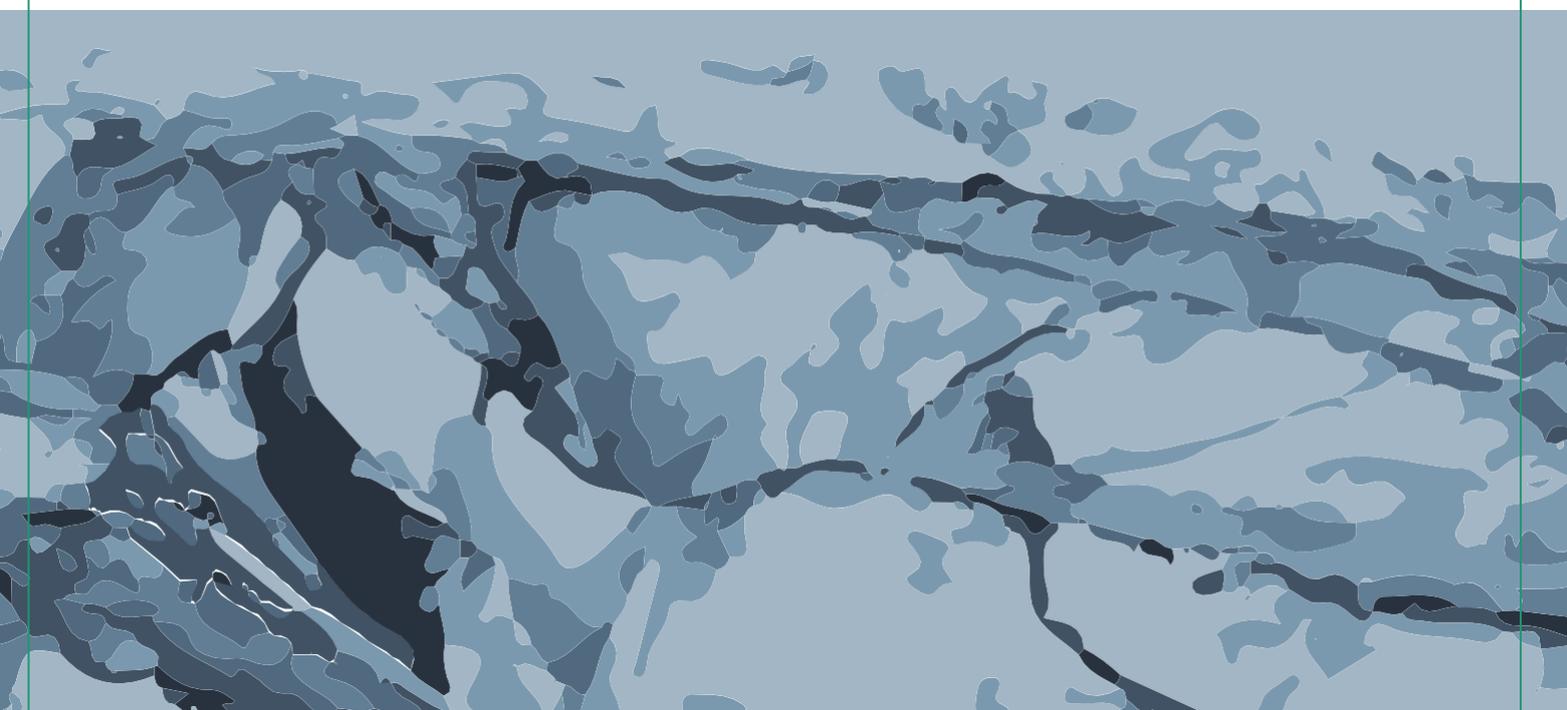ChiNorBC

REVIEW OF BC/OC EMISSIONS INVENTORIES

Chinese-Norwegian Project on Emission, Impact, and Control Policy for Black Carbon and its Co-benefits in Northern China

CAEP

°CICERO

CRAES

Norwegian Environment Agency

NIPH

Review of BC/OC emission inventories

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About this report

This report is part of a series of outputs produced under the Chinese-Norwegian Project on Emission, Impact, and Control Policy for Black Carbon and its Co-benefits in Northern China (ChiNorBC). The project is jointly implemented by the Chinese Research Academy of Environmental Sciences (CRAES) and the Norwegian Environment Agency (NEA), in partnership with the Chinese Academy of Environmental Planning (CAEP), the Norwegian Institute of Public Health (NIPH) and CICERO (Center for International Climate Research), with financial support from the Norwegian Ministry of Foreign Affairs.

There is no internationally agreed definition of black carbon (BC) and organic carbon (OC). BC is the light-absorbing component of fine particles and is produced by incomplete combustion of fossil fuel, biofuel, and biomass. BC is always co-emitted with OC. Emissions of BC and OC affect the climate and have adverse health effects. Reductions of BC and OC will have co-benefits for climate, air quality, and health.

ChiNorBC will develop improved emission inventories for BC- and OC-emissions in China using the most recent, best available national statistics and measurements obtained in the project. Based on this, new estimates of effects of BC/OC on climate, air quality, and health will be provided. The project will further raise scientific, governmental, and public awareness and enhance the understanding of the positive impacts of BC/OC emissions reductions. Ultimately the ChiNorBC will provide Chinese policy makers with policy solutions for reducing BC/OC emissions in China which maximize the co-benefits.

The project has six outputs. This report is a result of Output 2, *Review of BC/OC emissions inventories*. For a more comprehensive description of the project, and to get access to all the project reports, please visit the project web site http://chinorbc.net/.

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Findings and opinions expressed in this paper are not necessarily shared by those contributing to the work, and any errors and omissions are the responsibility of the authors and partner institutions.

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The cover design is non-figurative and created by Eilif Ursin Reed, Communication Advisor, Cicero, and is inspired by melting glaciers and polluted snow.

About the partner institutions in the ChiNorBC-project

Chinese Research Academy of Environmental Sciences

The Chinese Research Academy of Environmental Sciences (CRAES), founded in 1978, is a leading institute in environment-related studies in China, including studies on short-lived climate pollutants and their impacts. There are more than 1000 employees whose backgrounds cover all important areas of environmental sciences, including atmospheric science. One of the main responsibilities of CRAES is to provide technical and scientific support for decision making of the Ministry of Ecology and Environment (MEE).

Norwegian Environment Agency

The Norwegian Environment Agency (NEA) is an advisory and executive body under the Ministry of Climate and Environment (MCE), fully funded by the Norwegian Government. It has about 700 employees in Trondheim and Oslo as well as in local offices throughout the country. NEA was established 1st July 2013 after a merger of the former Directorate for Nature Management (est. 1965) and the Climate and Pollution Directorate (est. 1974). The Norwegian Nature Inspectorate (SNO) is organized as a department within NEA. The primary tasks of NEA are to reduce greenhouse gas emissions, manage Norwegian nature, and prevent pollution.

Chinese Academy of Environmental Planning

The Chinese Academy of Environmental Planning (CAEP) is a public institution with independent legal status founded in 2001. Its missions are: Carrying out strategic research on national ecological civilization, green development and beautifying China, and undertaking technical support for the preparation and implementation of national medium- and long-term ecological environment planning, key river basins and regions planning, and environmental planning in key fields, so as to meet the major needs of the country.

The Norwegian Institute of Public Health

The Norwegian Institute of Public Health (NIPH) is a Norwegian government agency and research institute and is Norway's national public health institute. NIPH acts as a national competence institution placed directly under the Ministry of Health and Care Services, with approximately 1400 employees in Oslo and Bergen. It is responsible for knowledge production and systematic reviews for the health sector and provides knowledge about the health status in the population, influencing factors, and how it can be improved.

Center for International Climate Research

Center for International Climate Research-Oslo, Norway (CICERO) is a private foundation that for over 30 years has delivered interdisciplinary research of high scientific quality on climate science, economics, and policy. CICERO's mission is to conduct research and provide reports, information, and expert advice about issues related to global climate change and international climate policy with the aim of acquiring knowledge that can help mitigate the climate problem and enhance international climate cooperation. CICERO has approximately 80 employees situated in the Oslo Science Park.

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Acronyms and Abbreviations

CAEP	Chinese Academy for Environmental Planning, China
CICERO	Center for International Climate and Environmental Research-Oslo, Norway
CRAES	Chinese Research Academy of Environmental Sciences
MEE	Ministry of Ecology and Environment of China
NIPH	Norwegian Institute on Public Health, Norway
NEA	Norwegian Environment Agency
UNEP	United Nations Environmental Programme
WMO	World Meteorological Organization
IPCC	The Intergovernmental Panel on Climate Change
EEA	European Environment Agency
EMEP	Cooperative Program for Monitoring and Evaluation of Long Range Transmission of Air Pollution in Europe
IMO	International Maritime Organization

Definition of Concepts

BC	Black carbon
CO	Carbon monoxide
GWP	Global warming potential
NOx	Nitrogen oxides
OC	Organic carbon
$PM_{2.5}$	Fine particles with a diameter of 2.5 micrometers or less
PM_{10}	Inhalable particles with a diameter of 10 micrometers or less
SLCFs	Short-lived climate forcers
SO_2	Sulfur dioxides
COPERT model	A mathematical model, which is implemented using Python language in Apache Spark in order to reduce the time taken for each query. Apache Spark reduces the time taken per job significantly.
SLCFs	Short-lived Climate Forcers
National IV	National IV emission standard
China's "2+26" cities	Beijing, Tianjin, Hebei and surrounding "2 + 26" Cities

Summary

This review is a delivery from OUTPUT 2 In the ChiNorBC project, and is a basis for deciding the BC/OC emission factors and activity data? to be applied in the novel emission inventory. The focus is on refining emission data for households and transportation as these are large sectors with high uncertainties.

As regards the BC/OC emission factors in our new inventories, the ChiNorBC project plans to use an average of values from three origins: direct measurements performed within the ChiNorBC project, government recommendations and literature reports (provided each origin has its own data). This implies that our review results for BC/OC emission factors are only one of the three inputs, namely the literature review. In the project's Final report, we will show how we derived the BC/OC emission factors for emission calculations in our new inventories.

In this review, the identified BC emission factors (average $\pm$ standard deviation, same hereafter) for household raw coal are (2.15$\pm$1.58) g/kg and for household briquette coal are (0.17$\pm$0.21) g/kg; the emission factors of OC for household raw coal are (4.32$\pm$2.95) g/kg and for household briquette coal are (3.11$\pm$1.95) g/kg.

For mobile sources, the BC or OC emission factors are derived from the BC/PM ratio or OC/PM ratio by multiplying by the PM emission factors. The BC/PM ratios or OC/PM ratios found in the literature are presented in Appendix Table 12. The PM factors needed are derived from the official release "The China Road Motor Vehicle Air Pollutant Emission Inventory Development Technical Guidelines" and "The Technical Guidelines for the Development of Inventories of Atmospheric Pollutants from Non-road Mobile Sources," as shown in Appendix Table 13 and Appendix Table 14.

The BC and OC factors of inland ships reported from the literature are shown in Appendix Table 17 BC factors of inland ships from the literature. A BC factor of 0.36g/kg fuel frequently occurred and was picked as the inland ship BC factor.

There are two more points about the emission factors derived from the literature. First, the distribution of literature data is rarely a normal shape but is usually a non-normal shape (refer to Figure 4 and Figure 5); the expression format of average $\pm$ standard deviation is for reference only. Second, through review of the literature, we have been able to derive not only the emission factors of BC and OC for household coal, but also the emission factors for other pollutants such as $PM_{2.5}$, $PM_{10,}$ SO2, NOX, CO, VOC and

NH$_3$. Thus, we could also calculate the emissions of pollutants, other than BC and OC alone, for our emission inventories. This will be further elaborated in the Final report.

In the literature, the total BC emissions in China are reported to range from 1.05 million tonnes (in 2000) to 1.8 million tonnes (in 2006). The contribution of mobile sources/transportation sources to the total BC emission varies from 1.8% to 32.3%, illustrating the large variation between different estimates. The contribution from the residential sector to China's total BC emissions is large and about 50% but displaying much less variation than mobile/transportation sources. This suggests the special importance of residential sector and mobile sources in BC emissions and control.

1   Introduction

This review is to honor the requirement of OUTPUT 2 of the ChiNorBC project. The project document for OUTPUT 2 stipulates preparation of "Review literature on the BC/OC emission inventories for northern China and estimation methodology in China and other countries." We will actually consider that the inventories to be built by the project are not only for northern China, but for all of China. Prior to systematic drafting of this review, the two parties of this project, from China and Norway, initially collaborated to formulate the review framework and then interactively commented on and revised the report.

The first challenge, however, is understanding exactly what BC is. Researchers around the world find it difficult to agree on terminology that considers all aspects of specific properties, definitions, measurement methods, and related uncertainties. This leads to much ambiguity in the scientific literature on measurements and numerical models, where BC may be referred to with different names or based on different properties of the particles, with no clear definition of the terms. For example, global emission inventories and modelling studies (e.g., Bond et al., 2007; Granier et al., 2011; Junker and Liousse, 2008; Lee et al., 2012; Vignati et al., 2010), as well as scientific assessments (Solomon et al., 2007; Bond et al., 2013) depend on BC data sets that do not include information on measurement methods. For this reason, Petzold et al. (2013) proposed definitions of terms and recommendations for reporting measurements of "black carbon," "elemental carbon," "light absorption," "refractory carbon," and other properties related to this distinct fraction of the carbonaceous aerosol. Soot is a useful qualitative description when referring to carbonaceous particles formed from incomplete combustion, though non-carbonaceous matter is also included in soot. Soot and BC have been used interchangeably in much existing literature to refer to light absorbing carbon, especially in early publications when BC was not so

deeply concerning the scientists. In this review, we prefer to use BC in most cases, without excepting the use of other terms, such as Elemental Carbon (EC), when necessary.

Available literature explains various aspects of black carbon (BC) (e.g., Bond & Bergstrom, 2006; UNEP, 2015; UNEP/WMO, 2011). BC is the light-absorbing component of carbonaceous particles; the light absorbing property comes from its graphitic bonds. BC is produced by incomplete combustion of fossil fuel, biofuel and biomass. BC is emitted by various devices and processes, such as diesel cars and trucks, residential stoves, forest fires, agricultural open burning, and some industrial facilities. The warming effects of BC on the atmosphere are caused by soot particles absorbing direct or reflected sunlight and then reemitting heat to the atmosphere, and by reducing albedo when deposited on snow and ice. The warming impact of BC on climate is about 700 times stronger than CO_2 when BC's global warming potential (GWP) is estimated over a 100-year time scale (Please add reference or use the same as me). In a short-term perspective the impact is even larger due to the short impact of BC in the atmosphere (GWP (20) = 2700) (Aamaas and Berntsen, 2021, Table 8) BC also influences cloud formation and impacts regional circulation and rainfall patterns. In addition, BC impacts human health as a primary component of particulate matter in air pollution.

In recent decades, on the one hand, the rapid growth of China's economy has been accompanied by a considerable increase in the combustion of coal, other fossil fuels, and biofuels, resulting in an increase in BC/OC emissions (Cheng et al., 2017; Zhi et al., 2017). On the other hand, China's continually intensified clean air pursuit has prompted China to accelerate the transfer from solid fossil energy to clean energy (gas, solar energy, electricity), especially in the residential sector and mobile sources (Pelegov and Eremenko., 2021; Zhang et al., 2020). There are therefore multiple benefits for sustainable development from establishing an efficient policy system for the emission reduction of BC/OC on both regional and national levels in China.

