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Current status and prediction of major atmospheric emissions from coal-fired power plants in Shandong Province, China

Tianqi Xiong, Wei Jiang*, Weidong Gao

School of Resources and Environment, University of Jinan, Jinan 250022, China

HIGHLIGHTS

- An emission inventory of coal-fired power plants in Shandong is updated to reflect 2012 data.
- SO_2, NOx, $PM_{2.5}$ and Hg are included in the targeted air pollutant emissions.
- The major contributors of coal-fired emissions in Shandong are analyzed.
- The future emissions are projected up until 2030 with three emission scenarios.
- Efficiency should be improved through technological progress and strict regulation.

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ABSTRACT

Shandong is considered to be the top provincial emitter of air pollutants in China due to its large consumption of coal in the power sector and its dense distribution of coal-fired plants. To explore the atmospheric emissions of the coal-fired power sector in Shandong, an updated emission inventory of coal-fired power plants for the year 2012 in Shandong was developed. The inventory is based on the following parameters: coal quality, unit capacity and unit starting year, plant location, boiler type and control technologies. The total SO_2, NOx, fine particulate matter ($PM_{2.5}$) and mercury (Hg) emissions are estimated at 705.93 kt, 754.30 kt, 63.99 kt and 10.19 kt, respectively. Larger units have cleaner emissions than smaller ones. The coal-fired units ($\geq$300 MW) are estimated to account for 35.87% of SO_2, 43.24% of NOx, 47.74% of $PM_{2.5}$ and 49.83% of Hg emissions, which is attributed primarily to the improved penetration of desulfurization, LNBs, denitration and dust-removing devices in larger units. The major regional contributors are southwestern cities, such as Jining, Liaocheng, Zibo and Linyi, and eastern cities, such as Yantai and Qindao. Under the high-efficiency control technology (HECT) scenario analysis, emission reductions of approximately 58.61% SO_2, 80.63% NOx, 34.20% $PM_{2.5}$ and 50.08% Hg could be achieved by 2030 compared with a 2012 baseline. This inventory demonstrates why it is important for policymakers and researchers to assess control measure effectiveness and to supply necessary input for regional policymaking and the management of the coal-fired power sector in Shandong.

1. Introduction

Shandong Province, located in East China (see Fig. 1), is one of the fastest developing provinces and heavy industrial bases in Mainland China. The coal-dominated energy structure of Shandong causes complex and severe atmospheric pollution problems, such as acid rain, photochemical smog and haze (PGSD, 2013). The coal consumption of the power sector in Shandong was up to 153.99 Mt in 2012, accounting for 8.6% of the total coal-power consumption in China. Due to its large consumption of coal in the power sector and its dense distribution of coal-fired plants, Shandong is considered to be the top provincial emitter of air pollutants in China (Chen et al., 2014; Tian et al., 2013). An ambitious control program, known as the "Air Pollution Control Plan for Shandong Province during 2013–2020", has recently been released, setting specific targets and proposing detailed technological roadmaps for the reduction of air pollutant emissions in Shandong.

Understanding the current status and future trends of air pollutant emissions from coal-fired power plants is vital for decision makers to assess the effectiveness of control measures and

* Corresponding author.
E-mail address: stu_Jiangw@ujn.edu.cn (W. Jiang).

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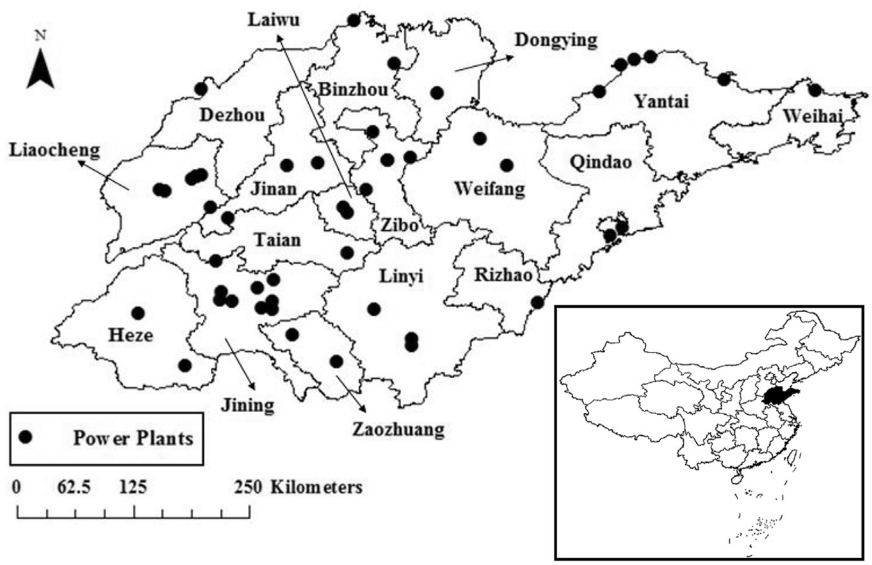

