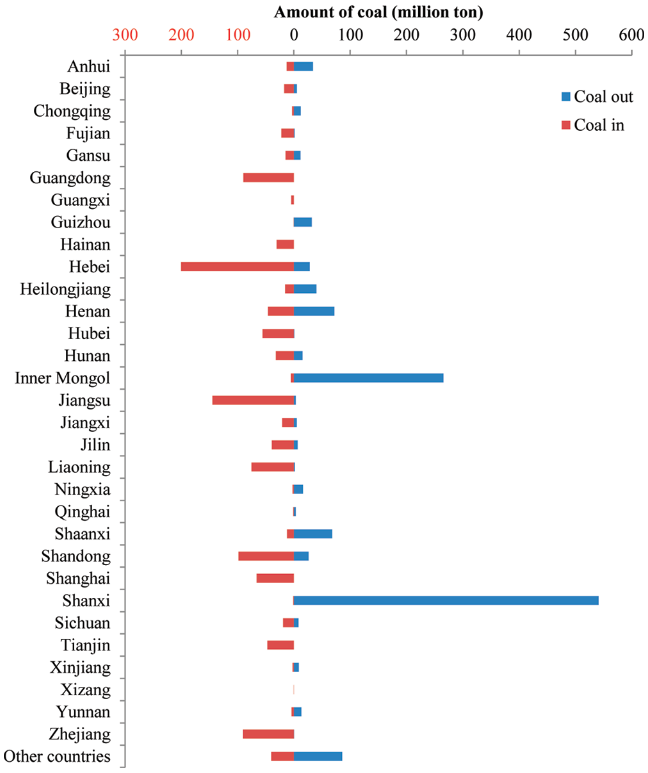

Figure 2. Import and export of raw coal for each province in China in 2008.

transport matrix was developed. The mercury content of coal as burned was calculated on the basis of the mercury content of coal as mined and the coal transport matrix. Table 1 shows the average mercury content of coal as used in CFPPs in China. The national average turned out to be 0.17 mg/kg. The lowest value occurred in Xinjiang province, while the highest value was found in Chongqing province. However, the differences between provinces are not as significant as those for the mercury content of raw coal as mined because of the interprovincial coal transport.

Mercury Removal Efficiencies of APCDs. The mercury removal efficiencies given by the literature were summarized in Table 2. The mercury removal efficiencies of the most commonly used APCD combinations were included in this study. The other APCD combinations that are either not commonly used or have few test data are not considered in this study. The influence of the coal type is not considered in the inventory development in this study. The mercury removal efficiencies of APCD combinations also have large uncertainties.

Table 2. Average Mercury Removal Efficiencies of Different APCD Combinations[a]

APCD combination	mercury removal efficiency (%)	number of tests
ESP	29	63
ESP + WFGD	62	19
FF	67	10
SCR + ESP + WFGD	67	3
FF + WFGD	87	3
SCR + FF + WFGD	87	estimate
SNCR + ESP + WFGD	62	estimate
SMC + SCR + ESP + WFGD	95	estimate
coal wash	30	estimate

[a] ESP, electrostatic precipitator; FF, fabric filter; WFGD, wet flue gas desulfurization; SCR, selective catalytic reduction; SNCR, selective noncatalytic reduction; and SMC, specialized mercury control technology. The mercury removal efficiency of SCR + FF + WFGD is referred to that of FF + WFGD. The mercury removal efficiency of SNCR + ESP + WFGD is referred to that of ESP + WFGD. References for this table are provided in refs 21−51.

The most widely used APCD combinations in China are ESP and ESP plus wet flue gas desulfurization (ESP + WFGD). Data from the literature for these two types of APCDs were analyzed using Crystal Ball. The removal efficiency of ESP fits the Weibull distribution. The best estimated value (P50) was 26%, lower than the mean value (29%). Mercury removal efficiencies of ESP + WFGD fit the Weibull distribution as well. The best estimated value (P50) was 65%, higher than the mean value (62%). Mean values were used for other APCD combinations because of the lack of test results.

The mercury removal efficiencies of the future APCD combinations, also shown in Table 2, are assumed on the basis of existing combinations. The efficiency of SCR + FF + WFGD is assumed to be the same as that of FF + WFGD. The efficiency of SNCR + ESP + WFGD is assumed to be the same as that of ESP + WFGD. The combination of specific mercury control (SMC) technologies and other APCDs, SMC + SCR + ESP + WFGD, is assumed to have a mercury removal efficiency of 95%. Coal washing can remove 10−50% of the mercury in coal.[11] An average mercury removal efficiency of 30% is used for coal washing.

