BLACK CARBON EMISSION INVENTORY IN CHINA

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Introduction

Black carbon (BC) is an important component of the combustion byproducts commonly referred to as soot [1]. It is mainly produced from fossil fuel (coal and oil) combustion and biomass burning [2]. BC is known to cause major environmental problems. It contributes to global warming, induces effects such as glacier retreat and sea ice melting[2], and causes serious health problems[3] by carrying carcinogenic compounds. It is the second largest contributor to global warming only after CO_2 [2],[4-6]. Small particles such as soot BC, which varies in size from ultrafine (less than 0.1 µm) to fine (less than 2.5 µm), can be more detrimental to health than larger ones. Particulate air pollutants contains ultra-fine soot globules that migrate deep into the lungs and carry very toxic, often carcinogenic compounds such as polycyclic aromatic hydrocarbons [3]. After inhalation, particles larger than 4 µm and below 0.002 µm have a higher tendency to deposit in the mouth and throat, while particles between 0.002 ± 0.2 µm tend to deposit in the alveolar region of the lungs [18].

As is known, BC is formed both in controlled combustion(CC) and open burning(OB). In this paper, we discuss the estimations of BC emission factors and emission inventory for CC and OB sources. The total emissions of BC from CC and OB in China are also estimated and compared with previous BC emission inventories and we find the inventories tend to be overestimated. As China becomes the largest contributor to global BC emissions, studies for characterizing BC emissions from OB and CC sources are absent in China.

Materials and methods

Black carbon emissions are produced from a complex process, which is influenced by a variety of factors, such as fuel type, combustion method, combustor design, operators, and even weathers. Thus, the estimation of BC emissions is difficult, and the estimation is far from accurate with the current state of the knowledge.

Bond et al. [7] estimated the technology-based global inventory of black carbon emissions from combustion. Their approach to estimating emissions is based on combining fuel consumption data and application of combustion technologies and emission controls. The total emissions for each country and species were given by the sum over all fuel/sector combinations. Emissions for a particular fuel/sector combination, in turn, were given by the contributions of all technologies within that sector. Total emissions for each species and country are:

$$Em_{j,k} = \sum_{l}\sum_{m} FC_{k,l,m}\left[\sum_{n} EF_{j,k,l,m,n} X_{k,l,m,n}\right]$$

Where

j, k, l, m, n species, country, sector, fuel type, fuel/technology combination;

Em emissions;

FC fuel consumption, kg/yr;

EF emission factor specific to fuel/technology, including the effects of control devices;

X fraction of fuel for this sector consumed by a specific technology, where ΣX = 1 for each fuel and sector.

Most reports on particulate matter (PM) emissions were based on total mass, because the important differences in behavior of PM with different chemical compositions have received attention only recently. When measured emission factors of black and organic carbons are not available, we have estimated them on the basis of mass emission measurements combined with data on the submicron and carbonaceous fractions of the emissions as described in earlier papers. The net BC emission factor for submicron particles is given by:

$$EF_{BC} = EF_{PM} F_{1.0} F_{BC} F_{cont}$$

where EF_{PM} is the bulk particulate emission facto r in g/kg; $F_{1.0}$ is the fraction of the emissions with diameters smaller than one micrometer, intended to separate BC from larger particles such as ash and char; F_{BC} is the fraction of the fine particulate matter that is black carbon; and F_{cont} is the fraction of fine PM that penetrates the control device. For combustion without emission controls, $F_{cont} = 1.0$.

In this paper, we use similar methods that used by Bond et al. to estimate black carbon emissions in China. The total emissions of BC are estimated by the equation shown below:

$$Q_{BC} = \sum Q_{i,j} EF_{i,j}$$

Where Q_{BC} is the total emissions of BC; Q_{ij} is the amount of fuel type i consumed by a specific technology j, while $EF_{i,j}$ is the emission factor of BC when fuel i is consumed by technology j. The two estimates used the similar method; the emission factors employed were more or less identical. Method used by Liu is simpler, so the calculation is much easier.

In this inventory, emission factors are adopted from the analysis of Cao *et al.* [8] and Liu *et al.*[9], they combined the data obtained by international experts and data presented in papers published in China. Emission factors that have not been obtained from previous studies in China, the values obtained from international researches will be used. Emission factors used in this section are listed in Table 1. The data are more representative of China's situation. The fuel consumption data are taken from the statistical results published by the Chinese government [10]. As the BC emission factors are related to the combustion conditions, especially combustion using outdated technology, their emission factors are closely related to combustion technology (e.g. combustion efficiency and particulate emission control). In China there are few direct measurements of BC emission factors available, so we obtain the emission factors by two approaches: 1) The experimental results of BC emissions measured in China, if their direct measurement results have been published; 2) If data from direct measurements of BC emissions are not available, emission factors obtained from two well known published studies [7],[11] are adopted.

Coal use is mainly divided into the following four sections: power plant, coke making, heating and other industries, and residential use. A study by Yuan and Min [9] listed most of the estimated emission factors for coal use, but the emission factor for coke use is not appropriate for China's case. In China, coke is mainly used in blast furnace and also in other industrial sectors. In our estimated inventory, coke use emission factor is adopted from another study [7], and is listed in Table 1. Emission factors for oil use are also adopted from the same literature [9] that listed most of the emission factors for coal use. Biomass burning is a major contributor of BC emissions, its emission factor is adopted from a published study focusing on BC emissions from China [12].