Fig. 1. Study domain and location of major coal-fired power plants in Shandong.

establish future regional policy (Ohara et al., 2007; Streets et al., 2003; Zhang et al., 2009). Previous studies have primarily examined the conventional air pollutants emitted from coal-fired power plants such as SO_2, NOx and particulate matter (PM). Zhao et al. (2008) established a unit-based inventory of SO_2, NOx and PM emissions from coal-fired power plants in China in 2005. Li et al. (2010) applied an Ozone Monitoring Instrument to observe the reduction in SO_2 emissions from Chinese power plants from 2005 to 2008. Wang et al. (2012) investigated the NOx emissions from power plants from 2005 to 2007 using bottom-up estimates and satellite observation methods. In the literature, there are few studies focusing on the contribution of the coal-fired power sector to fine particulate matter ($PM_{2.5}$) and mercury (Hg) emissions. Though PM pollution has been reduced over the last decade, $PM_{2.5}$ is still a severe environmental problem in China (Cheng et al., 2013). An emissions limit for Hg and its compounds has recently been added to the latest emission standard of air pollutants for thermal power plants (GB13223-2011, DB37/664-2013). Shandong local authorities have recently begun to enforce regulation of Hg emissions from coal-fired power plants. Previous studies have mainly concentrated on the temporal and spatial characteristics of individual pollutants based on the detailed characteristics of coal-fired units (Lu et al., 2010; Wang et al., 2010a). The literature seems to lack a systematic understanding of the overall emission status of major air pollutants and the future emissions trends within the power sector. Furthermore, in the previous projection work, the base years of the emission inventory for the coal-fired power sector have primarily been 2010, 2005 or earlier (Cai et al., 2007; Zhao et al., 2013a; Zhang et al., 2013), which does not capture the influence of the latest emission control policies. These studies for emission projections, which primarily focused on energy conservation and the application of end-of-pipe measures, lack consideration for the improvement of emission control measures.

Air pollutant emissions from coal-fired power plants have mainly been analyzed at the national level. In this research, we based our analyses on the dynamics between the provincial economy, energy structure and local government controls on the coal-fired power sector. The paper proceeds as follows. Section 2 provides a discussion of the data sources and methodology. Section 3 presents a bottom-up emission inventory of Shandong's coal-fired power sector in 2012, including SO_2, NOx, $PM_{2.5}$ and Hg emissions, and analyzes the contributions of various unit groups and spatial distribution characteristics of coal-fired emissions. The comparison with other inventories and the uncertainties are also discussed in section 3. Finally, section 4 tentatively predicts the future emission trends of the coal-fired power sector in Shandong until 2030.

2. Data and methods

2.1. Study domain and basic method

The study domain is from 114.792 °E to 122.705 °E, and 34.382 °N to 38.400 °N, including 17 cities as shown in Fig. 1. The region covers 1,57,126 km^2, only approximately 1.6% of China, but it accounted for 7.15% of the population, 9.63% of the GDP, and 8.07% of thermal power generation in 2012 (SDSB, 2013; NBS, 2013). Coal-fired plants accounted for approximately 93% of the whole power sector in Shandong by the end of 2012, a number that far surpassed the national average (66% in 2012) (CEC, 2013). This study investigates the various operational parameters of major coal-fired power plants in Shandong, including unit capacity, unit starting year, boiler type and corresponding control technologies.

The basic formulas can be expressed as follows:

$$E_{SO_2,i} = 2 \times M_i \times S \times Sr_j \times (1 - \eta_k) \quad (1)$$

$$E_{NO_x,i} = M_i \times EF_{NO_x,j,k,l,m} \times (1 - \eta_k) \quad (2)$$

$$E_{PM_{2.5},i} = M_i \times Aar \times w_j \times (1 - \eta_k) \quad (3)$$

$$E_{Hg,i} = M_i \times C \times F_j \times (1 - \eta_k) \quad (4)$$

Where i, j, k, l, m represent unit, boiler type, emission control technology, coal type, unit capacity, respectively; E is pollutants emissions from power plants; M is coal consumption; S is the sulfur content of coal; Sr is the sulfur release ratio; EF is the emission factor; η is removal efficiency; Aar is the ash content of coal as burned; C is the Hg content of coal as burned; w is the conversion