BC and organic carbon (OC) emission data related to northern or all of China are published by different institutions and are often inconsistent in total or in specific sectors due to the substantial differences in emission factors chosen, activity levels recognized, and methodologies applied (Li et al., 2017a). The inconsistent emission results often lead to misunderstanding and confusion and add difficulty to identifying major emission sources and formulating control policy. For this reason, a more comprehensive and convincing emission inventory of BC and OC for northern China is necessary to provide scientific data supporting the formulation and implementation of policies by incorporating new emission factors derived from measurements, investigated activity levels, and improved methodology.

To this end, the ChiNorBC project has set aside a separate subject (OUTPUT 2) to address a BC/OC emission inventory of northern China and throughout China. The project document states: "The purpose of OUTPUT 2 is to establish a gridded, temporal and source-specific BC and OC emission inventory and provide updated gridded data in northern China. These data will be used for modelling and policy recommendations."

In response to the requirement, whilst led by CRAES, the two parties agreed to work together on this review. Among the several targets of the review, the analysis of BC/OC emission factors is of top importance. This will contribute to the development of emission factor tables for mobile and residential sources, which are generally considered major sectors in a BC/OC emission inventory.

This review is composed of five sections, as follows:

- Summary

- Introduction

- BC/OC emission inventories

- BC/OC emission factors in key sectors

- Activity data for key sectors and other sectors

2 BC/OC emission inventories

2.1 Approaches to establishing air pollutant emission inventories

There are usually two approaches to establishing air pollutant emission inventories: bottom-up and top-down. The "bottom-up" approach works out total emissions of individual pollutants based on the detailed fuel consumption (activity level) data of sectors multiplied by corresponding emission factors (e.g., Bond et al., 2004; Cao et al., 2006). The "top-down" approach infers emissions from one or more indicators relevant to emissions. Such indicators may be ambient concentrations observed by ground equipment or column concentrations observed by satellite. In top-down rationale, inverse modelling is an important approach, which translates observed concentrations into primary emissions by using measurements of atmospheric concentrations in combination with modeled fields. However, modelling processes such as transport and removal also result in biases. In most cases, a bottom-up approach is preferred in establishing basic emission inventories; such inventories can be used for model inputs so as to simulate

ambient concentrations.

The top-down approach is more widely used as an important constraining indicator to test, validate, and evaluate bottom-up emissions. For example, Kaiser et al. (2012) derived a global average enhancement factor of 3.4 for emissions of the organic aerosols (OA) and BC resulting from biomass burning and summarized several other top-down studies that estimated emissions two to four times greater than the bottom-up estimates. This shows that top-down estimates can expose underestimations of BC emissions from bottom-up estimates. A thesis by Zhao (2019) describes a top-down estimate of regional BC emissions using ground and satellite observations for the Yangtze River Delta Region. Bond et al. (2013) presented more examples to compare the bottom-up emissions and the top-down estimates.

2.2 Global emissions

Because of the impacts of BC emissions on climate change, local air pollution, and human health, there have been many studies on the sources of BC emissions since the 1990s. The emission figures and sources of BC in different parts of the world have been explored and are summarized below.

Cooke et al. (1999), at the Mixte CNRS-CEA laboratory of France, calculated the global-scale emissions of carbonaceous aerosols from fossil fuel usage. Using a top-down method, they estimated the global BC emissions from the burning of fossil fuels in 1984 to be approximately 5.1–6.4 million tonnes, of which China contributed about 1.15–1.46 million tonnes, accounting for about 22.8% of global BC emissions. The contribution of BC emissions from mobile/transport sources was 17–23%.

Penner et al. (1993), in the U.S., estimated that global BC emissions (biomass burning excluded) were about 12.61 million tonnes in 1980, of which China contributed about 2.68 million tonnes.

Bond et al. (2004) also calculated global BC emissions, using the bottom-up approach, by assigning emission factors on the basis of fuel type and economic sectors (regions and countries). They estimated that global BC emissions in 1996 were about 8 million tonnes, of which China contributed about 1.49 million tonnes or about 18.6% of the total. Bond et al. (2004) also estimated in detail the contributions of different sources to BC emissions. The "open burning" source contributed the largest part of BC emissions, about 42%. About 10% of global BC emissions were from industrial sources, 24% from residential sources, and 24% from mobile sources (Figure 1).
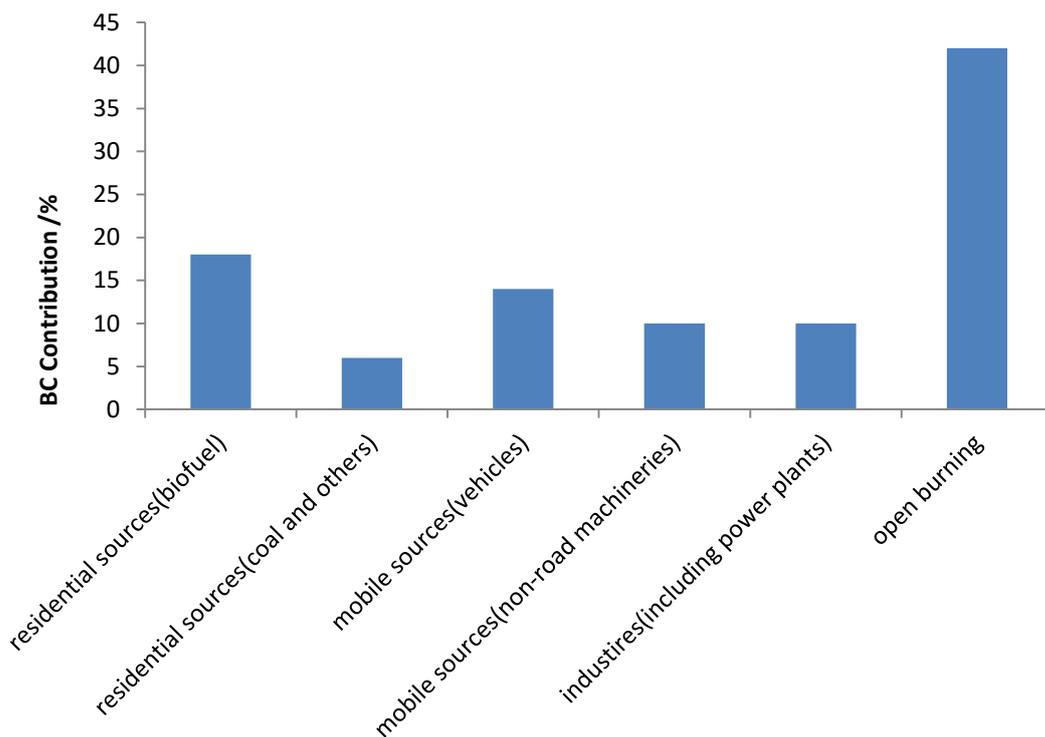
Figure 1 Global BC contribution of different sources in 1996（Bond et al. 2004）

Bond et al. (2007) estimated that global BC emissions in 2000 were about 8.4 million tonnes. Asia, parts of Africa and Latin America (Central and South America) contributed most of the BC emissions.

Lamarque et al. (2010) showed that 75% of the world's BC emissions in the year 2000 (biomass burning included) came from three main regions: (1) Asia (China, India); (2) Africa; and (3) Latin America. Asia accounted for 40% of the emissions, while Africa and Latin America accounted for about 23% and 12%, respectively (Figure 2).
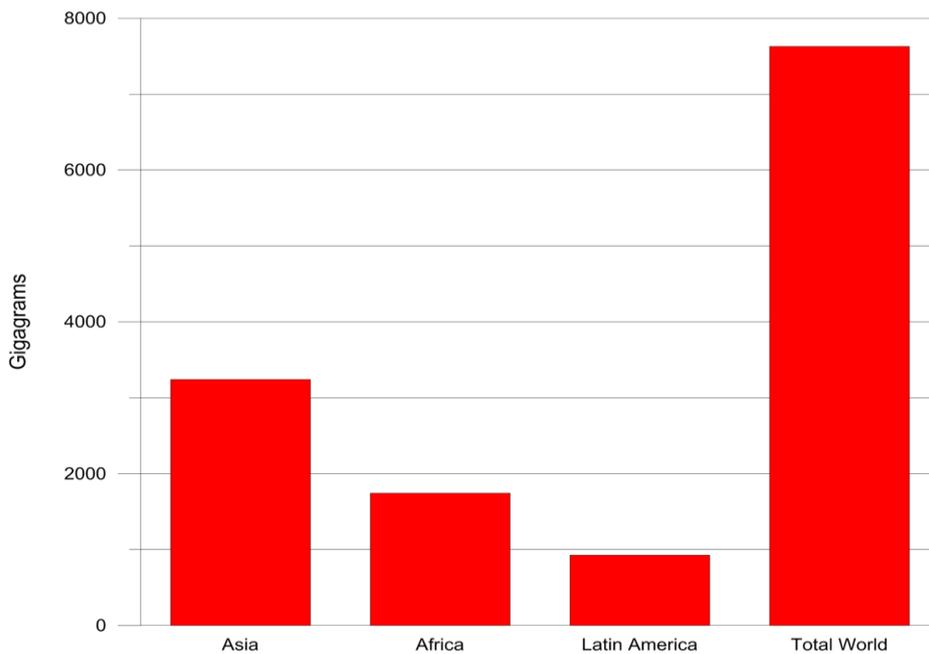
Figure 2 Global and regional BC emissions

In addition, Lamarque et al. (2010) divided global BC emissions into six major sources. They estimated that global BC emissions were still dominated by open biomass combustion (including wildfires), which accounted for about 35%, while BC emissions from domestic stoves and heating accounted for about 25% of the global total (Figure 3). In developing countries, BC from combustion was mainly due to the burning of coal, biomass, or animal waste, by which China, India, and Africa accounted for nearly two thirds of global anthropogenic BC emissions.
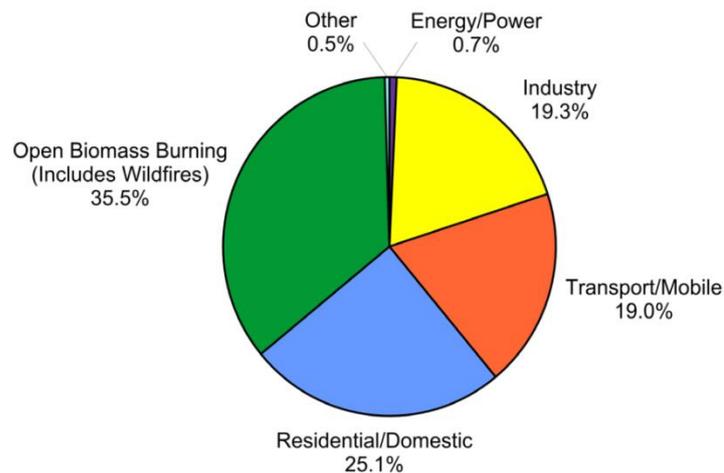
Figure 3 Main sources of global BC

Several inventories covering more recent years are now available. For the sixth cycle of the Coupled Model Intercomparison Project (CMIP6) and IPCC Assessment Report, the Community Emission Data

System (CEDS) provided new historical emission estimates for anthropogenic aerosol and precursor emissions, up to 2014 (Hoesly et al. 2018). Emission estimates in this first CEDS release are generally slightly higher than in other global inventories, with global anthropogenic BC and OC emissions in 2014 of 8 and 19.7 million tonnes while in 2010 of 7.7 and 18.7, respectively. Two other global inventories with 2015 as the most recent year, the Emissions Database for Global Atmospheric Research version 5 (EDGAR5) (Crippa et al., 2019; https://edgar.jrc.ec.europa.eu/dataset_ap50) and the ECLIPSEv5 created with the Greenhouse Gas – Air Pollution Interactions and Synergies (GAINS) model (Amann et al., 2011; Klimont et al., 2017), both have lower global BC and OC estimates. Global anthropogenic BC emissions are approximately 5 million tonnes in both these inventories, while OC emissions are 13 and 11.7 million tonnes in ECLIPSEv5 and EDGAR5, respectively.

These inventories also differ somewhat in their regional and global temporal trends. For instance, while CEDS shows a rapid increase in Asian emissions over the 2000–2014 period, the evolution is flatter in ECLIPSEv5 and levels off in 2014 and 2015 in EDGAR5. An updated release of the CEDS emissions, extending to year 2019 (O'Rourke et al., 2021), shows a levelling off in global emissions since 2014, driven by a combination of increasing emissions in some regions, such as South Asia and Africa south of the Sahara, and a decline in emissions in China, the latter in line with recent observational evidence (Kanaya et al., 2020). A similarity across inventories is in the sectoral and regional distributions, where the largest individual contributions to global emissions are from the residential and commercial sectors and from China and the rest of the Asia-Pacific region, for both pollutants. While significant work has been undertaken to improve the estimates of global and regional emission inventories of aerosols and precursors, uncertainties in magnitude and spatiotemporal patterns remain.

2.3 Regional

2.3.1 The Asia-Pacific regional emission inventories led by the U.S.

Compared with developed countries (such as European countries and the U.S.), China's research on the emission inventory of air pollutants was launched much later due to the late start of industrial development. For research on air pollution in China, one of the most widely used emission inventories is the one called "TRACE-P emission inventory" (Streets et al., 2003). This inventory is an outcome of the project "Transport and Chemical Evolution over the Pacific, TRACE-P" (Jacob et al., 2003; Streets et al., 2006) from the National Aeronautics and Space Administration (NASA) and the project "Asian Pacific Regional Aerosol Characterization Experiment, ACE-Asia" (Huebert et al., 2003). These projects

were funded by the National Oceanic and Atmospheric Administration (NOAA) and National Science Foundation (NSF). The target of these studies was to understand and quantify the effects of chemical outflows from Asia on the U.S. Emissions were estimated at 2.54 Tg BC and 10.4 Tg OC for all major anthropogenic sources, including biomass burning, in 64 regions of Asia. China dominated Asian emissions, accounting for 41.3% of total BC and 32.7% of total OC. China's energy data in "TRACE-P" came from the research results of Sinton and Fridley (2000) rather than official energy statistics. The other data in "TRACE-P" came from the results of the project "RAINS-ASIA" (Amann et al., 2004). Information on pollutant emission factors were taken from several different sources including Fu et al. (2001) for motor vehicles, Andreae and Merlet (2001) for biomass burning, and Bouwman et al. (1997) for NH_3. Aerial experiments have also been carried out over the western Pacific in combination with ground observations, satellite data, and model simulations for emission inventories preparation (Ohara et al., 2007).

Then, in 2006, the project "Intercontinental Chemical Transport Experiment-Phase B, INTEX-B," launched by NASA, prepared the INTEX-B emission inventory (Zhang et al., 2009). This inventory is a continuation of the TRACE-P emission inventory. It uses official energy statistics and gives a relatively accurate picture of emissions across Asia, particularly in China. Emissions in 2006 were estimated at 2.97 Tg BC and 6.57 Tg OC for all major anthropogenic sources, excluding biomass burning. China also dominated Asian emissions, representing 60.6% of the total BC and 48.7% of Asian total OC. The authors estimated 2001 emissions for China using the same methodology and found that all components showed an increasing trend during 2001–2006, including 14% for both BC and OC, though for most sectors net emission factors were fundamentally changed due to dramatic economic growth and dynamic technology penetration. For example, in power plants the net emission factors of $PM_{2.5}$ declined from 2.0g/kg coal to 1.2g/kg coal.

2.3.2 The Asian emission inventory led by Japan

Besides the Asia-Pacific emission inventory led by the U.S., "International Institute for Applied Systems Analysis, IIASA" and the World Bank launched the project "RAINS-Asia," which provided data support for acid rain mitigation in Asia in the 1990s. On this basis, Japan's National Institute of Environmental Research developed the Regional Emissions Asian Inventory (REAS) (Ohara et al., 2007), which is a relatively complete and comprehensive emission inventory of Asia (biomass burning excluded). REAS-1.1 version integrated historical emission data (up to 2007) and forecasted future emissions (up to 2020).

