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Short communication

Anthropogenic atmospheric emissions of cadmium in China

Xiao Shao, Hongguang Cheng, Qian Li, Chunye Lin*

State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, China

HIGHLIGHTS

- Atmospheric emissions of anthropogenic Cd in China in 2010 were estimated.
- Temporal change of Cd emissions from 1990 to 2010 was instigated.
- Spatial distribution of Cd emissions in 2000, 2005 and 2010 was identified.
- The reasons for temporal and spatial changes of Cd emissions were analyzed.
- Major sources and major regions for Cd emissions were documented in China.

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ABSTRACT

In this study, we estimated atmospheric Cd emissions from anthropogenic sources in China from 1990 to 2010 on the basis of consumption or output data and emission factors. China emitted approximately 2186 t Cd to the atmosphere in 2010, with approximately 77% and 14% of the emissions arising from non-ferrous metal smelting and coal combustion, respectively. Temporal changes in the total Cd emissions were characterized by two periods of increase (1990–2000 and 2001–2010) and a short period of decrease (2000–2001) due to application of energy-saving and cleaner production technologies. Overall, atmospheric Cd emissions increased from 474 t in 1990 to 2186 t in 2010 due to rapid economic growth, whereas energy-saving and cleaner production technologies have been in use since 2000. Spatial distribution of the atmospheric Cd emissions was dominated primarily by non-ferrous metal smelting and coal combustion. Emissions are high in Hunan and Yunnan Provinces because of high production non-ferrous metal smelting and in Shandong Province because of high coal consumption and moderate non-ferrous metal production.

1. Introduction

Given that Cd is a toxic metal posing severe risks to human health, Cd contamination and Cd sources in environmental media have been investigated worldwide. Most anthropogenic Cd is first emitted to the atmosphere and then precipitated onto soils and waters. Estimating atmospheric emissions of Cd is therefore extremely important and has been performed worldwide (Nriagu, 1979; Yamagata, 1979; Pacyna, 1984; Cook and Morrow, 1995; Olendrzyński et al., 1996). These studies show that anthropogenic Cd emissions to air arise mainly from coal combustion (CC), oil combustion (OC), non-ferrous metal smelting (NFMS), iron and steel smelting (ISS), municipal solid waste incineration (MSWI), cement production (CP), and phosphorus fertilizer production (PFP).

China has the largest population in the world, and its economic growth in the past three decades has been the fastest among major nations, with an approximately 10% annual increase in gross domestic product (GDP). The consumption of fossil fuels and the output of steel and non-ferrous metals are currently the highest in the world. The atmospheric emissions of Cd from various sources have not been estimated previously, but atmospheric emissions of Cd from coal combustion have been reported in China (Tian et al., 2012a).

For the first time, this study estimates the atmospheric emissions of anthropogenic Cd for China from 1990 to 2010 and for each province in 2000, 2005, and 2010 from various sources, employing the emission factor (EF) method (Pacyna and Pacyna, 2001).

2. Methodology, data sources, and key assumptions

In this study, atmospheric Cd emissions were estimated from the following sources: CC, OC, NFMS, ISS, MSWI, CP, and PFP on the basis of consumption or output data and EF.

* Corresponding author.
E-mail address: c.lin@bnu.edu.cn (C. Lin).

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2.1. Coal combustion sources

Cd emissions from CC were calculated according to the methods developed by Tian et al. (2009, 2012a), taking into account Cd content in the coal consumed and EF related to the types of boilers and control equipment. Detailed EF values from Tian et al. (2009, 2012a) are cited and are presented in Appendix 1. The data on consumption and output of coal for each province are quoted from the China Energy Statistical Yearbook (CESY) (NBS, 1990–2010a). The coal combustion sources are divided into the four economic sectors: power plants, industry, residential, and others. Cd content in the raw coal for each province was summarized from the literature (Zhuang and Yang, 1999; Tang, 2002; Bai and Li, 2007). Cd content in the raw coal consumed in each province was calculated using the method developed by Tian et al. (2010). Cd content in the produced and consumed raw coal is shown in Appendix 2.

2.2. Non-ferrous metal smelting sources

Cd EFs from NFMS depend on ore types, smelting methods, and control measures, etc. Noting that an EF for Cd from NFMS has been measured only very little in China, we used EF values for Asian countries (Pacyna and Pacyna, 2001) to estimate Cd emissions from NFMS for the period from 1990 to 2000. In 2000, the best available control technology (BACT) was widely used in NFMS (Deng, 2010); the rate of industrial dust emissions per metric ton of non-ferrous metal output has therefore been decreasing annually (NBS, 1990–2010b; ECNMI, 1990–2010), leading to decreased Cd EF values (Tian et al., 2012b). Calibrated EF values for NFMS according to the dust emission rate were therefore used to estimate the Cd emissions from 2001 to 2010 (Tian et al., 2012b). The detailed EF values are shown in Appendix 3.