Mercury Emission Inventory for CFPPs in China. Information on the mercury content of coal and mercury removal efficiencies of APCDs was combined with the coal consumption from power plants in China in 2008 to calculate the mercury emission inventory for CFPPs in China. The total mercury emissions and the uncertainty ranges by province are shown in Figure 3. The bar represents the P50 value of

Table 1. Average Mercury Content of Coal as Used in Power Plants (mg/kg)

province	mercury content	province	mercury content	province	mercury content
Anhui	0.19	Heilongjiang	0.08	Qinghai	0.06
Beijing	0.16	Henan	0.19	Shaanxi	0.20
Chongqing	0.25	Hubei	0.18	Shandong	0.15
Fujian	0.13	Hunan	0.15	Shanghai	0.19
Gansu	0.08	Inner Mongolia	0.21	Shanxi	0.15
Guangdong	0.17	Jiangsu	0.20	Sichuan	0.17
Guangxi	0.22	Jiangxi	0.23	Tianjin	0.20
Guizhou	0.21	Jilin	0.11	Xinjiang	0.04
Hainan	0.15	Liaoning	0.15	Xizang	0.16
Hebei	0.17	Ningxia	0.20	national average	0.17

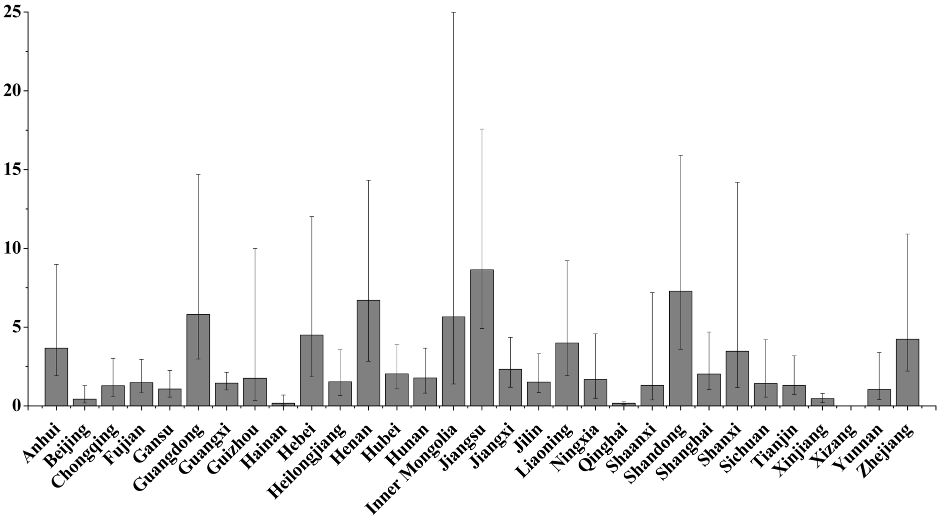

Figure 3. Total mercury emissions and uncertainty ranges for CFPPs by province, 2008 (tons).

emissions, and the short lines superimposed on each bar represent the P10 and P90 value. The best estimate for mercury emissions from CFPPs in China was 96.5 tons (P50) in 2008, with the confidence interval from 57.3 tons (P10) to 183.0 tons (P90). From Figure 3, we can see that Jiangsu, Shandong, and Henan provinces were the top three emitters in the coal power sector in China in 2008 based on the best estimates. However, the P90 value of Guizhou was high, 571% of its P50 value, because of the large variations of the mercury content of coal. The top 10 emitters contributed 56% of the total mercury emission from the power sector in China.

With the growing electricity demand, the emission for 2008 would be 20% higher than that for 2005 if no control measures were taken. Because of the phasing out of small units and installation of FGD, the mercury emission from CFPPs in China actually decreased from 108.6 tons in 2005 to 96.5 tons in 2008. The co-benefit of SO_2 emission control on mercury removals was 33.9 tons (see Figure 4), among which 12.8 tons were attributed to the FGD installation in the newly built power plants, 13.4 tons were as a result of the FGD installation in existing power plants, and 7.7 tons were because of the phasing out of small units. The synergetic mercury removal benefit from the SO_2 control measures during the 11th 5-year period was significant.