It was subsequently updated to REAS-2.1 (Kurokawa et al., 2013), in which the spatial resolution was further improved. This version of REAS revised the data of different regions in China by referring to the INTEX-B emission inventory. It took into account in detail not only the effect of pollution control technologies on emission factors, but also China's basic energy consumption in the statistical yearbook of each province. Asian emissions for BC and OC in 2008 were estimated at 3.03 Tg and 7.72 Tg in this inventory, up 35% and 21% compared with 2000. By country, China and India were respectively the largest and second largest contributors because of their continuous increases in energy consumption, industrial activities, and infrastructure development.

2.4 China

The BC emissions of China calculated by different scholars differ considerably, but all show a large contribution to global BC emissions. Streets et al. (2001) studied the 1995 emissions of China by sector and province. Using the bottom-up method and emission factors by sectors and fuel types (based on consumption of various fuel types) derived from different studies, they estimated that the BC emissions of China were about 1.342 million tonnes in 1995. The residential sector contributed the largest part of BC, about 83.3%. The industry sector contributed about 7.2% of the total BC emissions, ranking second. The power generation sector contributed about 8,300 tonnes of BC emissions, accounting for about 0.6% of the total. The total BC emissions from mobile sources was 43,400 tonnes, accounting for 3.2% of the total. Field combustion (open burning) released about 74,700 tonnes BC, representing about 5.6% of the total. They also forecasted that China's BC emissions would fall to 1.224 million tonnes by 2020 after adoption of particle/BC emission control technology. But Streets et al. expected a faster increase in the number of vehicles in China. Therefore, they used the BC emission factor of 1995 and predicted that BC emissions from mobile sources in China would rise to 139,300 tonnes by 2020, accounting for 11.4% of the expected BC total.

The first BC-related emission inventory made by Chinese scholars was most likely that by Cao et al. (2006), with the Chinese Academy of Meteorological Sciences. This study was later expanded with more pollutant types (Cao et al., 2011) (biomass burning included). Based on the method developed for the INTEX-B emission inventory, Tsinghua University updated the statistical data and the calculation method, and recalculated China's emissions in the INTEX-B emission inventory (Lei et al., 2011) (biomass burning excluded). The uncertainties of the emissions in the inventory were also quantified (Zhao et al., 2011). Subsequently, Tsinghua University established the first multi-scale air pollutant emission inventory, "Multi-resolution Emission Inventory for China, MEIC," based on the method for

emission inventory construction for technology and dynamic processes (biomass burning excluded). MEIC (V1.0) was released in 2012 (Lu et al., 2011). It includes 10 pollutants (SO_2, NO_x, CO, NH_3, NMVOC, PM_{10}, $PM_{2.5}$, BC, OC, CO_2) and more than 700 emission sources (including power plant, industrial, agricultural, residential, and traffic). MEIC is adapted to user needs by setting different temporal and spatial resolutions. The latest version of MEIC, V1.2, was released in 2015 (Tong et al., 2020).

At present, there are many universities and scientific research institutions in China carrying out emission inventory studies, but these focus on selected types of pollutants or selected areas (Ni et al., 2014; Qi et al., 2017; Wang et al., 2012; Zhang et al., 2013; Zhao et al., 2012).

Cao et al. (2007) also calculated a detailed high-resolution emission inventory of BC for China in the year 2000 by sectors, provinces, and months. The latest activity data include fossil and biomass fuels and socio-economic statistics from government agencies, mostly at county levels. Total BC emissions were about 1.50 million tonnes in 2000, and the burning of coal and biomass contributed about 87% of the total. BC emissions from industrial coal combustion were 497,100 tonnes, accounting for 33.15% of the total. BC emissions from domestic coal combustion were 520,800 tonnes, accounting for 34.73%. BC emissions from industrial straw combustion were 100,100 tonnes, accounting for 6.68%. BC emissions from traffic sources were only 26,800 tonnes, accounting for 1.79% of total emissions. The authors attributed the low contribution of traffic to the fact that the BC emission factor for heavy-duty vehicles was estimated by using the BC emission factor of light-duty vehicles in tunnel tests, which might substantially deviate from the actual situation.

Later, Cao et al. (2011) updated the emission factors and estimated BC emissions of mainland China at 1.4 million tonnes in 2007, which was lower than found in the previous study. Mobile sources contributed 7.4% of the total, which was higher than previously reported. Cao et al. believed the emission factors used in their new paper had smaller relative errors due to newer emission measurement data, which led to more accurate emission estimation.

BC emissions of China in 2007 were also calculated by Ni et al. (2014), using emission factors obtained from domestic and foreign literature and the statistical data bulletin of China. They estimated emissions at about 963,000 tonnes (biomass burning included), less than reported by the studies mentioned above. They estimated the contribution of traffic BC emissions at about 8.9%.

Zhang et al. (2013) from Peking University calculated the BC emission inventory (biomass burning

included) for 2008 in China (except for Hong Kong, Macao, and Taiwan) based on the national statistical data, the latest measured emission factor data in China, and a vehicle emission factor model developed in line with actual vehicle emissions in China. They estimated that total BC emissions of mainland China in 2008 were 1,604,940 tonnes, of which industrial and residential sources were 695,000 tonnes and 636,000 tonnes, respectively, together accounting for 82.9% of total BC emissions. BC emissions from transport sources were 194,630 tonnes, accounting for 12.1%, which was higher than reported by Cao et al. (2007, 2011). According to Zhang et al. (2013), this was mainly due to the small number of emission factor samples chosen by Cao et al., the deviation in obtaining activity data, and BC emission factors being used without considering the changes in emission standards for motor vehicles. By collecting and collating data on BC emissions and establishing a database of emission factors more in accordance with China's actual vehicle emission situation, Zhang et al. (2013) expected improved accuracy in calculating vehicle emission.

Qin et al. (2011) updated China's BC emission inventory for 2009 (biomass excluded). Using a top-down approach to update annual changes in fuel consumption activity levels, they found that China's BC emissions in 2009 amounted to 1.88 million tonnes, of which mobile sources emitted about 241,000 tonnes, accounting for about 12.8%.

Wang et al. (2012) calculated a more detailed BC emission inventory for 2007 for mainland China (biomass burning included) by making a more detailed classification of industry types and using updated BC emission factors. Based on the sub-industry types of fuel consumption from surveys, such as of statistical literature, they estimated that BC emissions in mainland China were 1.957 million tonnes in 2007, which was higher than reported by other studies. Of the total, residential coal contributed about 27.5% and was the largest source of emissions, followed by coke production and civil biomass combustion sources, accounting for 17.3% and 12.7%, respectively. Motor vehicle emissions accounted for about 9.4%.

Fu et al. (2018) calculated mainland China's BC inventory for 2012 (biomass burning excluded) using statistical data. According to their research, total BC emissions were about 1.887 million tonnes, of which BC from household sources were 818,000 tonnes, about 43.3%, making households the largest source of emissions. Transportation sources contributed 178,000 tonnes, about 9.4% of the total.

Zhou et al. (2018) used the multi-regional input-output (MRIO) analysis (top-down BC estimation method) to compile national and provincial BC emissions (unclear on biomass burning contribution).

They estimated that total BC emissions in mainland China in 2010 were 1.259 million tonnes, of which emissions from transportation, storage, and postal service accounted for about 14%.

Some scholars in China studied BC emissions at the provincial or regional level. Li et al. (2017) from South China University of Technology adopted "bottom-up" and "top-down" methods, using collected anthropogenic activity level data and the latest emission factors measured, to establish the BC and OC emission inventory of anthropogenic sources in Guangdong Province in 2012. Their research showed anthropogenic emissions of BC and OC were 53,500 tonnes and 78,800 tonnes, respectively. BC emissions were mainly from road mobile sources and biomass combustion sources, 30.1% and 29.4%, respectively. The uncertainty ranges of BC and OC emission source inventories established were 66–154% and 63–126%, respectively.

Xu et al. (2018) from Dongguan Research Institute of Sun Yat-sen University calculated BC emission characteristics of motor vehicles in Guangdong province, using a bottom-up method and the BC emission factors recommended in the COPERT model. Their study showed that in 2014 the emissions were about 645.69 million tonnes. Since 2012, BC emissions of motor vehicles decreased by 17.4%. Xu et al. believed the decreasing trend might be related to the implementation of upgraded National Emission Standards for heavy-duty diesel vehicles and fuel products following National IV requirement in 2013.

Huang et al. (2017) from Nanjing University used the COPERT model and BC emission factors based on real-time measurement data of Chinese vehicles to establish the motor vehicle air pollutants emission inventory of Jiangsu Province in 2012. Based on the measured emissions data, the BC and OC emissions of the vehicles were 15,700 tonnes and 5,100 tonnes, respectively. Based on the COPERT model calculation, the BC and OC emissions were 4,700 tonnes and 3,000 tonnes, respectively. In Huang et al. (2017), the motor vehicles' BC and OC emissions in Jiangsu were 11,900 tonnes and 2,800 tonnes, respectively. The research showed that the COPERT model likely underestimated the BC emissions of motor vehicles in China, mainly due to low emission factors for heavy vehicles.

In parts 2.2 to 2.4 in this review report, we have tried to piece together the BC emission inventories on global, regional, and national scales. We acknowledge that there is not enough information to fully and clearly account for whether differences among inventories arise from rapidly changing emissions, improvements in statistics, different methods, or all of these factors.

In the following we will focus on two large sources with substantial uncertainty, namely the mobile and residential sectors.

2.5 Mobile sources

Estimates of BC emissions from mobile sources and their contribution to anthropogenic BC emissions are summarized in Table 1. The total BC emissions in China, as reported in the literature, range from 1.05 million tonnes (in 2000) to 1.8 million tonnes (in 2006), and the contribution of mobile sources/transportation to total BC emission varies from 1.8% to 32.3%, displaying substantial variation between different reports.

Table 1 Mobile Source BC emission from different studies

Author	base Year	Method	Results (million tonnes BC)	Mobile/Transportation's contribution
Cooke et al., 1999	1984	Top-down	Global: 6.40, China: 1.46（about 22.8%）	none
Streets et al., 2001	1995	Bottom-up	China: 1.342	3.23%, including road transport 1.16%, non-road transport 1.74%, and ships 0.33%
Bond et al., 2004	1996	Bottom-up	Global: 7.95, China: 1.4（18.7%）	18.8% (Global), including on-road (diesel fuel) 9.96%, non-road (diesel fuel) 7.28%, and others (gasoline) 1.57%
Streets et al., 2003	2000	Bottom-up	Asia: 2.54, China: 1.05 (41.3% of Asia)	19% (Asia), no further classification
Zhang, et al., 2009	2006	Top-down/local bottom-up (China)	Asia: 2.97, China: 1.8 (60.6% of Asia)	About 14% (Asia, vehicle), no further classification
Cao, et al., 2007	2000	Bottom-up	China Mainland: 1.5	1.8% (China), including diesel fuel 1.7% and gasoline fuel 0.1%
Cao, et al., 2011	2007	Bottom-up	China Mainland: 1.4	7.4% (China), no further classification
Zhang, et al., 2013	2008	Bottom-up	China Mainland: 1.6	Transportation Sources 12.1%, including road transport (vehicle) 12.06% and aviation 0.04%
Wang, et al., 2012	2007	Top-down (classify sub-	China Mainland: 1.957	9.4% (vehicles, China), including vehicle (diesel) 8.0%, vehicle (gasoline)

		industry fuel consumption)		1.4%, and aviation (kerosene) 0.085%
Qin, et al., 2011	2009	Bottom-up	China: 1.88	Transportation Sources 12.8%, no further classification
Fu et al., 2018	2012	Bottom-up	China Mainland: 1.887	Transportation Sources (9.4%), including trucks (diesel) 3.8%, diesel passenger vehicles (car, coach, bus, etc.) 5.5%, and others (gasoline) 0.1%

At present there is little literature about off-road mobile BC emissions in China. Two reviews (Bai et al., 2016; Yun, 2020) focused on BC emission quantities of marine vessels and their effect on sea ice. The former study, showed that in 2013, BC emissions from international marine vessels accounted for about 2% of the global total of BC emissions and about 9% of all diesel combustion BC emissions, about one third of which were emitted in areas north of 40 ˚N. The latter study reviewed the progress and legislative trends of IMO regarding BC emissions from ships, and introduced definitions, methods for BC surveys, measures for reducing BC emissions, and advice on the BC emission reduction issue for ships in the Arctic region, in consideration of China's rights and interests.

2.6 Residential sector

Table 2 summarizes residential sector BC and OC emissions found in some available emission inventories. According to an estimate by Peking University, in 2007 a total of 1,957 Gg (Giga gram, 10^9 tonnes) BC was emitted in China, of which 989 Gg was emitted by the residential sector, accounting for 50.5% of total emissions. Industrial emissions of 646 Gg accounted for 33.0% of the total, transport emissions of 188 Gg for 9.6%, power plant emissions of 50.7 Gg for 2.6%, 77.7 Gg from biomass opening burning for 4.0%, and other sources for 3.4% (Wang et al., 2012). Results of a Tsinghua University MEIC emission inventory for China also showed that residential emissions were the largest BC emission source in China. Total residential emissions in 2010 accounted for about 50% of the total emissions that year, which is consistent with the research conclusions of several scholars (Streets et al., 2001; Ohara et al., 2007; Lei et al., 2011; Lu et al., 2011).

An important reason why residential emissions are so large is that many Chinese rural residents use a

variety of cooking stoves for heating/cooking, with coal and biomass as fuels. The characteristics of low combustion efficiency, no emission control measures but high emission intensity, and low emission height are collectively responsible for the high share (Zhang et al., 2020). Especially during winter heating, the high concentration of air pollutants discharged by residential coal burning over a long time is one of the main causes of autumn/winter haze in northern China (Liu et al., 2016). According to a survey by the Chinese Academy of Environmental Sciences, 97% of rural households in northern China use coal. Such accounts for nearly 80% of domestic energy consumption (Zhi et al., 2015), though the rate has gone down due to intense promotion of clean energy in northern China. Almost all such coal is used for heating in winter. This means that large quantities of coal are consumed in winter in inefficient stoves without any control measures, releasing large amounts of pollutants. According to the latest estimates by Zhu et al. (2019), 51% of national BC emissions in 2014 came from the residential source, 80% of which came from rural areas.

Table 2 BC/OC emissions in China's residential sector

References	Inventory year	BC（Gg）	OC（Gg）
(Bond et al., 2004)	1996	546	1,689
(Streets et al., 2003)	2000	781	2,572
(Ohara et al., 2007)	2000	938	2,497
(Cao et al., 2006)	2000	818	2,651
(Lei et al, 2011)	2006	700	2,610
(Zhao et al., 2011)	2006	841	2,528
(Zhang et al., 2009)	2006	1002	2,606
(Cao et al., 2011)	2007	651	1,546
(Wang et al., 2012)	2007	989	-
(Zhang et al., 2013)	2008	636	-
(Kurokawa et al., 2013)	2008	715	2,496
(Winijkul and Bond, 2016)	2010	860	2,280
(Lu et al., 2011)	2010	936	2,790
(Zhao et al., 2013)	2010	809	2,228
(Li et al., 2017a)	2010	848	2,481
(Li et al., 2017b)	2010	908	2,752
Mean ± SD	-	**829±116**	**2,464±318**

3 BC/OC emission factors in key sectors

Data described in this section are from peer reviewed literature. The following sources were not evaluated because emission factors from Europe (EEA/EMEP Guidebook (https://www.eea.europa.eu/publications/emep-eea-guidebook-2019#additional-files) and North America (U.S. AP-42 Compilation of Air Emissions Factors (https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors) were found not to be representative of Chinese conditions: The IPPC emission factor database (https://www.ipcc-nggip.iges.or.jp/EFDB/main.php) does not currently contain emission factors for BC and OC. Work has started under the IPCC to develop globally applicable methodology for SLCFs including BC and OC, in line with the IPCC 2006 Guidelines and 2019 Refinement for GHG.