Table 1 Emission factors of BC emission in China (adapted from Liu *et al.*[9], Streets *et al.*[11] and Cao *et al.* [8])

Emission factor (g/kg)	Thermal power	Coking	Heating	Primary industry	Industry	Construction	transportation	Tertiary industry	Urban-residential consumption	Rural-residential consumption
Raw coal	0.0029	0.6	0.224	0.224	0.224	0.224	0.3	0.224	0.32	0.497
Cleaned coal	0.0029	0.6	0.224		0.224	0.224	0.3			
Other washed coal	0.0029	0.6	0.224	0.224	0.224	0.224	0.3	0.224	0.32	0.497
Other coking products					0.003					
Crude oil	0.36		036		0.36					
Gasoline	0.08		0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Kerosene				0.11	0.11	0.11	0.11	0.11	0.11	0.11
Diesel oil	0.25			1.1	0.25	1.1	1.1	1.1	1.1	1.1
Fuel oil	0.36		0.36	0.36	0.36	0.36	0.36	0.36		
LPG			0.067	0.067	0.067	0.067	0.067	0.067	0.067	0.067
Other petroleum products	0.36		0.36		0.36	0.36				
Refinery gas	0.0001		0.0001		0.0001					
Natural gas	0.0001		0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Coke oven gas	0.0001		0.00 01		0.00 01			0.0001	0.0001	
Other gas	0.0001	0.0 001	0.00 01		0.00 01		0.0001	0.0001	0.0001	0.0001
Stalks										0.66
Firewood										0.7
Biogas										0.0001

Results and discussion

The total BC emissions from China in 2007 are estimated to be 963.4 Gg, less than those obtained by Streets *et al.* [11] in 1995 which are 1,342 Gg, and they are also less than the 1,499.2 Gg estimated by Cao *et al.*[12] in 2000. Streets *et al.* [11] estimate that BC emission in China is 1,224.4Gg in 2020. The results of our estimation (963.4 Gg) are much lower than those estimated previously. Streets *et al.* [13] suggested that in China and India, inconsistencies are still found between modeled aerosol concentrations and optical properties that use current inventories and field measurements of the same quantities. The emission factor or emission source is not properly estimated, and will cause high uncertainty in the former estimation. Judging from our most recent estimate, the BC emission inventories estimated previously are more likely to be overestimated. As Figure 1 illustrates, rural-residential combustion is the largest emission source, it contributes 39.6 % to the total emissions. Reducing rural emissions is potentially one of the most effective BC emissions control strategies. Most of the rural-residential combustion emissions are due to biomass burning. Heating (3.7%) and thermal power generation (0.4%) only account for a small portion of the total emissions, because of the applications of more advanced combustion technologies and more pollutant emission control facilities. Industry including coking accounts for nearly half of the total emissions; the combustion technologies used in small factories are obsolete, and they needto be replaced by more advance technologies in order to reduce BC emissions.

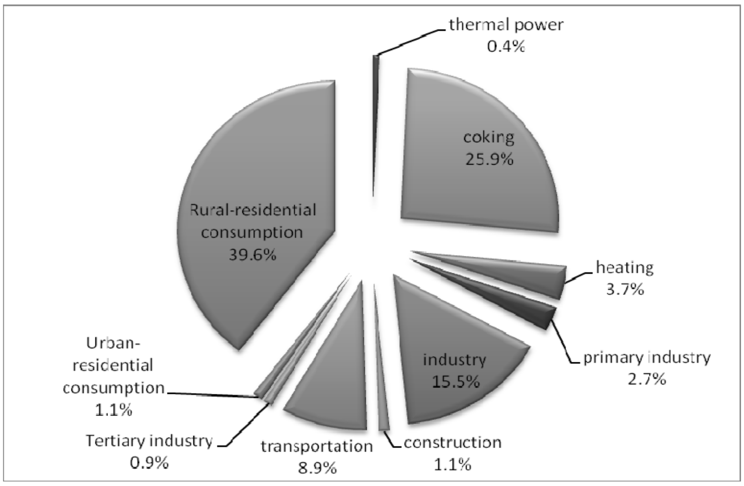

Figure 1 BC emission by sector

As shown in Figure 2, coal combustion is the biggest BC emissions contribution, because in the present energy structure of China, coal accounts for the biggest contribution (46%). Biomass burning is the second largest contribution (37%), to reduce emissions of this significant source, open burning activities should be reduced. Oil and gas combustion only accounts for a small portion of the total energy consumption (17%).

The estimation of China's BC emissions needs to be improved. The emission factors used in the previous works were mostly obtained by international experts based on their studies conducted outside China. Emission factors for different industrial sector sources in China need to be investigated. More detailed BC emissions by different regions and in different seasons are also very useful for obtaining a better estimation of BC emissions in China.

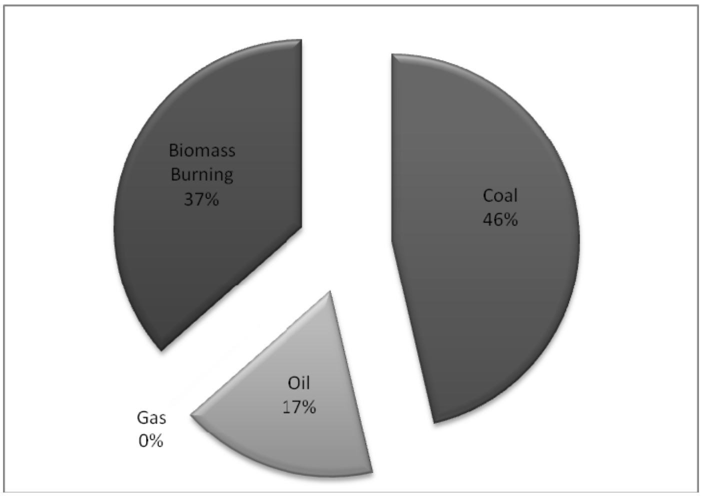

Figure 2 BC emission by fuel type

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