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Spatiotemporal variation of domestic biomass burning emissions in rural China based on a new estimation of fuel consumption

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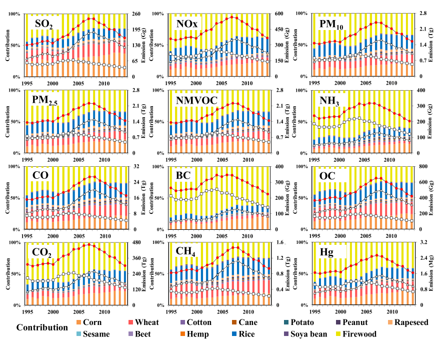
HIGHLIGHTS

- Groups of models are developed to complement the missing P_{straw} and Fc.
- DBB emissions for 12 kinds of pollutants in China during 1995–2014 are estimated.
- DBB have higher emissions than other rural emission sources for some pollutants.
- National DBB emissions increase initially and then decreased since 2007–2008.
- Spatial variation occur in northeast, north, central–south and coastal China.

GRAPHICAL ABSTRACT



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ABSTRACT

Domestic biomass burning (DBB) influences both indoor and outdoor air quality due to the multiple pollutants released during incomplete and inefficient combustion. The emissions are not well quantified because of insufficient information, which were the key parameters related to fuel consumption estimation, such as province- and year-specific percentage of domestic straw burning (P_{straw}) and firewood consumption (Fc). In this study, we established the quantitative relationship between rural-related socioeconomic parameters (e.g., rural per-capita income and rural Engel's coefficient) and P_{straw}/Fc. DBB emissions, including 12 crop straw types and firewood for 12 kinds of pollutants in China during the period 1995–2014, were estimated based on fuel-specific emission factors and detailed fuel consumption data. The results revealed that the national emissions generally increased initially and then decreased with the turning point around 2007–2008. Firewood burning was the major source of the NH_3 and BC emissions; straw burning contributed more to SO_2, NMVOC, CO, OC, and CH_4 emissions; while the major contributor changed from firewood to domestic straw burning for NOx, PM_{10}, $PM_{2.5}$, CO_2, and Hg emissions. The emission trends varied among the 31 provinces. The major agricultural regions of north-eastern, central, and south-western China were always characterized by high emissions. The spatial variation mainly occurred in the northeast and north China (increase), and central–south and coastal regions of China (decrease).

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1. Introduction

Biomass burning is an important energy source in rural household of China. Biomass burning releases multiple pollutants including gaseous and particulate matter that have a harmful effect on air quality (Zong et al., 2016; Cheng et al., 2017), climate (Sun et al., 2016; Yadav et al., 2017; Pokhrel et al., 2017) and human health (Sarigiannis et al., 2015; Alves et al., 2015). According to our previous study (Zhou et al., 2017), domestic biomass burning (mainly including crop straw residues and firewood) has a large contribution (55–88%) to the total biomass burning emissions in China for various pollutants. Domestic emissions of some pollutants (e.g., $PM_{2.5}$, BC, OC) from biomass burning are even greater than those from coal burning in China (Ma et al., 2017), which has raised increasing amount of concern and is considered an important pollution source in rural areas (Cheng et al., 2017). Compared with in-field burning, domestic biomass burning not only has a negative impact on air quality (Li et al., 2017a; Chan, 2017) and climate (Pandey and Tyagi, 2012; Healy et al., 2015), but also has a more direct influence on the health of indoor residents (Sigsgaard et al., 2015; Das et al., 2017) due to the incomplete and inefficient fuel combustion in traditional stoves (Chen et al., 2017).

In recent years, most research on biomass burning emissions has focused on in-field burning, including the multi-year trend analysis on specific single (Shon, 2015; Li et al., 2016a; Zhang et al., 2016) or multiple pollutants (Song et al., 2007; Shi and Yamaguchi, 2014; Li et al., 2016b). There are several emission estimations involving domestic biomass burning either based on emission factors (EFs) developed for foreign nations (Cao et al., 2005; Tian et al., 2011) or without distinguishing the detailed crop straw (e.g., rice, corn, and wheat, Yan et al., 2006). There are several reports on the local EFs (Wang et al., 2009; Li et al., 2009; Li et al., 2016a), which have been used in recent studies (Zheng et al., 2012) on emission estimation including our previous study (Zhou et al., 2017) for biomass burning. However, to our knowledge, the study about the detailed estimation of domestic biomass burning emissions and their spatiotemporal variation for China were limited (Zhang et al., 2008; Zhang et al., 2011) especially in recent years, it can be attributed to the limited data for several key parameters, such as percentage of domestic straw burning (P_{straw}, the domestic straw burning amount to total straw yield ratio) and firewood consumption (Fc). Such parameters have influence on the accuracy of fuel consumption calculation, which are responsible for the uncertainty in emission estimates (Hong et al., 2017). P_{straw} data are not currently publicly available. There are several emissions estimations involving domestic biomass burning for particular years (Huang et al., 2011a) or multiple years (Chen et al., 2013) based on the same P_{straw} data for different provinces and years, which were obtained from extensive data collection (Gao et al., 2002). However, this introduces uncertainties in the emission estimation due to large variations of P_{straw} for different regions and years in areas with various economic development status (Gao et al., 2002; Gao et al., 2009; Cai et al., 2011). The National Bureau of Statistics of China (NBSC) provides official information on energy consumption, including detailed firewood consumption data for various regions. However, the firewood consumption data have not been reported in the NBSC after 2007 and this limits emission estimations. In summary, the available EFs need to be updated for different fuel types and the insufficient data should be supplemented in order to develop the detailed domestic biomass burning emission inventory and upgrade its accuracy.