3.1 Household coal

Accurate understanding of pollutant emissions is the basis for evaluating the effectiveness of emission reduction (Seinfeld, 2008), while the emission factor is the important basis for the total emission estimate. In estimating BC emission factors, the emission factor of total particulate matter is often multiplied by the proportion of BC in the particulate matter, leading to a high uncertainty (Streets et al., 2001; Zhi, 2008).

In the last two decades, many scholars have started to directly measure the emission strength of BC/OC after dilution of high concentration flue gas by using dilution systems. Great progress has been made in in-depth research on the mechanisms and emission factors of residential coal combustion. It has been found that the relationship between residential coal emission factors and coal maturity is a bell-shaped distribution (coal maturity denotes the degree of coalification; coalification is a process in which volatile matter is converted into coal of increasingly higher rank with anthracite as the final product). In other words, BC emission factors are relatively low when coal maturities are at the high or low end, but relatively high in the middle range of coal maturity (Zhi et al., 2008). Emission factors can be even hundreds of times greater in the middle range than at the high or low end of maturities (Chen et al., 2006; Chen et al., 2009a). However, coal with low maturity (e.g., lignite) is fragile and does not burn well, while coal with high maturity (anthracite) is expensive and hard to burn. As a result, residents prefer to use moderately mature coal that has higher emission factors and leads to higher soot pollution in China. In addition, the combustion form of coal and the type of stove have significant impacts on emission factors. Making coal into briquette (honeycomb briquette) increases the specific area of a piece of coal

several times, which is conducive to oxygen-supported combustion and can reduce the emission factor of BC of bituminous coal by 35 times (Chen et al., 2009b). If briquettes are used with efficient stoves, the BC emissions will be further reduced (Zhi et al., 2009).

Table 3 and Table 4 give the emission factors of BC and OC for residential coal combustion from different sources. These data were processed with a statistical tool and the distributions are shown in Figure 4 and Figure 5.

Table 3 BC emission factors of coal (g/kg)

BC	Chunk		Briquette	
	EFs	References	EFs	References
	0.68	Li et al., 2016b	0.65	Li et al., 2016b
	2.75	Zhang et al., 2008	0.09	Zhang et al., 2008
	0.28	Chen et al., 2005	0.32	Liu et al., 2007
	3.51	Liu et al., 2007	0.03	Liu et al., 2007
	3.81	Zhi et al., 2008	0.08	Zhi et al., 2008
	3.05	Chen et al., 2009a	0.09	Chen et al., 2009a
	0.51	Zhi et al., 2009	0.05	Zhi et al., 2009
	1.23	Zhi et al., 2009	0.09	Zhi et al., 2009
	2.89	Zhi et al., 2009	0.16	Zhi et al., 2009
	0.18	Zhi et al., 2009	0.03	Zhi et al., 2009
	3.05	Chen et al., 2009b	0.09	Chen et al., 2009b
	0.83	Shen et al., 2014	0.006	Shen et al., 2014
	0.31	Shen et al., 2014	0.004	Shen et al., 2014
	4.80	Shen et al., 2014	0.18	Shen et al., 2014
	2.04	Chen et al., 2015a	0.67	Chen et al., 2015a
	0.006	Shen et al., 2014		
	2.80	Tian et al., 2017		
	4.92	Sun et al., 2018		
	2.00	Thompson et al., 2019		
	3.7	Streets et al., 2003		
	2.63	Ministry of Ecology and Environment of People's Republic of China, 2014		
	0.23	Shen et al., 2010		
	3.32	Chen et al., 2006		
Average ± SD	2.15±1.58		0.17±0.21	

Table 4 OC emission factors of coal (g/kg)

OC	Chunk		Briquette	
	EFs	References	EFs	References
	2.49	Li et al., 2016b	4.02	Li et al., 2016b
	5.93	Zhi et al., 2008	4.16	Zhi et al., 2008
	5.39	Liu et al., 2007	1.24	Liu et al., 2007
	8.29	Chen et al., 2006	4.15	Liu et al., 2007
	2.98	Zhang et al., 2008	2.27	Zhang et al., 2008
	5.5	Chen et al., 2009a	3.74	Chen et al., 2009a
	6.22	Zhi et al., 2009	5.48	Zhi et al., 2009
	9.76	Zhi et al., 2009	4.94	Zhi et al., 2009
	5.76	Zhi et al., 2009	6.17	Zhi et al., 2009
	4.31	Zhi et al., 2009	2.50	Zhi et al., 2009
	1.00	Shen et al., 2014	0.007	Shen et al., 2014
	0.66	Shen et al., 2014	0.02	Shen et al., 2014
	5.90	Shen et al., 2014	4.80	Shen et al., 2014
	0.80	Chen et al., 2015a	1.99	Chen et al., 2015a
	0.65	Chen et al., 2015b	1.15	Chen et al., 2015b
	0.10	Shen et al., 2014		
	7.82	Chen et al., 2005		
	1.90	Tian et al., 2017		
	3.65	Sun et al., 2018		
	9.70	Thompson et al., 2019		
	3.12	Ministry of Ecology and Environment of People's Republic of China, 2014		
	3.00	Streets et al., 2003		
Average ±SD	4.32±2.95		3.11±1.95	
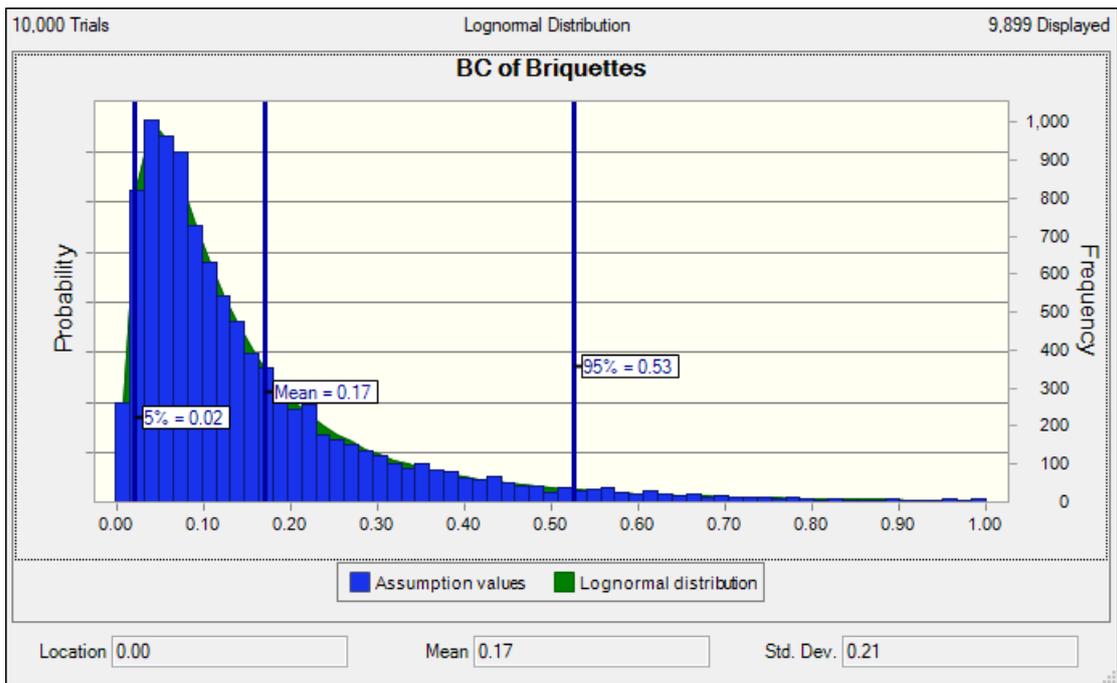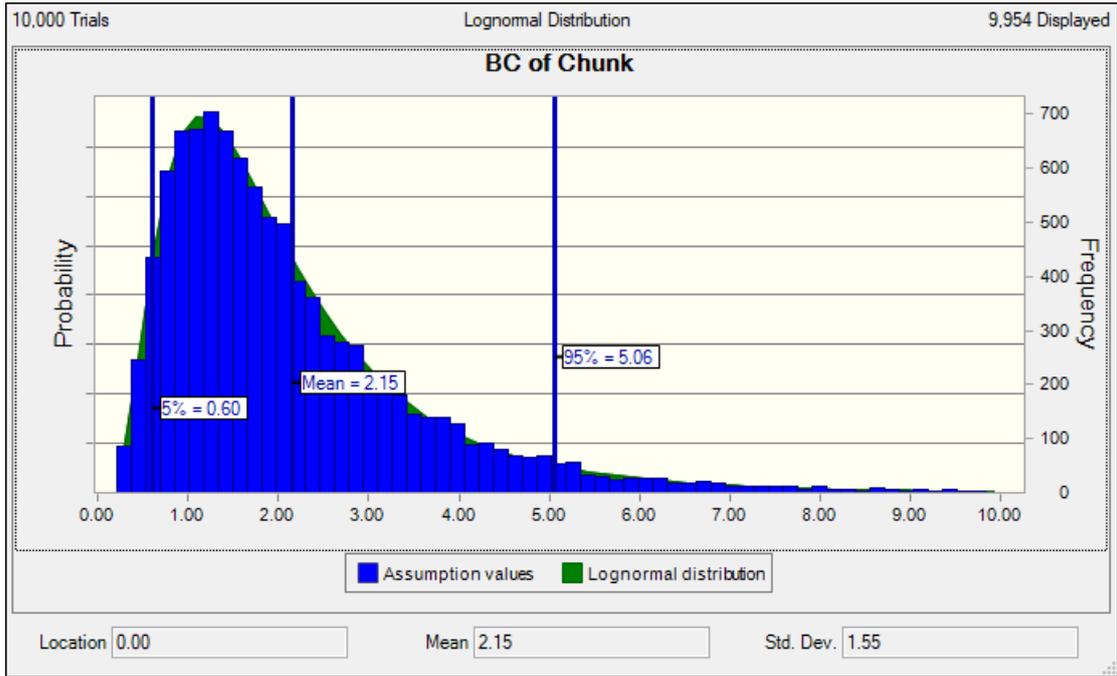
Figure 4 BC emission factor uncertainty distribution of coal and briquette
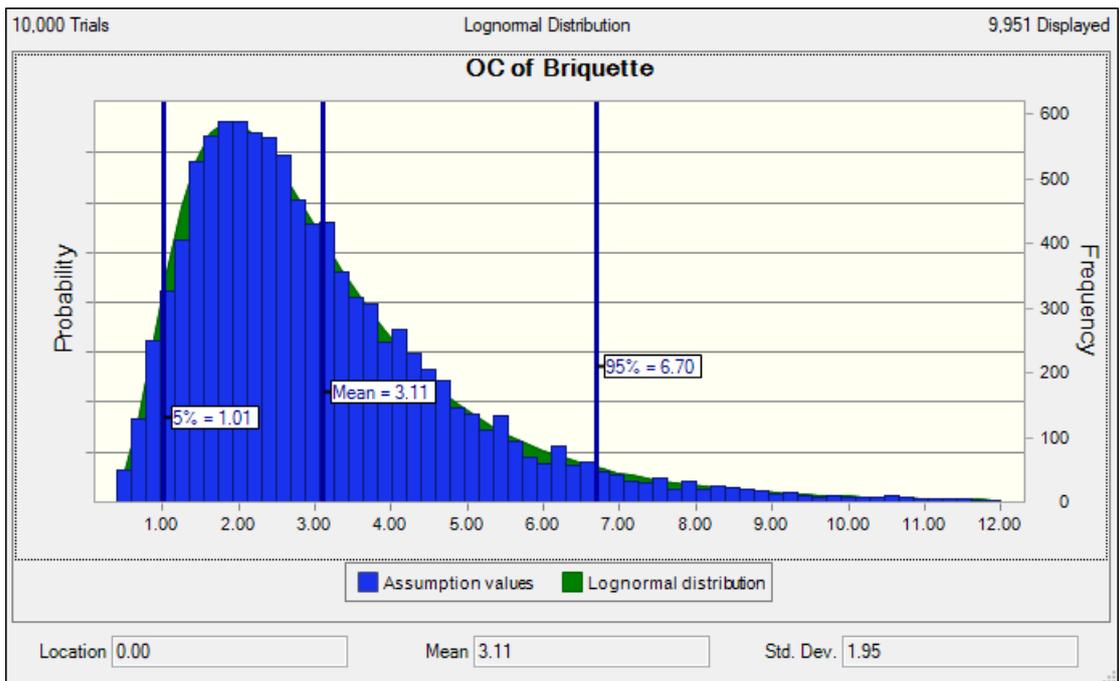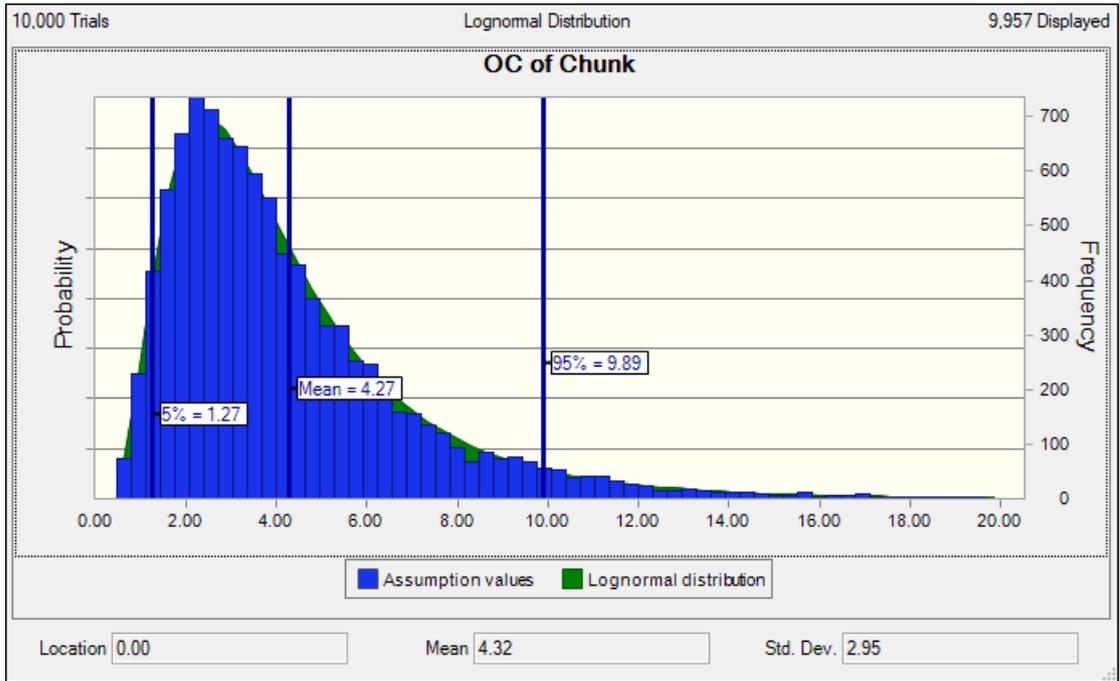
Figure 5 OC emission factor uncertainty distribution of coal and briquette

3.2 Mobile sources

At present, there is no official test method for measuring BC emissions for mobile sources in China. The main measurement method for mobile source BC is to measure PM and then analyze the EC/soot part from the particulate matter. This method can sometimes provide PM_{10} and $PM_{2.5}$ measurements. Measurements of particulate matter are complex, as some of the emitted particulate matter is filterable

and some is coagulated. Table 5 summarizes the official U.S. particulate matter sampling method (U.S. EPA, 2006). For sampling diesel particulate matter, the EPA mainly uses 40CFR Part1065. The measurement of BC mainly uses the method of thermo-optical analysis, but it is not the official test standard.