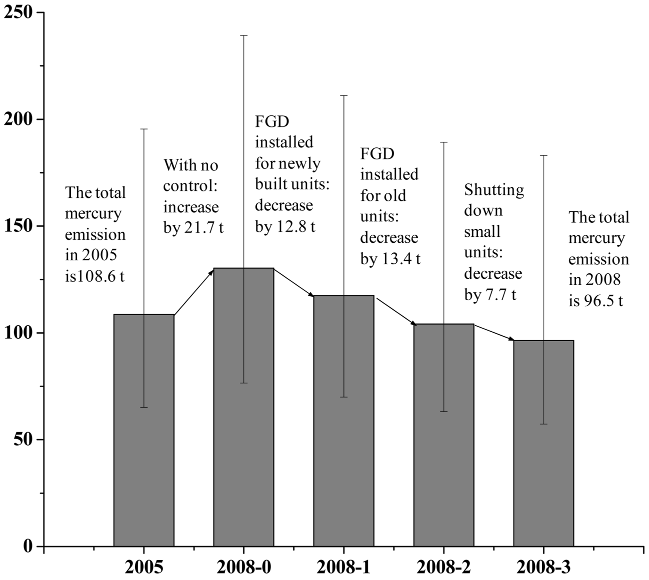

Figure 4. Co-benefit of mercury removal by SO_2 control measures, 2005–2008 (tons).

Most of the previous studies use the deterministic emission factor method to estimate mercury emissions. Using the deterministic emission factor model, Wu et al.[7] reported a total mercury emission of 100.1 tons from CFPPs in China in 2003 and our previous study[12] estimated the total emission to be 140.7 tons in 2005. The result from this study is much lower than the previous estimate mainly because of the improvement of the calculation method. It can be seen from the comparisons that the deterministic emission factor model, not considering the variation in both the mercury content of coal and the mercury removal efficiencies by APCDs, would overestimate the mercury emission from CFPPs in China. The probabilistic model demonstrated a better performance in inventory development.

Projections of the Coal Consumption in CFPPs. With the economic development in China, the electricity consumption per capita (ECPC) will keep increasing in the near future. On the basis of the statistics[13] from the International Energy Agency (IEA), the ECPCs for the U.S.A. and Japan in 2006 were 13515 and 8220 kWh, respectively, and remained consistent from 2000 to 2006. The period with high ECPC growth rate for both the U.S.A. and Japan was from the 1970s to 2000 when the ECPC values for both countries almost doubled. The ECPCs for China was 2589 kWh in 2008. The stage of development in the next decade for China will probably be similar to the period of the 1970s to 2000 for developed countries. However, from 2020 to 2030, the development might slow significantly just like the period of 2000–2010 for developed countries. Therefore, two energy scenarios were projected on the basis of the ECPC, namely, reference energy scenario and alternative energy scenario. The reference energy scenario assumes that current and past energy consumption trends and related legislation will remain the same in the future. The alternative energy scenario assumes that new energy saving policies will be implemented. In the year 2020, the ECPC is predicted to be 5600 and 4800 kWh in the reference and alternative energy scenarios, respectively (as shown in Table 3). The electricity consumptions in the two energy scenarios for 2030 will be 5800 and 5000 kWh, respectively.

Table 3. Prediction of Scenarios for Coal Power Development in China in 2020

item	2020 scenario reference	2020 scenario alternative	2030 scenario reference	2030 scenario alternative
electric power consumption per capita (kWh)	5600	4800	5800	5000
total population (billion)	1.45		1.48	
total power generation (10^{12} kWh)	8.12	6.96	8.58	7.40
coal power proportion (%)	75	60	70	55
coal power generation (10^{12} kWh)	6.09	4.18	6.01	4.07
hours of power generation (h)	5000	4500	5000	4500
installed capacity of coal power (GW)	1218	929	1202	904
standard coal consumption (gce/kWh)	315		305	
total coal consumption (10^9 tons)	2.69	1.84	2.57	1.74

Different forecasts of China's population agree fairly well with each other. In this study, we adopted the forecast in the National Population Development Strategy Research Group[14] and made some adjustments based on the recent population growth. The total population will be 1.45 billion and 1.48 billion in the years 2020 and 2030, respectively.