In this study, in order to complement the missing key parameters for estimating domestic biomass fuel consumption, several rural-related socioeconomic parameters affecting P_{straw} and Fc were identified and were used to develop quantitative relationship between P_{straw} or Fc and these parameters. The long-term (1995–2014) fuel-specific (12 crop straw types and firewood) domestic biomass burning emissions including air pollutants and greenhouse gases (SO_2, NOx, PM_{10}, $PM_{2.5}$, NMVOC, NH_3, CO, BC, OC, CO_2, CH_4, and Hg) for the mainland China were estimated, based on the updated fuel-specific EFs and detailed activity data including missing P_{straw} and Fc complemented through the regression models. The spatiotemporal variation of the emission in this paper could provide a critical basis for further research into environmental pollution in rural areas and the impact on climate and human health, which has raised increasing amount of concern.

The remainder of this paper is organized as follows. Section 2 describes the method involving emission estimation, regression of P_{straw} and Fc, and emission uncertainty estimation. Section 3 presents the regression models of P_{straw}, Fc and its validation. The inter-annual variation of emissions at national and provincial level, comparison with other major rural emission sources, spatial variation analysis and discussion of the reliability in the emission estimation are given in Section 4. Section 5 summarizes the conclusions.

2. Materials and methods

2.1. Estimation of emissions

Domestic biomass burning emissions were estimated based on the mass of fuel consumption and the corresponding emission factor (EF). The algorithm for estimation of domestic straw (straw burned as indoors fuel) and firewood burning emissions are expressed as Eqs. (1) and (2), respectively.

$$E\_straw_{m.k} = \Sigma\left(Y_{i,j,m} \times N_{i,j} \times P_{straw\ \ i,m} \times D_j \times EF_{j,k} \times CE_j\right)/1000 \quad (1)$$

$$E\_firewood_{m,k} = \Sigma\left(Fc_{i,m} \times EF_k \times CE_j\right)/1000 \quad (2)$$

where E_straw and E_firewood are the annual emissions of domestic straw and firewood burning, respectively (Gg); the subscripts i, j, m, and k represent province, biomass fuel type, year (1995–2014) and pollutant, respectively; Y is the amount of crop yield (Gg) which is derived from NBSC (NBSC, 1996–2015); N is the straw-to-production proportion (%); P_{straw} is the percentage of domestic straw burning (%); D is the dry matter fraction (%); CE is the combustion efficiency (%); Fc is the firewood consumption (Gg); and EF is the emission factor (EF) (g/kg).

Unlike previous estimation, considering the different climate conditions, we attempted to select N values varied between regions based on the literature review. The EF dataset of 12 different crop straws and firewood was updated from the collection of the localized measurement in the literature. The data sources of N, D, CE, and EFs are described in Tables S1–S3. P_{straw} is the key parameter related to estimation of the domestic straw burning emissions. It is not currently publicly available and is usually obtained from field investigation. The Fc has a direct relationship with firewood burning emission estimation but there are no publicly available sources of detailed Fc data after 2007. In view of this unavailability of key information, we attempted to complement the missing P_{straw} and Fc data in different provinces and years using mathematical statistical methods based on survey of the related references and statistics.

2.2. Province- and year-specific P_{straw}

In order to supplement the missing P_{straw} dataset in different provinces and years, first, as many as possible P_{straw} data were collected through the related literature collection as shown in Table S4 and were used as a dependent variable. Then, taking data availability into consideration, several natural and socio-economic parameters which may impact P_{straw} were examined for their significant influence (significant correlations, $P < 0.05$ was used as criteria for including variables, Hutton, 2014) on P_{straw} through correlation analysis in each province and used as the potential independent variable. These parameters included annual mean temperature (AMT), straw yield (S), total population (TP), rural population (RP), total households (TH), rural