Table 5 EPA of U.S. Particle Sampling and Measurement Method

Method	PM Type	Filtration Temperature/°F	Purpose	CFR Reference
EPA Method 5	Filterable	248±25	General	40CFR 60 Appendix A-3
EPA Method 5A	Filterable	108±18	Asphalt Roofing	40CFR 60 Appendix A-3
EPA Method 5B	Filterable	320±25	Utility Plants	40CFR 60 Appendix A-3
EPA Method 5D	Filterable	248±25	Positive Pressure Baghouses	40CFR 60 Appendix A-3
EPA Method 5E	Filterable and Total Organic Material	248±25	Wool Fiberglass	40CFR 60 Appendix A-3
EPA Method 5F	Filterable	320±25	Non sulfate Filterable PM	40CFR 60 Appendix A-3
EPA Method 5G	Filterable and Condensable	<90	Wood Heaters-Dilution	40CFR 60 Appendix A-3
EPA Method 5H	Filterable and Condensable	<248 and >68	Wood Heaters	40CFR 60 Appendix A-3
EPA Method 5I	Filterable	248±25	Low level general	40CFR 60 Appendix A-3
EPA Method 17	Filterable	stack temperature	General	40CFR 60 Appendix A-6
EPA Method 201	Filterable 10μm	stack temperature	General-Particle Sizing	40CFR 51 Appendix M
EPA Method 201A	Filterable 10μm/2.5μm	stack temperature	General-Particle Sizing	40CFR 51 Appendix M

EPA Method 202	Condensable	85		General-Condensable PM	40CFR 51 Appendix M
EPA Conditional Test Method-039	Total 10μm/2.5μm (Filterable and Condensable)	85		General-Dilution based PM	
Example State, VCS, and International Methods					
CARB 5	Filterable	248±25			
CARB 501	Filterable, multiple aerodynamic sizes	stack temperature		General-Particle Size	
ASTM D6831-05a	Filterable	stack temperature		Continuous PM	
ISO 9096 and EN 13284	Filterable				
VDI 2066 Part.10 method and in the Norm EN 13284-1	Filterable 10μm/2.5μm				

As for measurements of BC of mobile sources in real-time driving conditions, the emissions vary greatly with respect to differences in fuel type, vehicle type, and running conditions. The sampling temperature has great influence on the sampling of particulate matter and the measurement of BC. The general sampling method always requires pre-dilution with ambient air.

BC emission factors of mobile sources derived from different reports can be separated into two categories. One is BC emissions directly per fuel consumed (g/kg fuel) or per mileage traveled (g/km). The other is to derive the BC emission factor from the emission factors of particles (EF_{PM10} or $EF_{PM2.5}$) by assigning a fraction of particles to BC or OC. Such BC factors are affected by different types/fuels used and standards as well as conditions, etc. Different BC factors reported in the literature are given in Table 6 and Table 7. BC and/or OC fractions in particles are given in Table 8.

Table 6 BC/OC emission factors from the literature

	Low-income countries (g/kg)		Middle-income countries (g/kg)		High-income countries (g/kg)		BC/OC Origin	Reference
	BC	OC	BC	OC	BC	OC		
Diesel	/	/	/	/	2.0	/	Literature review of EC measurement	Cooke and Wilson, 1996
Gasoline	/	/	/	/	0.1	/		

Category							Method	Reference
							with thermal-optic method	
Diesel	10	5.0	10	5.0	2.0	1.0	Literature review of EC measurement with thermal-optic method	Cooke et al., 1999
Gasoline	0.15	0.73	0.15	0.73	0.03	0.07		
Gasoline	/	/	/	/	0.049	/	Literature review of PM factors multiplied BC fractions in PM	Cao Guoliang, 2007
Diesel	/	/	/	/	1.1	/		
Gasoline, Light-duty vehicle	/	/	0.26	/	0.13	/	Literature review of PM factors and BC fractions in PM	Klimont et al., 2009
Diesel, Light-duty vehicle	/	/	3.1	/	0.55	/		
Diesel, heavy-duty truck	/	/	1.45	/	0.042	/		
Diesel, Light-duty truck	2.2(China 0),0.85(China I)	/	0.76(China II),0.46(China III)	/	0.27(China IV)	/	Literature review of BC factors by optical measurement with a micro Aethalometer	Song, et al., 2012
Diesel, Light-duty cars	1.5(China 0),0.6(China I)	/	0.4(China II),0.2(China III)	/	0.15(China IV)	/		
Diesel, Heavy-duty truck	2.3(China 0),1.24(China I)	/	0.55(China II),0.33(China III)	/	0.2(China IV)	/		
Gasoline, Light-duty vehicle	0.09(China 0),0.054(China I)	/	0.029(China II),0.018(China III)	/	0.009(China IV)	/		
faGasoline, large/heavy-duty vehicle	0.14(China 0),0.08(China I)	/	0.04(China II),0.025(China III)	/	0.015(China IV)	/		
Gasoline	/	/	/	/	0.07	/	Calculated by EF_{PM} (CPOERT model)	Qin, et al., 2011
Diesel	/	/	/	/	0.25	/		

							Reference	
							multifield by F_{BC} (Bond, et al., 2004)	
Gasoline	/	/	/	/	0.056	/	Calculated by EF_{PM} (Huang, et al., 2014) multifield by F_{BC} (Bond, et al., 2004)	Zhou, et al., 2018
Diesel	/	/	/	/	1.22	/		

Table 7 BC emission factors (g/km) from Krecl, et al., 2017

	Year:2006	Year:2013	Reference
Gasoline	0.011	0.0025	Calculated, Krecl, et al., 2017
Diesel	0.0948	0.0234	
Gasoline	0.0005	0.0003	From TRANSPHORM database, Krecl, et al., 2017
Diesel	0.0929	0.0238	

Table 8 BC/OC fractions by PM (g/kg or g/km)

	Emission Factor	$F_{2.5}/F_{1.0}$	F_{BC}	F_{OC}	Reference
Gasoline	EF_{PM10}:0.124-0.392(g/kg fuel)	$F_{2.5}$:0.74-0.95	0.32	/	Streets, et al., 2003
Diesel	EF_{PM10}:0.34-4.33(g/kg fuel)	$F_{2.5}$:0.95	0.52	/	
Gasoline, large passenger bus	$EF_{PM2.5}$:0.08(g/km)	/	0.27	0.58	Li, et al., 2017
Diesel, large passenger coach	$EF_{PM2.5}$:0.71(g/km)	/	0.51	0.32	
Gasoline, light-duty vehicles	$EF_{PM2.5}$:0.02(g/km)	/	0.27	0.58	
Diesel, light-duty vehicles	$EF_{PM2.5}$:0.12(g/km)	/	0.51	0.32	
Gasoline, heavy-duty truck	$EF_{PM2.5}$:0.07(g/km)	/	0.27	0.58	
Diesel, heavy-duty truck	$EF_{PM2.5}$:0.78(g/km)	/	0.51	0.32	

Gasoline, light-duty truck	$EF_{PM2.5}$:0.064(g/km)	/	0.27	0.58	
Diesel, light-duty truck	$EF_{PM2.5}$:0.253(g/km)	/	0.51	0.32	
Bus	$EF_{PM2.5}$:0.775(g/km)	/	0.51	0.32	
Taxi	$EF_{PM2.5}$:0.018(g/km)	/	0.27	0.58	
Motorcycle	$EF_{PM2.5}$:0.03(g/km)	/	0.12	0.53	
Fishing vessels	$EF_{PM2.5}$:2.16(g/ kg fuel)	/	0.44	0.33	
Agricultural machinery	$EF_{PM2.5}$:4.0(g/ kg fuel)	/	0.31	0.44	
Agricultural farm vehicle	$EF_{PM2.5}$:2.78(g/ kg fuel)	/	0.31	0.44	
Construction machinery	$EF_{PM2.5}$:6(g/ kg fuel)	/	0.31	0.44	
Diesel, on-road/standards in place	EF_{PM}:1.5	$F_{1.0}$:0.86	0.66	0.21	
Diesel, on-road/standards beginning	EF_{PM}:3.5	$F_{1.0}$:0.86	0.66	0.21	
Diesel super emitters	EF_{PM}:12	$F_{1.0}$:0.86	0.66	0.21	
Diesel farm vehicles	EF_{PM}:4.0	$F_{1.0}$:0.86	0.66	0.21	
Diesel nonfarm off-road vehicles	EF_{PM}:5.5	$F_{1.0}$:0.86	0.66	0.21	
Diesel and heavy oil, ships	EF_{PM}:1.8	$F_{1.0}$:0.86	0.66	0.21	
Gasoline, all vehicles/standards in place	EF_{PM}:0.15	$F_{1.0}$:0.85	0.34	0.36	Bond et al., 2004
Gasoline, all vehicles/standards beginning	EF_{PM}:0.5	$F_{1.0}$:0.85	0.34	0.36	
Gasoline super emitters	EF_{PM}:2.0	$F_{1.0}$:0.85	0.34	0.36	
Gasoline, two-stroke/standard	EF_{PM}:15	$F_{1.0}$:0.95	0.05	0.79	
Gasoline, two-stroke/high-emission practice	EF_{PM}:30	$F_{1.0}$:0.95	0.05	0.79	
Diesel, Heavy-duty trucks - EURO I	/	/	0.65	/	COPERT model

Diesel, Heavy-duty trucks - EURO II	/	/	0.65	/	
Diesel, Heavy-duty trucks - EURO III and above	/	/	0.70	/	
Diesel, Buses - EURO I	/	/	0.65	/	
Diesel, Buses - EURO II	/	/	0.65	/	
Diesel, Buses - EURO III and above	/	/	0.70	/	
Diesel, Electronically controlled injection vehicle			0.56	/	Zheng X, 2016
Diesel, Mechanical injection vehicle			0.43	/	

In addition, Yan et al. (2014) investigated the traffic flow impacts on BC emissions, including hourly profiles for total traffic volume, fleet composition by vehicle category, and average speed on a typical freeway (the North Fourth Ring Road in Beijing) during 2009. By applying the Emission Factor Model for the Beijing Vehicle Fleet (EMBEV) in combination with previous studies on vehicle emissions of BC, the BC emission factors and emission intensity from on-road vehicles were derived. In combination with simultaneously measured meteorological data in Beijing, dispersion of road traffic BC emissions was simulated with the AERMOD model in a roadside environment and was further validated with concurrently observed BC concentration data. Results showed that the hourly average BC emission factor was very strongly correlated with the proportion of the traffic volume of heavy-duty diesel vehicles (for example, diesel-powered passenger buses and freight trucks). Due to the traffic restrictions on truck use in the urban area of Beijing during daytime (6 a.m. to 11 p.m.), the average BC emission factor was (9.3±1.2) mg/km/veh during daytime but increased to (29.5±11.1) mg km^{-1} veh^{-1} during nighttime. Two peaks of BC emission intensity were observed synchronized with traffic volume peaks (106.1±13.0) g km^{-1} h^{-1} during the morning rush period (7:00 to 9:00) and (102.6±6.2) g km^{-1} h^{-1} during the evening rush period (5:00 to 7:00). During the day, light-duty passenger cars were the largest contributor (1.07±1.57 μg·m^{-3}, about 40% contribution) among all vehicle categories, followed by the public bus fleet (0.58±0.85 μg·m^{-3}). During nighttime, trucks became the dominant contributor (2.44±2.31 μg·m^{-3}) to the BC concentration on the road, which contributed to about 70% of the concentration.

4 Activity data for key sectors and other sectors

4.1 Household coal

The preferred method of estimating the coal use in the residential sector is to use official statistics. Many emission inventories make use of such data as inputs. In China, however, researchers found risks in directly utilizing official statistics on rural coal (Zhi et al., 2017; Zhang et al., 2020). With economic development and improvement of living conditions in China, the demand for heating in rural areas has greatly increased (Liu et al., 2013; Ma et al., 2019; Zhu et al., 2019). Especially in 2009, under the State Council's "Project to Renovate the Dilapidated Houses in Rural Areas," many farmers took the opportunity to renovate their houses and upgrade their heating approach, from a stove-direct-heating mode to a mini-boiler-water-circulation-heating mode (Ministry of Housing and Urban-Rural Development of the People Republic of China, 2009). This dramatically improves heating of the house and indoor air quality (Shan et al., 2015). At the same time, rural winter heating coal consumption greatly increased, and thus rural air quality deteriorated (Liao et al., 2017). Compared with coal use in industry and power plants, the use and circulation of rural coal are almost in a vacuum in terms of official statistics and supervision (Zhang et al., 2020), and therefore the management of rural coal use is still in a largely chaotic and non-standard condition (Peng et al., 2019; Zhi et al., 2017; Cheng et al., 2017).

Under the circumstances, the sufficient quality activity levels of residential coal consumption can only be obtained by means of investigation. Fortunately, quite a few scholars have investigated the true situation of coal consumption for rural heating in winter in recent years (Chen et al., 2018; Gao et al., 2016; Li et al., 2016a; Li et al., 2015; Liu et al., 2013; Peng et al., 2019; Ru et al., 2015; Wang and Jiang, 2017; Wang et al., 2017; Xiao et al., 2017; Zhang et al., 2015; Zhang et al., 2014; Zhao et al., 2015; Zhi et al., 2017). Zhi et al. (2017) found that coal consumption in Baoding was nearly five times that shown by the data in the government's statistical yearbook. Even in the same region the results of different studies vary considerably. For example, Liao et al. (2017) found coal consumption in Beijing to be four times greater than reported by Li et al. (2015). All of the above evidence indicates that the activity level of residential coal consumption is still very uncertain. Of particular importance is that northern China is endeavoring to switch its rural household coal use to clean energy (gas or electricity), and the rate of switching to clean energy must be considered when calculating the BC/OC emissions from rural household coal.