Coal will continue to be the dominant energy source in China before 2030, but the share of coal power in the total power generation will decrease, attributable to the rapid development of clean energy power, including natural gas power, nuclear power, hydro power, wind power, solar power, and biomass power. The development of clean energy was discussed in detail in a research report on the 2050 scenario for low carbon development.[15] Benchmark scenario and low-carbon scenario from 2000 to 2050 were developed based on the Integrated Policy Assessment Model of China (IPAC). In their projections, the share of coal power was going to be 76 and 59% in 2020 and 72 and 48% in 2030 in the two scenarios, respectively. Their projection for the 2030 low-carbon scenario was relatively optimistic, which might not be achieved because of economic and technological difficulties. Our projections were based on their study but tended to be relatively conservative. As a result, in 2020, the share of coal power was predicted to be 75 and 60% in the reference and alternative energy scenarios, respectively. In 2030, the share of coal power would drop to 70 and 55% in the reference and alternative energy scenarios, respectively. On the basis of all of these assumptions, the total coal power generation was calculated (as shown in Table 3). From Table 3, we can see that the power generation from coal-fired power plants will reach from 4.2 billion to 6.1 billion MWh in 2020 and from 4.1 billion to 6.0 billion MWh in 2030.

The energy efficiency of coal-fired power plants will increase in the future. On one hand, newly built power plants are dominated by large units (larger than or equal to 300 MW), and smaller units (less than 100−200 MW) will be phased out in the near future. On the other hand, more advanced technologies for power generation, including supercritical (SC) technology, ultra-supercritical (USC) technology, and integrated gasification combined cycle (IGCC), will be used in the future. The standard coal consumption rate of power supply was 345 gram coal equivalent (gce)/kWh in 2008. The lowest standard coal consumption rate of power supply in China by 2010 has reached 279 gce/kWh in a 1000 MW ultra-supercritical unit.[16] In our study, the national average standard coal consumption rate of power supply was predicted to be 315 and 305 gce/kWh in 2020 and 2030, respectively, which will result a coal consumption of 1.8−2.7 billion tons in 2020 and 1.7−2.6 billion tons in 2030.

Projections of the Emission Control Technology Applications. As a first attempt to gain insight into the implications of taking additional actions versus not taking additional actions to control mercury emissions for the target year of 2020 and 2030, three control scenarios, namely, baseline (BAU) scenario, and extended emission control (EEC) scenario, and accelerated control technology (ACT) scenario, were considered in this study. The BAU scenario assumes that the air pollution control will follow the laws and regulations by 2008. The EEC scenario assumes more advanced air pollution control technologies gradually spread out based on the policies implemented after 2008 and those with the potential to be implemented in future. The ACT scenario speeds up the implementation of all of the air pollution control technologies. The projected application rates of each emission control technology are shown in Table 4. On the basis of Table 4, the share of each APCD combination is shown in Figure 5.

Table 4. Application Rate of Emission Control Technologies by 2020 and 2030[a]

	2020 BAU	2020 EEA	2020 ACT	2030 BAU	2030 EEA	2030 ACT
capacity with ESP (%)	90	85	80	80	65	65
capacity with FF (%)	10	15	20	20	35	35
capacity with WFGD (%)	90	95	100	95	100	100
capacity with SCR (%)	45	85	95	60	95	95
capacity with SNCR (%)	0	0	0	0	5	5
capacity with SMC (%)	0	0	0	10	30	50
coal washing (%)	10	20	30	15	25	35

[a] ESP, electrostatic precipitator; FF, fabric filter; WFGD, wet flue gas desulfurization; SCR, selective catalytic reduction; SNCR, selective noncatalytic reduction; and SMC, specific mercury control technology.

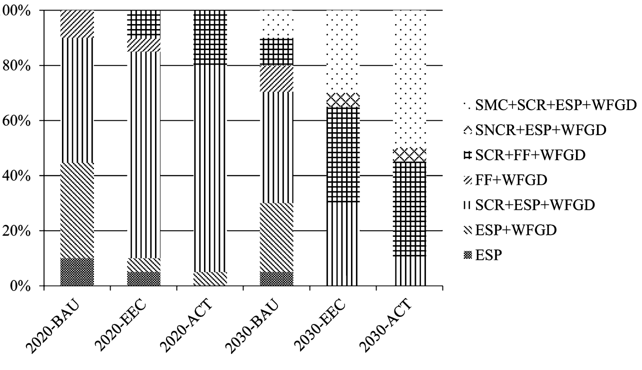

Figure 5. Application share of emission control technologies in 2020 and 2030.

