Atmospheric Environment 142 (2016) 303–312

Contents lists available at ScienceDirect

Atmospheric Environment

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

Trends of multiple air pollutants emissions from residential coal combustion in Beijing and its implication on improving air quality for control measures

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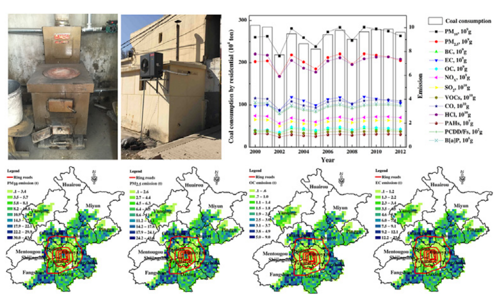
HIGHLIGHTS

- A comprehensive emission inventory of HAPs from coal stoves of Beijing is developed.
- Temporal trend of historical period 2000–2012 and the future till 2030 is assessed.
- Spatial characteristics of primary air pollutants emissions in 2012 are presented.
- Contribution to the atmospheric pollution from residential coal stoves is simulated.
- Replacing coal stove with clean energy is critical to improve air quality in winter.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 28 April 2016
Received in revised form
30 July 2016
Accepted 2 August 2016
Available online 3 August 2016

Keywords:
Residential coal combustion
Particulate matter

ABSTRACT

Residential coal combustion is considered to be an important source of air pollution in Beijing. However, knowledge regarding the emission characteristics of residential coal combustion and the related impacts on the air quality is very limited. In this study, we have developed an emission inventory for multiple hazardous air pollutants (HAPs) associated with residential coal combustion in Beijing for the period of 2000–2012. Furthermore, a widely used regional air quality model, the Community Multi-Scale Air Quality model (CMAQ), is applied to analyze the impact of residential coal combustion on the air quality in Beijing in 2012. The results show that the emissions of primary air pollutants from residential coal combustion have basically remained the same levels during the past decade, however, along with the strict emission control imposed on major industrial sources, the contribution of residential coal

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http://dx.doi.org/10.1016/j.atmosenv.2016.08.004

Emission inventory
Scenario analysis
CMAQ simulation
Temporal and spatial variation

combustion emissions to the overall emissions from anthropogenic sources have increased obviously. In particular, the contributions of residential coal combustion to the total air pollutants concentrations of PM_{10}, SO_2, NO_X, and CO represent approximately 11.6%, 27.5%, 2.8% and 7.3%, respectively, during the winter heating season. In terms of impact on the spatial variation patterns, the distributions of the pollutants concentrations are similar to the distribution of the associated primary HAPs emissions, which are highly concentrated in the rural-urban fringe zones and rural suburb areas. In addition, emissions of primary pollutants from residential coal combustion are forecasted by using a scenario analysis. Generally, comprehensive measures must be taken to control residential coal combustion in Beijing. The best way to reduce the associated emissions from residential coal combustion is to use economic incentive means to promote the conversion to clean energy sources for residential heating and cooking. In areas with reliable energy supplies, the coal used for residential heating can be replaced with gas-burning wall-heaters, ground-source heat pumps, solar energy and electricity. In areas with inadequate clean energy sources, low-sulfur coal should be used instead of the traditional raw coal with high sulfur and ash content, thereby slightly reducing the emissions of PM, SO_2, CO and other toxic pollutants.

1. Introduction

As the capital of China, Beijing is a typical rapidly growing megacity throughout the world. Heavy local and regional primary air pollutants emissions from various anthropogenic sources, as well as the unfavorable geographical conditions for good diffusion, result in severe air pollution and frequently episodes with high $PM_{2.5}$ concentration and low visibility in Beijing, which is regarded as one of the most polluted cities in the world (Huang et al., 2016; Lv et al., 2016; Tian et al., 2014; WHO, 2005). According to the Beijing Environmental Statements, the annual average mass concentration of $PM_{2.5}$ was 85.9 $\mu g\ m^{-3}$ in 2014, nearly 2.5 times of the National Ambient Air Quality Standard (NAAQS) (35 $\mu g\ m^{-3}$ as an annual average), indicating that Beijing is facing very severe fine particle pollution (Sun et al., 2015; Zhang et al., 2015).

Residential coal combustion is recognized as a significant source of atmospheric pollution that affects the atmospheric chemistry and climate change. The released hazardous air pollutants (HAPs), including PM, BC, OC, EC, SO_2, NO_X, CO, CO_2, and PCDD/Fs, affect both local and regional air quality and pose a serious threat to human health and the environment (Ge et al., 2004; Shen et al., 2010; Shi et al., 2015; Wornat et al., 2001; Zhi et al., 2008). However, the knowledge on the magnitude of various air pollutants emissions, their temp-spatial variations, and their effects on urban air quality is still quite limited. Therefore, accurate emission estimates for residential coal combustion are of great importance for predicting atmospheric composition and air quality (Edwards et al., 2004; Scott and Scarrott, 2011).

Several studies on residential coal combustion have been conducted using simple quantification descriptions and generalizations (Chang et al., 2015; Li et al., 2016; Li and Xie, 2014; Qiu et al., 2014). However, the emission inventories developed by previous studies considered a limited number of primary air pollutants and were mostly based on simply calculated and summarized statistical data that were not distinguished by combustion area or type of coal, such as non-smoke coal (bulk or honeycomb briquettes) and smoke coal (raw or honeycomb coal). With respect to the spatial distribution of residential coal combustion, previous studies generally adopted GDP and population as surrogate indexes to apportion the overall emission inventory into grids with varied resolution, and the associated uncertainty of this distribution was quite high. Consequently, the impact and contribution of residential coal combustion on air quality remains poor understandings and with high uncertainties.

The purpose of this study is to systematically analyze and summarize the residential energy structure of Beijing by adopting the best available emission factors (EFs) to compile the emission inventory of 13 types of HAPs from Beijing residential coal combustion for the period of 2000–2012, and investigate the effects on air quality by implementing control measures for residential coal combustion. Furthermore, in combination with scenario analysis, we predict the future emissions from residential coal combustion in Beijing, and propose guidelines for mitigating the pollution associated with residential coal combustion and analyze their implications for control measures or policies.

2. Materials and methods

2.1. Study domain

Beijing, the capital city of the P. R. China, is geographically located at 39°56′N and 116°20′E on the northwestern edge of the North China Plain and is surrounded by the Taihang and Yanshan Mountains to the west, north, and northeast (Gao et al., 2015). Beijing city covers a total area of 16,410.54 km^2 and is divided into 16 districts, with approximately 211,480,000 residents (BMBS, 2014). The demand for energy in the industrial sectors and residential communities for heating and cooking is very strong.

2.2. Emission inventory calculation

The magnitude and geographical distribution of multiple air pollutants emissions from residential coal combustion are closely related to the geographical position of the coal-burning area (such as urban or rural), coal stove type, type of burned coal, and the number of households, which can be generally calculated by using the household area, coal consumption by unit area and specific EF for each species, as shown in the following equation (1):

$$E = \sum_{i,j}^{n} HA_{i,n} \times CC_i \times EF_{i,j} \quad (1)$$

where *HA* is the household area (m^2), *CC* is the coal consumption by per unit area, *EF* is the emission factor for each species from residential coal-burning areas, and i, j, n are parameters that represent the geographical position of the coal-burning area (such as urban or rural), type of burned coal, and number of households, respectively.

2.2.1. Activity data

Activity data including the energy consumption, the population of urban and rural was obtained from Beijing Statistic Yearbook.