Meanwhile, data from investigations in a village or region usually indicate total consumption of a whole

year or winter instead of daily or monthly consumption. Moreover, once updating is needed, a new investigation has to be reorganized, which entails substantial manpower and material resources. Fortunately, there have been recent advances in building algorithms for allocation of year/winter totals to daily shares. Based on meteorological elements observed (temperature, relative humidity, wind speed, and sunshine hours), daily fractions of coal use can be derived (Zhang et al., 2020). With the algorithm, rural coal heating consumption data (Figure 6) and daily specific fractions of coal consumption (Figure 7) in China's "2+26" cities for the 2018–2019 heating season were calculated (Zhang et al., 2020). These developments have helped determine and allocate BC/OC emissions from rural household coal.
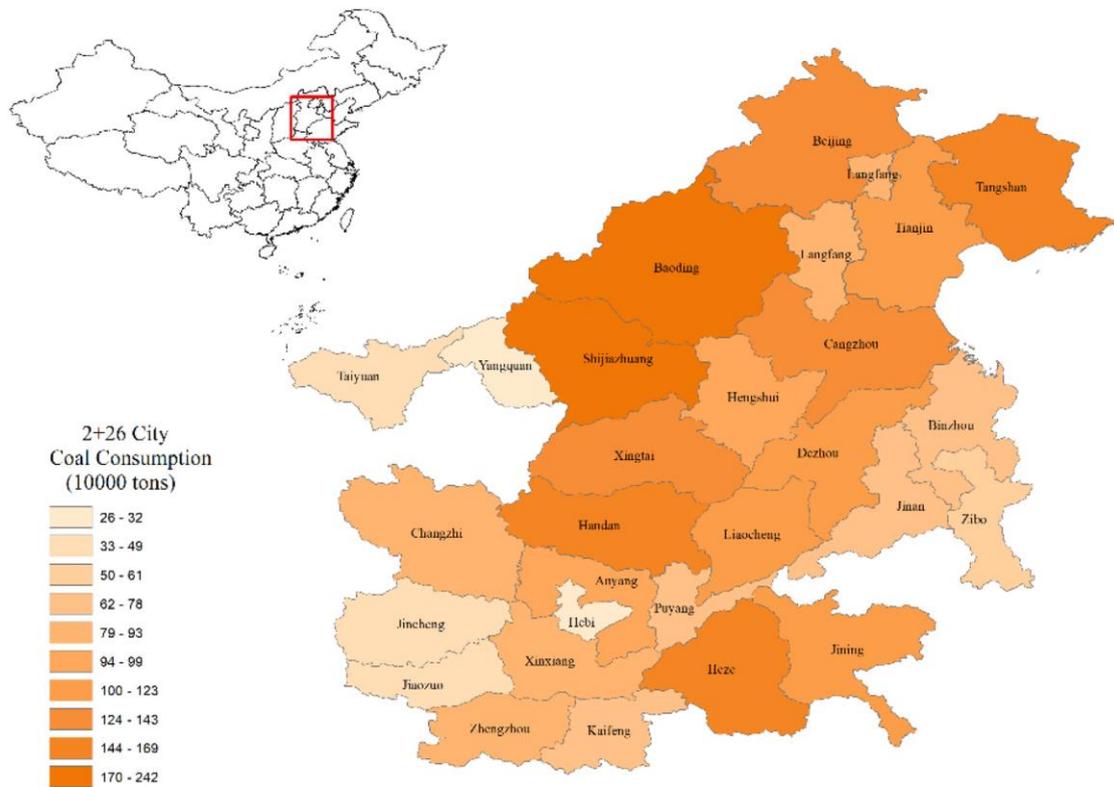
Figure 6 Algorithm-deduced rural coal heating consumption of China's "2+26" cities for the 2018–2019 heating season
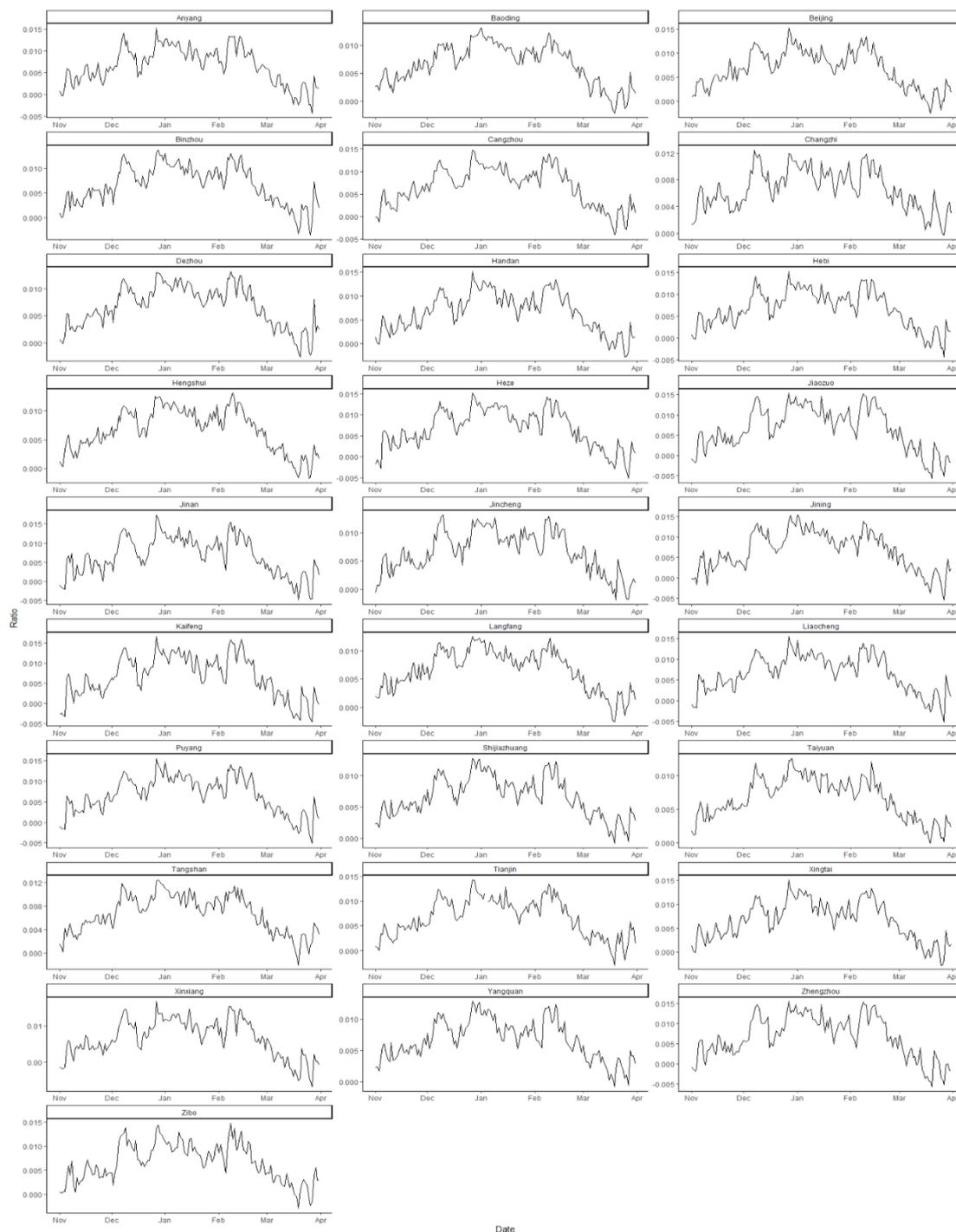
Figure 7 Temporal profile of the daily share of coal consumption for each "2+26" city during winter

4.2 Mobile sources

At present, the authoritative data are those found in the "Road Motor Vehicle Air Pollutant Emission Inventory Development Technical Guidelines" issued by the Ministry of Ecology and Environment in 2015 (MEE of China, 2015). The Guidelines divide motor vehicles into 11 categories according to their

application, weight, and size, among which passenger vehicles are classified into four types: large, medium, small, and micro; and trucks are divided into five categories: heavy-duty, medium-duty, light-duty, micro, and low-speed. Motorcycles are divided into two types: ordinary and light. Buses and taxis are listed separately from passenger cars. The annual average driving distances (VKT, km) for all types of road vehicles are given in Table 9.

Table 9 VKT recommended by the guide

Vehicle Type	VKT（km）
Small, micro passenger cars	18,000
Taxi passenger cars	120,000
Medium passenger cars	31,300
large passenger cars/Coach	58,000
Bus	60,000
light-duty, micro size truck	30,000
Medium-duty truck	35,000
Heavy-duty truck	75,000
Motorcycles	6,000
Low speed truck	30,000
Three-wheel truck	23,000

Qin Y et al. (2011) estimated the distance traveled by different vehicles by year (Table 10). We note that there are no published activity data later than 2009. Since 2009, Chinese authors have used the data recommended by the Guidelines mentioned above.

Table 10 Vehicle distance travelled (10,000 km) of each vehicle category, 2000–2009

Type	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Buses and Coaches	4.23	3.95	3.86	3.74	4.06	4.04	4.08	4.25	4.25	4.22
Passenger cars	3.75	3.80	3.85	3.90	3.95	4.00	4.00	4.00	4.00	4.00
Heavy-duty vans	5.50	5.38	6.80	6.87	7.07	7.21	7.75	8.34	8.92	9.54

		Working hours per year

Other-duty vans	3.00	2.92	3.68	3.70	3.80	3.86	4.13	4.43	4.74	5.07
Motorcycles	1.30	1.31	1.32	1.33	1.34	1.35	1.35	1.35	1.35	1.35

For the activity level of various types of non-road mobile machinery in China, recommended values are also given in the "Technical Guidelines for the Development of Inventories of Atmospheric Pollutants from Non-road Mobile Sources" issued by the Ministry of Ecology and Environment (MEE of China, 2015). The guide classifies non-road sources into engineering machinery, agricultural machinery, small general machinery, diesel generators, ships, diesel locomotives, and so on. Construction machinery includes excavators, bulldozers, loaders, forklifts, road rollers, pavers, graders, and other machinery. The agricultural machinery includes mainly tractors, agricultural transport vehicles (Farm Machinery Licensing), combine harvesters, drainage and irrigation machinery, and other machinery. Small general-purpose machines refer to small spark-ignition engines for non-road mobile machines, such as lawn mowers, powered primarily by gasoline. A diesel generator is a mobile electric generator that runs on diesel fuel at a constant speed. Vessels include inland and coastal vessels, capable of carrying out transportation and operations in navigable waters or while moored. A diesel locomotive is a railway locomotive powered by an internal combustion engine, primarily on diesel fuel, and driven by a transmission to move its wheels. For construction machinery, agricultural machinery, small general machinery, and diesel generators, the recommended average number of hours of use per year is shown in Table 11.

Table 11 Recommend working hours of non-road machinery per year

Types		Working hours per year
Construction machinery	Excavators	770
	Bulldozers	770
	Loaders	770
	Forklifts	770
	Road rollers	770
	Pavers	770
	Graders	770
	Others	770
Agricultural machinery	Large and medium tractors	500
	Small tractors	500

	Combine Harvesters	150
	Drainage and irrigation machinery	380
	Others	380
Small general-purpose machinery	Hand-held	50
	Non-hand-held	125
Diesel generators		770

It is presumed that the estimated railway locomotive activity level data are derived from diesel locomotive fuel consumption. The fuel consumption of diesel locomotives can be calculated by Railway Department Statistics or according to passenger and cargo turnover and daily freight production. The diesel locomotive fuel consumption coefficient of freight railways, passenger and freight turnover, daily freight production, and freight railway diesel locomotive fuel consumption coefficient can be obtained from relevant China Statistical Yearbooks or China Traffic Yearbooks. The ship fuel consumption is used to represent the activity level of inland river and coastal ships. The fuel consumption of inland water and coastal vessels is obtained by using data in the "Ministry of Transport of the People's Republic of China Bulletin" or data on passenger and cargo turnover from the "Highway and Waterway Transport Industry Development Statistics Bulletin" or the "China Traffic Yearbook."

References

Aamaas, B. and Berntsen, T. K. , 2021. Methodologies for the presentation of climate impact in both the short and long term, Cicero report 2021:01 and the Norwegian Environmetn Agency (NEA) report M-1719. In Norwegian but with an English summary. https://www.miljodirektoratet.no/publikasjoner/2020/juni-2020/metodikk-for-framstilling-av-klimaeffekt-pa-kort-og-lang-sikt/ (Accessed 24. June 2022)

Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., Klimont, Z., Nguyen, B., Posch, M., Rafaj, P., Sandler, R., Schöpp, W., Wagner, F., and Winiwarter, W., 2011. Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications, Environ. Modell. Softw., 26, 1489–1501, https://doi.org/10.1016/j.envsoft.2011.07.012.

Amann, M., Cofala, J., Heyes, C., Klimont, Z., Mechler, R., Posch, M., Schöpp, W., 2004. The Regional Air Pollution Information and Simulation (RAINS) model February 2004, in: Agency, E.E. (Ed.).

Andreae, M.O., Merlet, P., 2001. Emission of trace gases and aerosols from biomass burning. Global Biogeochemical Cycles 15, 955-966.

Bai C., Li Y., Jiang Z., 2016. The black carbon research status of marine vessels and the impact on the arctic (in Chinese). China shipping (second half), 16 (12): 152-154

Bond T.C, Doherty SJ, Fahey DW et al., 2013. Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research: Atmospheres. 118:5380-552. DOI: 10.1002/jgrd.50171.

Bond, T. C.; Bergstrom, R. W., 2006. Light absorption by carbonaceous particles: an investigative review. Aerosol Science and Technology, 40, 27-67.

Bond, T.C. Bhardwaj E. et al.,2007. Historical emissions of black and organic carbon aerosol from energy-relatedcombustion:1850-2000. Global Biogeochemical Cycles, vol.21, GB2018.

Bond, T.C., Streets D.G. et al., 2004. A technology-based global inventory of black and organic carbon emissions from combustion. Journal of Geophysical Research, v.109, n.D14.

Bouwman, A.F., Lee, D.S., Asman, W.A.H., Dentener, F.J., Van Der Hoek, K.W., Olivier, J.G.J., 1997. A global high-resolution emission inventory for ammonia. Global Biogeochemical Cycles 11, 561-587.

Cao G.L., Zhang X.Y., et al., 2007 Inventory of Black Carbon Emission from China, Advances in Climate Change Research, vol 3 (Suppl.),75-81.

Cao, G., Zhang, X., Gong, S., An, X., Wang, Y., 2011. Emission inventories of primary particles and pollutant gases for China. Chinese Science Bulletin 56, 781-788.

Cao, G., Zhang, X., Zheng, F., 2006. Inventory of black carbon and organic carbon emissions from China. Atmospheric Environment 40, 6516-6527.

Chen, J., Wu, Y., Song, M., Dong, Y., 2018. The residential coal consumption: Disparity in urban–rural China. Resources Conservation & Recycling 130, 60-69.

Chen, Y., Sheng, G., Bi, X., Feng, Y., Mai, B., Fu, J., 2005. Emission factors for carbonaceous particles and polycyclic aromatic hydrocarbons from residential coal combustion in China. Environmental Science & Technology 39, 1861-1867.

Chen, Y., Tian, C., Feng, Y., Zhi, G., Li, J., Zhang, G., 2015a. Measurements of emission factors of

PM2.5 , OC, EC, and BC for household stoves of coal combustion in China. Atmospheric Environment 109, 190-196.

Chen, Y., Zhi, G., Feng, Y., Fu, J., Feng, J., Sheng, G., Simoneit, B.R.T., 2006. Measurements of emission factors for primary carbonaceous particles from residential raw-coal combustion in China. Geophysical Research Letters 33, 382-385.

Chen, Y., Zhi, G., Feng, Y., Liu, D., Zhang, G., Li, J., Sheng, G., Fu, J., 2009a. Measurements of Black and Organic Carbon Emission Factors for Household Coal Combustion in China: Implication for Emission Reduction. Environmental Science & Technology 43, 9495.

Chen, Y., Zhi, G., Feng, Y., Tian, C., Bi, X., Li, J., Zhang, G., 2015b. Increase in polycyclic aromatic hydrocarbon (PAH) emissions due to briquetting: A challenge to the coal briquetting policy. Environmental Pollution 204, 58-63.

Chen, Y.J., Jiang X. H., Zhi G. R., 2009b. Black carbon emissions from residential coal combustion and reduction strategy (in Chinese). Sci China Ser D-Earth Sci 39, 1554-1559.

Cheng M, Zhi G, Tang W et al., 2017. Air pollutant emission from the underestimated households' coal consumption source in China. Science of the Total Environment. 580:641-50.

Cooke W.F. and Wilson J.N., 1996. A global black carbon aerosol model. Journal of Geophysical Research, vol. 101, n. d14, 19395-19409

Cooke W.F., Liousse C. et al.,1999. Construction of a $1° \times 1°$ fossil fuel emission data set for carbonaceous aerosol and implementation and radiative impact in the ECHAM4 mode. Journal of Geophysical Research, vol.104, n.d18:22137-22162.

