Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

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

Air pollutant emission from the underestimated households' coal consumption source in China

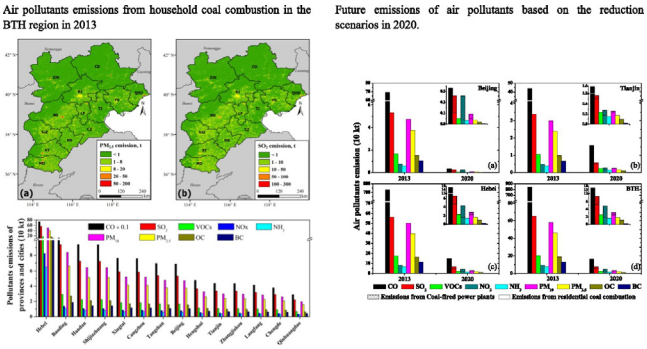
Miaomiao Cheng [a,1], Guorui Zhi [a,1], Wei Tang [a], Shijie Liu [a], Hongyan Dang [a], Zheng Guo [b], Jinhong Du [a], Xiaohui Du [a], Weiqi Zhang [a], Yujie Zhang [a], Fan Meng [a,*]

[a] State Key Laboratory of Environmental Criteria and Risk Assessment, Chinese Research Academy of Environmental Sciences, Beijing 100012, China
[b] Division of Remote Sensing Data Application, National Satellite Meteorological Centre, Beijing 100081, China

HIGHLIGHTS

- Residential coal consumption was significantly underestimated in the rural areas of BTH region.
- The residential coal combustion emissions were estimated in 2013 in the BTH region.
- The highest air pollutant emissions distribute along the Yan and Taihang Mountains.
- Air pollutant emissions will reduce around 95% during the period of 2016 to 2020.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 31 July 2016
Received in revised form 16 December 2016
Accepted 21 December 2016
Available online xxxx

Keywords:
Air pollutants
Emission inventory
Household coal combustion
Beijing-Tianjin-Hebei region
Future scenario

ABSTRACT

In order to improve the regional air quality, many control strategies have been developed by Chinese government for reducing air pollutant emission from power plants, industrial and transport sources during the past decade. However, little attention has been paid to residential combustion sources. To fill the knowledge gap, a series of surveys were carried out to investigate the residential energy use in Beijing-Tianjin-Hebei (BTH) region during the period of 2013–2014. Study shows that the actual average amount of residential coal consumption is over 0.7 t yr^{-1} per capita in 2013, which is much higher than that of 0.15 t yr^{-1} per capita reported in the 2014 China Energy Statistical Yearbook (CESY). Combining the investigated activities data with the best available emission factors (EFs), bottom-up method was used to evaluate the potential air pollutant emissions from residential coal combustion in BTH region in 2013. The results indicate that Baoding is the top contributor to the whole BTH region and accounts for approximately 15% of the regional residential emissions in 2013. The spatial pattern of air pollutants shows that high emissions locate in the southeast, along the Yanshan and Taihang Mountains, where much more rural people live and coal combustion is prevalent in winter. The future emission scenario at the end of the 13th Five Year Plan (in 2020) was also predicted based on the policy guidance for the residential coal consumptions in the BTH region. The scenario analysis indicates that air pollutant emissions will drop substantially around 90% because more strict rules will be made for reducing the residential coal consumption. With combined survey information and statistical data, the uncertainty of the emission inventory which was established in this

* Corresponding author.
E-mail address: mengfan@craes.org.cn (F. Meng).
[1] These authors contributed equally to this work.

http://dx.doi.org/10.1016/j.scitotenv.2016.12.143

study for the residential sector in the BTH region is reduced and the emission inventory is more reliable for air quality decision making.

1. Introduction

The frequent occurrence of heavy haze coinciding with the intensive household coal combustion in heating season has raised a great concern (Liu et al., 2016; Zhang et al., 2014). Although many counter-measures for reducing the emission from power plants, industrial and transport sources have been conducted (Schneck and Tutzke, 2014) (Liu et al., 2016; Zhang et al., 2012), the heavy haze days still frequently occurred and accounted for 20.7% (76 days) and 18% (66 days) of the total days in 2013 and 2014 in Beijing-Tianjin-Hebei (BTH) region, respectively (MEP, 2014; EPBH, 2015; Zhi et al., 2015). It indicates that current counter-measures are not enough and some important emission sources may even have been ignored. Meanwhile chemical composition analysis of $PM_{2.5}$ during the heating season in north China indicates that the coal combustion source from residential sector contributes substantially to the concentration of $PM_{2.5}$ (Sun et al., 2013; Wang et al., 2015a; Zhang et al., 2015b).