For PM control, only ESP and FF were considered in the three scenarios for 2020 and 2030. Wet particulate scrubbers are no longer applied in CFPPs in China. In 2008, 96% of the power plants were equipped with ESP. However, the requirement of PM control is becoming more and more stringent, which implies that the removal efficiency for finer particulate matter (i.e., $PM_{2.5}$ or PM_1) is likely to be improved in the near future. The new emission standard of air pollutants for power plants[17] released in July 2011 set a threshold of 30 mg/m^3 for the total suspended particulate (TSP). This threshold can be attained by combining ESP with FGD for coal with lower ash content. For coal with higher ash content, FF has to be installed to attain the emission limit. However, FF is more expensive, especially for the replacement of ESP in existing plants. Considering the implementation limits, the installed capacity with FF is assumed to take up 10−20% by 2020 and 20−35% by 2030 in various scenarios (see Table 4).

For SO_2 control, 60% of the units had been equipped with FGD in 2008 and the percentage had reached 81% by the end of 2010. On the basis of the new emission standards for air pollutants from power plants, the FGD installation rate will reach 100%. Chinese legislation requires that the power plant operate FGD no less than 95% of the electricity generating hours. Considering the maintenance of FGD, we assume that 90−100% of the units will use FGD by 2020 (see Table 4). In the policy and strict scenarios for 2030, the FGD application rate is assumed to reach 100%. Wet FGD is the most cost-effective SO_2 control technology and the only technology that can fit the new SO_2 emission standard. Therefore, all of the FGDs applied in the power plants are assumed to be wet FGDs.

For NO_x control, the Chinese government aims to reduce the total anthropogenic NO_x emissions by 10% during the 12th 5-year period (2011−2015),[18] and power plants are regarded as the key sector for NO_x emission reduction. The BAU scenario is in line with the total NO_x emission control in the 12th 5-year plan. As a result, 45 and 60% of the power units will be equipped with SCR by 2020 and 2030, respectively. The new emission standard is even more aggressive than the total NO_x emission control plan, which requires most power plants to be equipped with flue gas denitration technology. The EEC and ACT scenarios are based on the new emission standard. By 2020, 85 and 95% of the units will install SCR in the two scenarios, respectively. By 2030, 95% of the units will be applied with SCR and the remaining 5% with SNCR in both the EEC and ACT scenarios.

With the rising global awareness, a legally binding instrument on mercury is undergoing negotiation, which is supposed to be agreed upon by countries in 2013. The legally binding instrument on mercury might set up a challenging target for atmospheric mercury emission reduction. Therefore, SMC technologies, such as bromide injection into the furnace (BIF) and activated carbon injection (ACI), will be used, except for the existing APCDs. It will take several years to demonstrate and evaluate the best available technologies on mercury; thus, there will be no SMC applications before 2020. However, SMC will be gradually applied in the power plants from 2020 to 2030 with an application rate of 10−50%. The U.S. EPA has recently issued a new standard for mercury control in power plants.[19] On the basis of this new standard, the average mercury removal efficiency in U.S. power plants will be 91%.[20] Our control scenario projection is based on this new standard. In the ACT scenario by 2030, the average mercury removal efficiency in Chinese power plants will reach 90%.

Coal washing is an effective way to reduce multi-pollutants. In China, the amount of coal washing has increased from 0.70 billion tons in 2005 to 1.65 billion tons in 2010, resulting in a coal washing ratio increase from 33.28% in 2005 to 50.8% in 2010. However, the application rate of coal washing in the power sector by 2008 was only 2.5%. Because of the high price and the inapplicability to existing boilers, the application rate of washed coal is hard to grow rapidly. Therefore, the application rate is assumed to be 10−30% by 2020 and 15−35% by 2030.

Future Trends and Mitigation Potential of Mercury Emissions from CFPPs in China. On the basis of the projections of both the coal consumption in CFPPs in China and application of the emission control technologies, the future trends of mercury emissions from CFPPs were calculated with the probabilistic emission factor model, as shown in Figure 6.

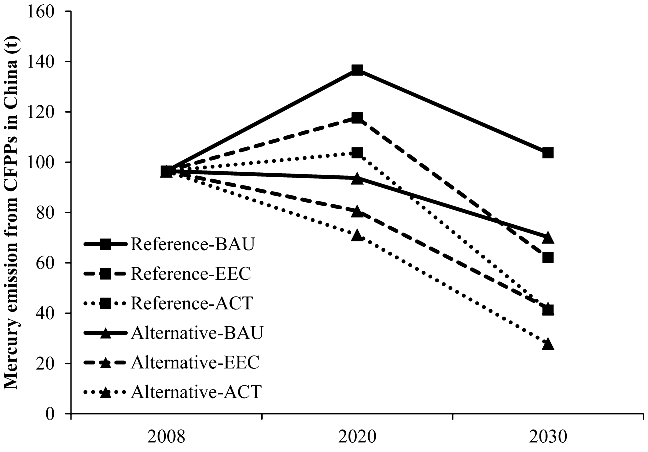

Figure 6. Scenarios for the mercury emissions from CFPPs in China in 2020 and 2030.