Crippa, M., Solazzo, E., Huang, G., Guizzardi, D., Koffi, E., Muntean, M., Schieberle, C., Friedrich, R., Janssens-Maenhout, G., 2019. High resolution temporal profiles in the Emissions Database for Global Atmospheric Research (EDGAR), Nature Scientific Data, doi:10.1038/s41597-020-0462-2.

Development Technical Guidelines (in Chinese). 2015, Beijing China.

Fu J.F., Qi M. et al., 2018. Emissions and spatial distribution of Anthropogenic black carbon of China in 2012. Science & Technology Review,vol.36,n2.

Fu, L., Hao, J., He, D., He, K., Li, P., 2001. Assessment of vehicular pollution in China. Journal of the Air & Waste Management Association 51, 658-668.

Gao, B., Yuan, H., Geng, L., Tang, J., 2016. Analysis on rural household energy consumption in Hebei province, in: Kim, Y.H. (Ed.), Proceedings of the 2016 5th International Conference on Energy and Environmental Protection, pp. 501-504.

Granier, C.; Bessagnet, B.; Bond, T.; D'Angiola, A.; van der Gon, H. D.; Frost, G. J.; Heil, A.; Kaiser, J. W.; Kinne, S.; Klimont, Z.; Kloster, S.; Lamarque, J. F.; Liousse, C.; Masui, T.; Meleux, F.; Mieville, A.; Ohara, T.; Raut, J. C.; Riahi, K.; Schultz, M. G.; Smith, S. J.; Thompson, A.; van Aardenne, J.; van der Werf, G. R.; van Vuuren, D. P., 2011. Evolution of anthropogenic and biomass burning emissions of air pollutants at global and regional scales during the 1980-2010 period. Climate Change 109, 163–190, doi:10.1007/s10584-011-0154-1.

Guan P.B. Shi H.D. et al., 2017. Study on black carbon aerosol simulation of climate effect in China (in Chinese). Journal of Environmental Engineering Technology, vol.7,n.4:418-423.

Hoesly, R. M., Smith, S. J., Feng, L., Klimont, Z., Janssens-Maenhout, G., Pitkanen, T., Seibert, J. J., Vu, L., Andres, R. J., Bolt, R. M., Bond, T. C., Dawidowski, L., Kholod, N., Kurokawa, J.-I., Li, M., Liu, L., Lu, Z., Moura, M. C. P., O'Rourke, P. R., and Zhang, Q., 2018. Historical (1750–2014) anthropogenic emissions of reactive gases and aerosols from the Community Emissions Data System (CEDS), Geosci. Model Dev., 11, 369–408, https://doi.org/10.5194/gmd-11-369-2018.

Huang Y H, Shen Z, Chen H, et al., 2014. Quantification of Global Primary Emissions of $PM_{2.5}$, PM_{10} and TSP from Combustion and Industrial Process Sources ［J］. Environmental Science & Technology,48(23):13834－13843.

Huang Y.W., Zhao Y., et al., 2017. Research on the emission inventory of air pollutants from motor vehicles based on different methods -- A case study of Jiangsu Province (in Chinese). China Sciencepaper,n3.

Huebert, B.J., Bates, T., Russell, P.B., Shi, G., Kim, Y.J., Kawamura, K., Carmichael, G., Nakajima, T., 2003. An overview of ACE-Asia: Strategies for quantifying the relationships between Asian aerosols and their climatic impacts. Journal of Geophysical Research: Atmospheres 108.

Jacob, D.J., Crawford, J.H., Kleb, M.M., Connors, V.S., Bendura, R.J., Raper, J.L., Sachse, G.W., Gille, J.C., Emmons, L., Heald, C.L., 2003. Transport and chemical evolution over the Pacific (TRACE-P) aircraft mission: Design, execution, and first results. Journal of Geophysical Research: Atmospheres 108, D003276.

Junker, C. and Liousse, C., 2008. A global emission inventory of carbonaceous aerosol from historic records of fossil fuel and biofuel consumption for the period 1860–1997. Atmospheric Chemistry and Physics, 8, 1195-1207.

Kaiser JW, Heil A, Andreae MO et al.,2012. Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power. Biogeosciences. 9:527-54, doi:10.5194/bg-9-527-2012.

Kanaya, Y., Yamaji, K., Miyakawa, T., Taketani, F., Zhu, C., Choi, Y., Komazaki, Y., Ikeda, K., Kondo, Y., and Klimont, Z., 2020. Rapid reduction in black carbon emissions from China: evidence from 2009–2019 observations on Fukue Island, Japan, Atmos. Chem. Phys., 20, 6339–6356, https://doi.org/10.5194/acp-20-6339-2020.

Klimont, Z., Cofala, J et al., 2009. Projections of SO_2, NOx and carbonaceous aerosols emissions in Asia. Tellus 61B:602-617.

Klimont, Z., Kupiainen, K., Heyes, C., Purohit, P., Cofala, J., Rafaj, P., Borken-Kleefeld, J., and Schöpp, W., 2017. Global anthropogenic emissions of particulate matter including black carbon, Atmos. Chem. Phys., 17, 8681–8723, https://doi.org/10.5194/acp-17- 8681-2017.

Krecl P., Christer J., Targino, Admir Creso, Strom, Johan, Burman L., 2017.. Trends in black carbon and size-resolved particle number concentrations and vehicle emission factors under real-world conditions. Atmospheric Environment, 165(sep.), 155-168.

Kurokawa, J., Ohara, T., Morikawa, T., Hanayama, S., Janssensmaenhout, G., Fukui, T., Kawashima, K., Akimoto, H., 2013. Emissions of air pollutants and greenhouse gases over Asian regions during 2000–2008: Regional emission inventory in ASia (REAS) version 2. Atmospheric Chemistry and Physics 13, 11019-11058.

Lamarque J.-F.; Bond T.C.et al.,2010. Historical (1850–2000) gridded anthropogenic and biomass burning emissions of reactive gases and aerosols: methodology and application. Atmospheric Chemistry and Physics, vol.10:7017-7039.

Lee, Y. H., Lamarque, J. F., Flanner, M. G., Jiao, C., Yoon, J. H., 2012. Evaluation of preindustrial to present-day black carbon and its albedo forcing from ACCMIP (Atmospheric Chemistry and Climate Model Intercomparison Project). Atmospheric Chemistry and Physics, 12, 21713-21778.

Lei, Y., Zhang, Q., He, K.B., Streets, D.G., 2011. Primary anthropogenic aerosol emission trends for

China, 1990–2005. Atmos. Chem. Phys. 11, 931-954.

Li, G., Sun, J., Dai, A., 2016a. Village differences in rural household energy consumption within the Loess hilly region of China. Energy Sustainability and Society 6, 33.

Li, M., Liu, H., Geng, G., Hong, C., Liu, F., Song, Y., Tong, D., Zheng, B., Cui, H., Man, H., Zhang, Q., He, K., 2017a. Anthropogenic emission inventories in China: a review. National Science Review 4, 834-866.

Li, M., Zhang, Q., Kurokawa, J.I., Woo, J.H., He, K., Lu, Z., Ohara, T., Song, Y., Streets, D.G., Carmichael, G.R., Cheng, Y., Hong, C., Huo, H., Jiang, X., Kang, S., Liu, F., Su, H., Zheng, B., 2017b. MIX: a mosaic Asian anthropogenic emission inventory under the international collaboration framework of the MICS-Asia and HTAP. Atmos. Chem. Phys. 17, 935-963.

Li, N., Bian Y.H., et al.,2017. Development and verification of black carbon and organic carbon anthropogenic emission inventory in Guangdong Province (in Chinese), Acta Scientiae Circumstantiae, vol37, n2.

Li, Q., Li, X., Jiang, J., Duan, L., Ge, S., Zhang, Q., Deng, J., Wang, S., Hao, J., 2016b. Semi-coke briquettes: towards reducing emissions of primary PM2.5, particulate carbon, and carbon monoxide from household coal combustion in China. Scientific Reports 6, 19306.

Li, X., Lin, C., Wang, Y., Zhao, L., Duan, N., Wu, X., 2015. Analysis of rural household energy consumption and renewable energy systems in Zhangziying town of Beijing. Ecological Modelling 318, 184-193.

Liao, J., Jin, A.Z., Chafe, Z.A., Pillarisetti, A., Yu, T., Shan, M., Yang, X., Li, H., Liu, G., Smith, K.R., 2017. The impact of household cooking and heating with solid fuels on ambient PM2.5 in peri-urban Beijing. Atmospheric Environment 165, 62-72.

Liu, J., Mauzerall, D.L., Chen, Q., Zhang, Q., Song, Y., Peng, W., Klimont, Z., Qiu, X., Zhang, S., Hu, M., 2016. Air pollutant emissions from Chinese households: A major and underappreciated ambient pollution source. Proceedings of the National Academy of Sciences 113, 7756-7761.

Liu, W., Spaargaren, G., Heerink, N., Mol, A.P.J., Wang, C., 2013. Energy consumption practices of rural households in north China: Basic characteristics and potential for low carbon development. Energy Policy 55, 128-138.

Liu, Y., Zhang, Y.X., J., W.Y., 2007. Measurement of emission factors of carbonaceous aerosols from

residential coal combustion (in Chinese). Acta Scientiae Circumstantiae 27, 1409-1416.

Lu, Z., Zhang, Q., Streets, D.G., 2011. Sulfur dioxide and primary carbonaceous aerosol emissions in China and India, 1996–2010. Atmos. Chem. Phys. 11, 9839-9864.

Ma, W., Zhou, X., Renwick, A., 2019. Impact of off-farm income on household energy expenditures in China: Implications for rural energy transition. Energy Policy 127, 248-258.

MEE of China, 2015. The guidelines for the development of inventories of emissions from non-road mobile sources (in Chinese). Beijing China.

Ministry of Ecology and Environment of People's Republic of China, 2014. Technical Guidelines for the Development of Atmospheric Fine Particulate Matter Primary Source Emission Inventory (Trial), Beijing.

Ministry of Housing and Urban-Rural Development of the People Republic of China, 2009. Guidance on expanding the pilot of rural dangerous housing renovation, in: Ministry of Housing and Urban-Rural Development of the PRC (Ed.), Beijing.

Ni, M., Huang, J., Lu, S., Li, X., Yan, J., Cen, K., 2014. A review on black carbon emissions, worldwide and in China. Chemosphere 107, 83-93.

Ohara, T., Akimoto, H., Kurokawa, J., Horii, N., Yamaji, K., Yan, X., Hayasaka, T., 2007. An Asian emission inventory of anthropogenic emission sources for the period 1980–2020. Atmos. Chem. Phys. 7, 4419-4444.

O'Rourke, P. R, Smith, S. J., Mott, A., Ahsan, H., McDuffie, E. E., Crippa, M., Klimont, S., McDonald, B., Z., Wang, Nicholson, M. B, Feng, L., and Hoesly, R. M., 2021. CEDS v-2021-02-05 Emission Data 1975–2019 (Version Feb-05-2021). Zenodo. http://doi.org/10.5281/zenodo.4509372.

Pelegov, D. V.; Eremenko, G. A., 2021. State support of electric vehicle industry in China: the driving forces, actions and perspectives. Economy of Region, 16, (3), 921-934.

Peng, L., Zhang, Q., Yao, Z., Mauzerall, D.L., Kang, S., Du, Z., Zheng, Y., Xue, T., He, K., 2019. Underreported coal in statistics: A survey-based solid fuel consumption and emission inventory for the rural residential sector in China. Applied Energy 235, 1169-1182.

Penner J.E., Eddleman H. et al., 1993. Towards the development of a global inventory for black carbon emissions. Atmos. Environ. Part A, vol.27, 1277-1295.

Petzold, A., Ogren, J. A., Fiebig, M., Laj, P., Li, S. M., Baltensperger, U., Holzer-Popp, T., Kinne, S., Pappalardo, G., Sugimoto, N., 2013. Recommendations for reporting "black carbon" measurements. Atmospheric Chemistry and Physics, 13, (16), 8365-8379.

Qi, J., Zheng, B., Li, M., Yu, F., Chen, C., Liu, F., Zhou, X., Yuan, J., Zhang, Q., He, K., 2017. A high-resolution air pollutants emission inventory in 2013 for the Beijing-Tianjin-Hebei region, China. Atmospheric Environment 170, 156-168.

Qin Y., Xie S. D. et al., 2011. Spatial and temporal variation of anthropogenic black carbon emissions in China for the period 1980–2009. Atmos. Chem. Phys. Discuss.,vol.11: 32877-32920

Ru, M., Tao, S., Smith, K., Shen, G., Shen, H., Huang, Y., Chen, H., Chen, Y., Chen, X., Liu, J., Li, B., Wang, X., He, C., 2015. Direct energy consumption associated emissions by rural-to-urban migrants in Beijing. Environ. Sci. Technol. 49, 13708-13715.

Seinfeld, J., 2008. Atmospheric science: Black carbon and brown clouds. Nature Geoscience 1, 15-16.

Shan, M., Wang, P., Li, J., Yue, G., Yang, X., 2015. Energy and environment in Chinese rural buildings: Situations, challenges, and intervention strategies. Build Environ 91, 271-282.

Shen, G., Xue, M., Chen, Y., Yang, C., Li, W., Shen, H., Huang, Y., Zhang, Y., Chen, H., Zhu, Y., 2014. Comparison of carbonaceous particulate matter emission factors among different solid fuels burned in residential stoves. Atmospheric Environment 89, 337-345.

Shen, G., Yang, Y., Wang, W., Tao, S., Zhu, C., Min, Y., Xue, M., Ding, J., Wang, B., Wang, R., Shen, H., Li, W., Wang, X., Russell, A.G., 2010. Emission factors of particulate matter and elemental carbon for crop residues and coals burned in typical household stoves in China. Environmental Science & Technology 44, 7157-7162.

Sinton, J.E., Fridley, D.G., 2000. What goes up: Recent trends in China's energy consumption. Energy Policy 28, 671-687.

Solomon, S, Qin, D, Manning, M，Chen, Z, Marquis, M.,2007, Climate Change 2007: The Physical Science Basis - Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press: Cambridge , UK, New York, U. S. .

Song W.W., He K.B., et al., 2012. Black carbon emissions from on-road vehicles in China, 1990-2030. Atmospheric Environment, vol.51:320-328.

Streets, D.G., Bond, T.C., Carmichael, G.R., Fernandes, S.D., He, D., Klimont, Z., Nelson, S.M., Tsai, N.Y., Wang, M.Q., 2003. An inventory of gaseous and primary aerosol emissions in Asia in the year 2000. Journal of Geophysical Research Atmospheres 108, 8809.

Streets, D.G., Gupta, S., Waldhoff, S.T., Wang, M.Q., Bond, T.C., Bo, Y., 2001. Black carbon emissions in China. Atmospheric Environment 35, 4281-4296.

Streets, D.G., Zhang, Q., Wang, L., He, K., Hao, J., Wu, Y., Tang, Y., Carmichael, G.R., 2006. Revisiting China's CO emissions after the transport and chemical evolution over the Pacific (TRACE-P) mission: Synthesis of inventories, atmospheric modeling, and observations. Journal of Geophysical Research: Atmospheres 111, D07118.

Sun, J., Zhi, G., Jin, W., Chen, Y., Shen, G., Tian, C., Zhang, Y., Zong, Z., Cheng, M., Zhang, X., Zhang, Y., Liu, C., Lu, J., Wang, H., Xiang, J., Tong, L., Zhang, X., 2018. Emission factors of organic carbon and elemental carbon for residential coal and biomass fuels in China- A new database for 39 fuel-stove combinations. Atmospheric Environment 190, 241-248.