2.3. Other sources

In this study, the EFs for Asian countries from other sources, including OC, ISS, CP, PFP, and MSWI, were quoted from Pacyna and Pacyna (2001) and are shown in Appendix 3.

Coal consumption by each sector for each province was compiled from CESY (NBS, 1990–2010a). The outputs of NFMS, ISS, CP, and PFP and the amount of MSWI were compiled from China Statistical Yearbooks (NBS, 1990–2010b) and the yearbooks of the Non-ferrous Metals Industry of China (ECNMI, 1990–2010).

3. Results and discussion

3.1. Atmospheric Cd emissions in 2010

The national total atmospheric emissions of Cd in 2010 were 2186 t (Table 1). Annual Cd emissions from various sources in decreasing order are the following: NFMS (1681 t) > CC (303 t) > ISS (124 t) > OC (24 t), CP (19 t), PFP (19 t), and MSWI (16 t). Cd emissions from NFMS were approximately 77% of the total Cd emissions, while Cd emissions from CC and ISS were only approximately 14% and 6% of total Cd emissions, respectively. This result is similar to the Cd emissions to the atmosphere in Europe, where Cd emissions are associated primarily with NFMS and fuel combustion (Järup, 2003; Dore et al., 2003). In addition, annual Cd emissions from Zn smelting were 1360 t. This amount accounts for approximately 62% of total Cd emissions, due primarily to high Cd content in Zn concentrate ore in China (Ye and Liu, 2001), leading to a high emission factor in the Zn smelting process. The industrial sector consumed much less raw coal than the power plant sector in 2010; however, the industrial sector emitted much more Cd than the power plant sector because the industrial sector used a higher share of boilers with inadequate air pollution control devices compared to power plants (Appendix 1). A previous study showed that the national atmospheric Cd emissions from CC were approximately 261 t in 2008 (Tian et al., 2012a), lower by 14% than the emissions in 2010 as estimated by this study.

Table 1
Atmospheric Cd emissions in China from various anthropogenic sources in 2010.

Source category	Fuel consumption or material yield (10^6 t)	Cd emissions (t)
Coal combustion	2594.1	303
Power plants	1525.7	59
Industries	870.1	194
Residential	83.3	12
Other	115.0	38
Oil combustion	408.5	24
Non-ferrous metal smelting	13.9	1681
Pb	4.2	35
Cu	4.5	286
Zn	5.2	1360
Pig iron and steel production	1234.6	124
Municipal solid waste incineration	23.2	16
Phosphate fertilizer production	15.3	19
Cement production	1881.9	19
Total		**2186**

The five provinces with the highest Cd emissions in 2010 were Hunan (346.0 t), Yunnan (268.7 t), Shaanxi (150.0 t), Guangxi (145.2 t), and Liaoning (126.4 t). The sum of Cd emissions from these five provinces is approximately 50% of the total national Cd emissions (Table 2). The five provinces with largest Cd emissions from CC were Shandong, Hunan, Hubei, Henan, and Guangdong (Table 2), due to the high coal consumption (e.g., Shandong, Henan) and/or high Cd content in the consumed raw coal (e.g., 1.64 $\mu g\ g^{-1}$ for Hunan and 1.24 $\mu g\ g^{-1}$ for Shandong; see Appendix 2). The highest Cd emissions due to NFMS were found in Hunan (314.7 t), followed by Yunnan (252.6 t), Shaanxi (143.0 t), and Guangxi Provinces (131.8 t). Atmospheric deposition of Cd in the NFMS area has often led to environmental contamination because of Cd (e.g., Bi et al., 2006).

3.2. Historical trend of Cd in China

The total emissions of Cd increased gradually from 474 t y^{-1} in 1999 to 1518 t y^{-1} in 2000. This rate suddenly decreased to 854 t y^{-1} in 2001 and subsequently showed a gradual increase to 2186 t y^{-1} in 2010 (Fig. 1). According to Pacyna et al. (2009), however, Cd emissions were reduced 60% during the last 2 decades in Europe, and a potential exists for further reduction in Cd emissions up to 37% until the year 2010.

Annual Cd emissions from CC gradually increased (albeit slightly) from 98 t in 1991 to 114 t in 1996, then gradually decreased to 92 t in 1999. However, this amount rapidly increased to 143 t in 2000 and thereafter gradually increased to 303 t in 2010 (Fig. 2). The decrease from 1996 to 1999 was due to the application of energy-saving technology leading to the reduction in coal consumption in the industrial and residential sectors. The rapid increase from 1999 to 2010 was due primarily to the rapid growth of China's economy with increasing consumption of coal in industries.