Along with the rapid economic growth, the coal consumption has been dramatically increased in residential sector, especially in rural area in north China (Liu et al., 2016; Zhang et al., 2009; Zhao et al., 2015; Zhi et al., 2015). Compared to the power plants and industrial sectors, coal combustion from residential sector is inefficient (Liu et al., 2016) and has not applied the dedusting-desulfurization-denitration technology (Ge et al., 2004; Wang et al., 2015b), lower emission height and higher pollution intensity (Lei et al., 2011; Zhi et al., 2015). Hence, it is essential to assess the contribution of pollutants emissions from residential coal combustion source to ambient air quality. However, the increasing household coal consumption has not been recorded in the China Energy Statistical Yearbook (hereafter referred as CESY) published by the National Bureau of Statistics of China. In addition, current emission inventories in China simply use the statistical data (Crippa et al., 2016) or surface temperature (Kurokawa et al., 2013) to evaluate the pollutants emissions in the residential sector, which may introduce large uncertainties in the emission inventory (Zhi et al., 2015). Therefore, it is important to establish an official emission inventory of residential sector based on the survey data of residential coal consumption.

A series of surveys for residential energy consumption and pollutants emissions were carried out in rural areas of BTH region during 2013–2015 (Sun et al., 2013; Zhang et al., 2014; Zhao et al., 2015; Zhi et al., 2015). The purpose of this study is to establish the latest gridded emission inventory with the highest spatial resolution and the best currently available emission factors (EFs) of air pollutants from household coal combustion in the BTH region. In addition, the future emission of household coal combustion at the end of the 13th Five Year Plan (2020) is predicted based on air pollutant control policies in the BTH region that aims to reduce the residential coal combustion emission throughout the 13th Five Year Plan from 2016 to 2020. This study provides an alternative approach to estimate the emissions of residential sector in the current emission inventory and is substantial to air quality management in the BTH region.

2. Methodology and data sources

2.1. The emission inventory method

Air pollutant emissions from household coal combustion are calculated using bottom-up method based on the activity level of investigated residential coal consumption and the best available EFs which were determined based on experiments and literatures (Chen et al., 2015; MEP, 2016). The integrated emission inventory of household coal combustion developed here includes five types of gaseous air pollutants (SO_2, NH_3, NO_x, CO and VOCs) and four types of particulate matters (BC, OC, $PM_{2.5}$ and PM_{10}). The emission was calculated based on the rural and urban population based on the 6th census data of 2010 (PCOSC and DPESNBS, 2012) at county-level. The algorithm for a bottom-up emission inventory of primary air pollutants from household coal combustion can be expressed using the following equations:

$$E_{l,i,j} = \sum_{l} \sum_{i} \sum_{j} A_{l,i,j} EF_i P_{l,j} \quad (1)$$

where l, i and j represent the counties, raw or briquette coal and urban or rural population. A represents the per capita coal consumption. P represents the population. EF is the net emission factor. For SO_2, the equation is given by:

$$EF_{SO_2} = 2 \times S_i \times (1 - SR_i) \quad (2)$$

where S_i is the sulfur content of raw or briquette coal. SR_i is the sulfur retention in ash.

Based on this framework, we estimated the air pollutant emission from household coal combustion in the BTH region for the year of 2013 and 2020.

2.2. Activity level and data sources

Two data sources are used for calculating household coal consumption in this study. Historical coal consumption of province-level was derived from the CESY of 1996–2014 (Department of Energy Statistics, 1996–2014) and the historical trend of residential coal consumption in BTH region was analyzed. However, some studies showed that the actual amount of household coal combustion was much higher than the statistical data in CESY (Zhang et al., 2014; Zhi et al., 2015), especially in heating season. Therefore, the surveys for rural household energy consumption were carried out and the amount of actual per capita coal consumption was obtained for heating season in 2013 in the rural area of Beijing and Hebei provinces. Table 1 summarizes the coal consumption of households for rural area of Hebei and Beijing based on the investigated data. Although the rural area of Tianjin was not included in the survey, considering the same living habit of residents in the BTH region, coal consumption per capita in the rural area of Tianjin is assumed to be the same as that of Beijing. The difference between statistical data and the survey data for urban household coal consumption in heating season would be small since the central heating systems almost cover the whole urban area in BTH region. Hence for the amounts of urban residential coal consumption, the statistical data was used. The 6th census data was used to calculate the actual per capita coal consumption of county-level for heating season in 2013 in the BTH region. Other three emission inventories, that were used to compare with the result of this study, were obtained from the Regional Emission inventory in Asia (REASv2.1, http://www.nies.go.jp/REAS/), the Emissions Database for Global Atmospheric Research (EDGARv4.2, http://edgar.jrc.ec.europa.eu/overview.php?v=42), and the Multi-resolution Emission Inventory for China (MEIC v.1.2, http://www.meicmodel.org)

Please cite this article as: Cheng, M., et al., Air pollutant emission from the underestimated households' coal consumption source in China, Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.12.143