Thompson, R.J., Li, J., Weyant, C.L., Edwards, R., Lan, Q., Rothman, N., Hu, W., Dang, J., Dang, A., Smith, K.R., Bond, T.C., 2019. Field emission measurements of solid fuel stoves in Yunnan, China demonstrate dominant causes of uncertainty in household emission inventories. Environmental Science & Technology 53, 3323-3330.

Tian, J., Ni, H., Cao, J., Han, Y., Wang, Q., Wang, X., Chen, L.W.A., Chow, J.C., Watson, J.G., Wei, C., Sun, J., Zhang, T., Huang, R., 2017. Characteristics of carbonaceous particles from residential coal combustion and agricultural biomass burning in China. Atmospheric Pollution Research 8, 521-527.

Tong, D., Cheng, J., Liu, Y., Yu, S., Yan, L., Hong, C., Qin, Y., Zhao, H., Zheng, Y., Geng, G., Li, M., Liu, F., Zhang, Y., Zheng, B., Clarke, L., Zhang, Q., 2020. Dynamic projection of anthropogenic emissions in China: methodology and 2015–2050 emission pathways under a range of socio-economic, climate policy, and pollution control scenarios. Atmos. Chem. Phys. 20, 5729-5757.

UNEP and WMO, 2011. Integrated assessment of black carbon and tropospheric ozone: summary for decision makers.

UNEP, 2015. The Climate and Environmental Benefits of Controlling SLCPs in P.R. China. United Nations Environment Programme (UNEP), Nairobi, Kenya.

US EPA, 2012. Report to congress on black carbon (EPA-450/R-12-001). EPA, US

US EPA. 40 CFR Part 50. https://www3.epa.gov/ttn/amtic/40cfr50.html [2006-10-17]/2020-11-13.

Vignati, E.; Karl, M.; Krol, M.; Wilson, J.; Stier, P.; Cavalli, F., 2010. Sources of uncertainties in modelling black carbon at the global scale. Atmospheric Chemistry and Physics. 10, 2595-2611.

Wang, R., Jiang, Z., 2017. Energy consumption in China's rural areas: A study based on the village energy survey. Journal of Cleaner Production 143, 452-461.

Wang, R., Tao, S., Wang, W., Liu, J., Shen, H., Shen, G., Wang, B., Liu, X., Li, W., Huang, Y., Zhang, Y., Lu, Y., Chen, H., Chen, Y., Wang, C., Zhu, D., Wang, X., Li, B., Liu, W., Ma, J., 2012. Black carbon emissions in China from 1949 to 2050. Environmental Science & Technology 46, 7595-7603.

Wang, X., Li, K., Li, H., Bai, D., Liu, J., 2017. Research on China's rural household energy consumption – Household investigation of typical counties in 8 economic zones. Renewable and Sustainable Energy Reviews 68, 28-32.

Winijkul, E., Bond, T.C., 2016. Emissions from residential combustion considering end-uses and spatial constraints: Part II, emission reduction scenarios. Atmospheric Environment 124, 1-11.

Xiao, H., Li, J., Li, Z., Han, F., Li, H., 2017. Energy consumption in rural Beijing: Current situation and major influence factors – based on the survey of 1866 rural househoulds in Beijing (In Chinese). Journal of China Agricultural Resources and Regional Planning 38, 127-137.

Xu J.W., Ma J.L., et al., 2018. Study on black carbon Emission characteristics of Motor Vehicles in Guangdong Province (in Chinese). Transport Energy Conservation & Environmental Protection,n5.

Yan Han, Wu Ye et al., 2014. Emission characteristics and concentrations of vehicular black carbon in a typical freeway traffic environment of Beijing (in Chinese). Acta Scientiae Circumstantiae, vol36,n8.

Yun Y.F., 2020. Study on ship black carbon emission in North pole (in Chinese). China marine safety, n10,40-42

Zhang Y, Zhi G, Guo S et al., 2020. Algorithm developed for dynamic quantification of coal consumption for and emission from rural winter heating. Science of the Total Environment. 737:doi: 10.1016/j.scitotenv.2020.139762.

Zhang, C., Zheng, J., Zang, P., Huang, Y., 2015. Rural household energy consumption structure and its influencing factors in Beijing-Tianjin-Hebei region (in Chinese). Chinese Agricultural Science Bulletin 31, 258-262.

Zhang, N., Qin, Y., Xie, S., 2013. Spatial distribution of black carbon emissions in China. Chinese Science Bulletin 58, 3830-3839.

Zhang, Q., Streets, D.G., Carmichael, G.R., He, K.B., Huo, H., Kannari, A., Klimont, Z., Park, I.S., Reddy, S., Fu, J.S., 2009. Asian emissions in 2006 for the NASA INTEX-B mission. Atmospheric Chemistry & Physics 9, 5131-5153.

Zhang, Y., Jiang, J., Ye, J., Fu, M., Zhang, F., 2014. Analysis of rural life energy consumption in Beijing-Tianjin-Hebei and suggestion on coal reduction and replace (In Chinese). Energy of China 56, 39-43.

Zhang, Y., Schauer, J.J., Zhang, Y., Zeng, L., Wei, Y., Liu, Y., Shao, M., 2008. Characteristics of particulate carbon emissions from real-world Chinese coal combustion. Environmental Science & Technology 42, 5068-5073.

Zhao X., 2019. Top-down estimate of regional black carbon emissions using ground and satellite observations for the Yangtze River Delta Region. Nanjing: Nanjing University;.

Zhao, B., Wang, P., Ma, J.Z., Zhu, S., Pozzer, A., Li, W., 2012. A high-resolution emission inventory of primary pollutants for the Huabei region, China. Atmos. Chem. Phys. 12, 481-501.

Zhao, W., Xu, Q., Li, L., Jiang, L., Zhang, D., Chen, T., 2015. Estimation of air pollutant emissions from coal burning in the semi-rural areas of Beijing plain (in Chinese). Research of Environmental Sciences 28, 869-876.

Zhao, Y., Nielsen, C.P., Lei, Y., McElroy, M.B., Hao, J., 2011. Quantifying the uncertainties of a bottom-up emission inventory of anthropogenic atmospheric pollutants in China. Atmos. Chem. Phys. 11, 2295-2308.

Zhao, Y., Zhang, J., Nielsen, C.P., 2013. The effects of recent control policies on trends in emissions of anthropogenic atmospheric pollutants and CO_2 in China. Atmos. Chem. Phys. 13, 487-508.

Zheng X.,2016. Emisison characteristics of black carbon and polycyclic aromatic hydrocarbon from heavy-duty diesel vehicles based on PEMS method (Ph.D. dissertation, in Chinese). Tsinghua University, Beijing, China.

Zhi G. R., 2008. Measurement methods of black carbon and its emission factors for household coal combustion, Guangzhou Institute of Geochemistry. Chinese Academy of Sciences, Guangzhou.

Zhi, G., Chen, Y., Feng, Y., Xiong, S., Li, J., Zhang, G., Sheng, G., Fu, J., 2008. Emission Characteristics of Carbonaceous Particles from Various Residential Coal-Stoves in China. Environmental Science & Technology 42, 3310.

Zhi, G., Peng, C., Chen, Y., Liu, D., Sheng, G., Fu, J., 2009. Deployment of coal-briquettes and improved stoves: possibly an option for both environment and climate. Environmental Science & Technology. 43, 5586-5591.

Zhi, G., Yang, J., Zhang, T., Guan, J., Du, J., Xue, Z., Meng, F., 2015. Rural household coal use survey, emission estimation and policy implications (in Chinese). Research of Environmental Sciences 28, 1179-1185.

Zhi, G., Zhang, Y., Sun, J., Cheng, M., Dang, H., Liu, S., Yang, J., Zhang, Y., Xue, Z., Li, S., Meng, F., 2017. Village energy survey reveals missing rural raw coal in northern China: Significance in science and policy. Environmental Pollution 233, 705-712.

Zhou S.L., Wei W.D. et al., 2018. Cross-regional black carbon transfer and management strategy: based on MRIO and WRF/Chem models(in Chinese). Journal of Environmental Economics, n4.

Zhu, X., Yun, X., Meng, W., Xu, H., Du, W., Shen, G., Cheng, H., Ma, J., Tao, S., 2019. Stacked Use and Transition Trends of Rural Household Energy in Mainland China. Environmental Science & Technology 53, 521-529.

Appendix

Table 12 the ratios of BC and OC from PM found in the literature

Mobile category	source	Fuel type	China 2 and before		China 3		China 4		China 5	
			BC	OC	BC	OC	BC	OC	BC	OC
Vehicle		Diesel	0.51	0.32	0.51	0.32	0.66	0.21	0.70	0.21
		Gasoline	0.27	0.58	0.27	0.58	0.27	0.58	0.27	0.58
Off-Road	construction machinery	Diesel	0.31	0.44	0.41	0.29	/	/	/	/

			China 1	China 2	China 3	China 4	China 5			
	agricultural machinery	Diesel	0.31	0.44	0.41	0.29	/	/	/	/

Table 13 PM$_{10}$ emission factors of vehicles recommended in the guideline (g/km)

			China 1	China 2	China 3	China 4	China 5
Passenger Vehicle	Light-Duty	Gasoline	0.029	0.012	0.008	0.003	0.003
		Diesel	0.070	0.058	0.036	0.034	0.034
	Medium-Duty	Gasoline	0.067	0.020	0.012	0.007	0.007
		Diesel	0.516	0.174	0.164	0.118	0.059
	Heavy-Duty	Gasoline	0.177	0.080	0.049	0.049	0.049
		Diesel	1.092	0.980	0.439	0.280	0.140
Truck	Light-Duty	Gasoline	0.067	0.020	0.012	0.007	0.007
		Diesel	0.299	0.290	0.114	0.064	0.013
	Medium-Duty	Gasoline	0.177	0.080	0.049	0.049	0.049
		Diesel	1.006	0.303	0.190	0.110	0.022
	Heavy-Duty	Gasoline	0.177	0.080	0.049	0.049	0.049
		Diesel	0.692	0.558	0.270	0.153	0.030

Table 14 PM$_{10}$ emission factors of machinery recommended in the guideline (g/kW.h)

Power Range	Fuel Type	Before China 1	China 1	China 2	China 3
Power<37kW	Diesel	1.2	1	0.95	0.55
Power > 37, < 56kW	Diesel	1.0	0.85	0.40	0.35
Power>75, <130kW	Diesel	0.8	0.7	0.3	0.25
Power>130kW	Diesel	0.7	0.54	0.20	0.18

The BC/OC emission factors obtained in the project are listed in Table 15 (on-road vehicles) and

Table 16 (off-road machinery) with Table 12 multiplied the data in Table 13 and Table 14.

Table 15 BC/OC emission factors of on-road vehicles (g/kW.h)

			China 1		China 2		China 3		China 4		China 5	
			BC	OC	BC	OC	BC	OC	BC	OC	BC	OC
Passenger Vehicle	Light-Duty	Gasoline	0.00783	0.01682	0.00324	0.00696	0.00216	0.00464	0.00081	0.00174	0.00081	0.00174
		Diesel	0.0357	0.0224	0.02958	0.01856	0.02016	0.01152	0.02244	0.00714	0.02448	0.00714
	Medium-Duty	Gasoline	0.01809	0.03886	0.0054	0.0116	0.00324	0.00696	0.00189	0.00406	0.00189	0.00406
		Diesel	0.26316	0.16512	0.08874	0.05568	0.09184	0.05248	0.07788	0.02478	0.04284	0.01239
	Heavy-Duty	Gasoline	0.04779	0.10266	0.0216	0.0464	0.01323	0.02842	0.01323	0.02842	0.01323	0.02842
		Diesel	0.55692	0.34944	0.4998	0.3136	0.24584	0.14048	0.1848	0.0588	0.1008	0.0294
Truck	Light-Duty	Gasoline	0.01809	0.03886	0.0054	0.0116	0.00324	0.00696	0.00189	0.00406	0.00189	0.00406
		Diesel	0.15249	0.09568	0.1479	0.0928	0.06384	0.03648	0.04224	0.01344	0.00936	0.00273
	Medium-Duty	Gasoline	0.04779	0.10266	0.0216	0.0464	0.01323	0.02842	0.01323	0.02842	0.01323	0.02842
		Diesel	0.51306	0.32192	0.15453	0.09696	0.1064	0.0608	0.0726	0.0231	0.01584	0.00462
	Heavy-Duty	Gasoline	0.04779	0.10266	0.0216	0.0464	0.01323	0.02842	0.01323	0.02842	0.01323	0.02842
		Diesel	0.35292	0.22144	0.28458	0.17856	0.1512	0.0864	0.10098	0.03213	0.0216	0.0063

Table 16 BC/OC emission factors of off-road machineries (g/kW.h)

Machinery Type		Before China 1		China 1		China 2		China 3	
		BC	OC	BC	OC	BC	OC	BC	OC
Construction Machinery	Excavators (100kW)	0.248	0.352	0.217	0.308	0.093	0.132	0.1125	0.0825
	Bulldozers (120kW)	0.248	0.352	0.217	0.308	0.093	0.132	0.1125	0.0825
	Loaders (135kW)	0.217	0.308	0.1674	0.2376	0.062	0.088	0.081	0.0594
	Forklifts (40kW)	0.31	0.44	0.2635	0.374	0.124	0.176	0.1575	0.1155
	Rollers (110kW)	0.248	0.352	0.217	0.308	0.093	0.132	0.1125	0.0825
	Paving machinery (80kW)	0.248	0.352	0.217	0.308	0.093	0.132	0.1125	0.0825
	Graders (110kW)	0.248	0.352	0.217	0.308	0.093	0.132	0.1125	0.0825
	Others (Diesel)(30kW)	0.372	0.528	0.31	0.44	0.2945	0.418	0.2475	0.1815
Agriculture Machinery	Larger and Medium Tractors (29.2kW)	0.372	0.528	0.31	0.44	0.2945	0.418	0.2475	0.1815
	Small Tractors (9.6kW)	0.372	0.528	0.31	0.44	0.2945	0.418	0.2475	0.1815
	Combine Harvesters (42.5kW)	0.31	0.44	0.2635	0.374	0.124	0.176	0.1575	0.1155
	Irrigation Machinerys (14.9kW)	0.372	0.528	0.31	0.44	0.2945	0.418	0.2475	0.1815
	Others (Diesel)(3.0kW)	0.372	0.528	0.31	0.44	0.2945	0.418	0.2475	0.1815

Table 17 BC factors of inland ships from the literature

Literature	EF/ (g/kg fuel)	Method
Lack D.A, Light absorbing carbon emissions from commercial shipping, Geophys. 25 Res. Lett., 35, 2008	0.36-1	Optical
Agrawal, H., Emission measurements from a crude oil tanker at sea, Environmental Science & Technology, 42 (19), 2008	0.1	Thermal
Corbett, J.J., Updated emissions from ocean shipping. Journal of Geophysical Research: Atmospheres, 108, 4650,2003	0.37	/
Petzold, A., Recommendations for reporting "black carbon" measurements. Atmospheric Chemistry and Physics, 13, 2013	0.06（85% load） 0.36（10% load）	Thermal
Naya Olmer, Bryan Comer, et al. Greenhouse gas emissions from global shipping, 2013–2015 Detailed methodology, ICCT, 2017	stroke, 50%laod HFO: 0.49(g/kg fuel) Distillate: 0.26(g/kg fuel) Average of HFO and Distillate: 0.375	/