All of the values are the best estimates (P50). Under the reference energy scenario, the mercury emissions will increase by 42, 22, and 8% for BAU, EEC, and ACT scenarios from 2008 to 2020, respectively. However, under the alternative energy scenario, the mercury emissions for BAU, EEC, and ACT scenarios will decrease by 3, 16, and 26%, respectively, compared to that in 2008. The high growth rate of the installation of FGD and SCR will play an important role during this period. The mercury emission of 2020 is almost at the same level as that of 2008, because of the influence of both the increase of the electricity demand and the implementation of air pollution control technologies. All of the scenarios for 2030 turn out to be lower than those for 2020. Most of the cases of 2030 are even lower than that of 2008, because of the gradually accelerated air pollution control measures. Only mercury emission in the reference BAU scenario for 2030 is 8% higher than that for 2008. Under the other two reference scenarios for 2030, the mercury emissions will decrease by 36 and 57% compared to that in 2008. With the alternative energy scenario, the mercury emissions in BAU, EEC, and ACT scenarios are 27, 56, and 71% lower than that in 2008, respectively.

The mercury emissions in the reference energy scenarios are 46 and 48% higher than those in the alternative energy scenarios in 2020 and 2030, respectively. This reveals the mercury reduction potential of mercury emission as a result of energy restructuring in the next 2 decades. As the share of coal power decreases, the mercury emission will be significantly reduced. The coal consumption in the reference energy scenario for 2020 almost doubles that of the base year 2008. If the application rates of all of the APCDs remain the same as

2008, the mercury emissions from CFPPs in the reference energy scenario for 2020 will be as high as 196 tons. However, the estimate in the reference EEC scenario is actually 121 tons because of the installation of SCR. The mercury emissions from CFPPs in 2030 would be only 5% lower than that of 2020 if the application rate of control technologies is kept the same. However, under the reference EEC scenario, the estimate for 2030 is 47% lower than that for 2020. This is due to the increase of SMC and FF applications, as well as the widespread application of SCR. When the reference EEC scenario is compared to the reference ACT scenario for 2030, the mercury emission in the ACT scenario is 34% lower, which is mainly due to the further enhancement of SMC applications. Under the alternative ACT scenario for 2030, the mercury emission can be reduced by 71% from the emission level of 2008. This shows the significant mitigation potential of mercury emissions from the CFPPs in China in the future.

■ CONCLUSION

This study reviewed the mercury content of coal in China, evaluated the mercury removal efficiencies of PM, SO_2, and NO_x control devices, and developed the mercury emission inventory for coal-fired power plants in China in 2008. For pulverized coal-fired boilers, the mercury removal efficiencies (P50) of the ESP and ESP + WFGD were 26 and 63%, respectively. On the basis of the mercury content of coal, the mercury removal efficiencies of APCDs, and the amount of coal consumption, the mercury emissions from coal-fired power plants in China were calculated using a probabilistic emission factor model. The best estimate for total mercury emissions from coal-fired power plants in China was 96.5 tons (P50) in 2008, with the confidence interval from 57.3 tons (P10) to 183.0 tons (P90).

With the increase of electricity demand, the emission for 2008 would be 20% higher than that for 2005 if no control measures were taken. The co-benefit of SO_2 emission control on mercury removals was 33.9 tons, among which 12.8 tons were from the FGD installation in the newly built power plants, 13.4 tons were from the FGD installation in existing power plants, and 7.7 tons were from the phasing out of small units. The synergetic mercury removal benefiting from the SO_2 control measures in the 11th 5-year period was significant.

Two energy scenarios (reference scenario and alternative scenario) and three pollution control scenarios (BAU scenario, EEC scenario, and ACT scenario), were developed to forecast the future trend of mercury emissions. The significant mitigation of mercury emission from 2008 to 2020 is primarily due to the installation of SCR. Under the reference EEC scenario, the mercury emission in 2030 is 47% lower than that in 2020, because of the increase of SMC and FF applications and the widespread application of SCR. More mitigation can be attained by further enhancement of SMC applications. Under the alternative ACT scenario for 2030, the mercury emission can be reduced by 71% from the emission level of 2008, which shows the significant mitigation potential of mercury emissions from the CFPPs in China in the future.

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Notes

The authors declare no competing financial interest.

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