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Supplement of

Evaluating China's fossil-fuel CO_2 emissions from a comprehensive dataset of nine inventories

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Figure S1

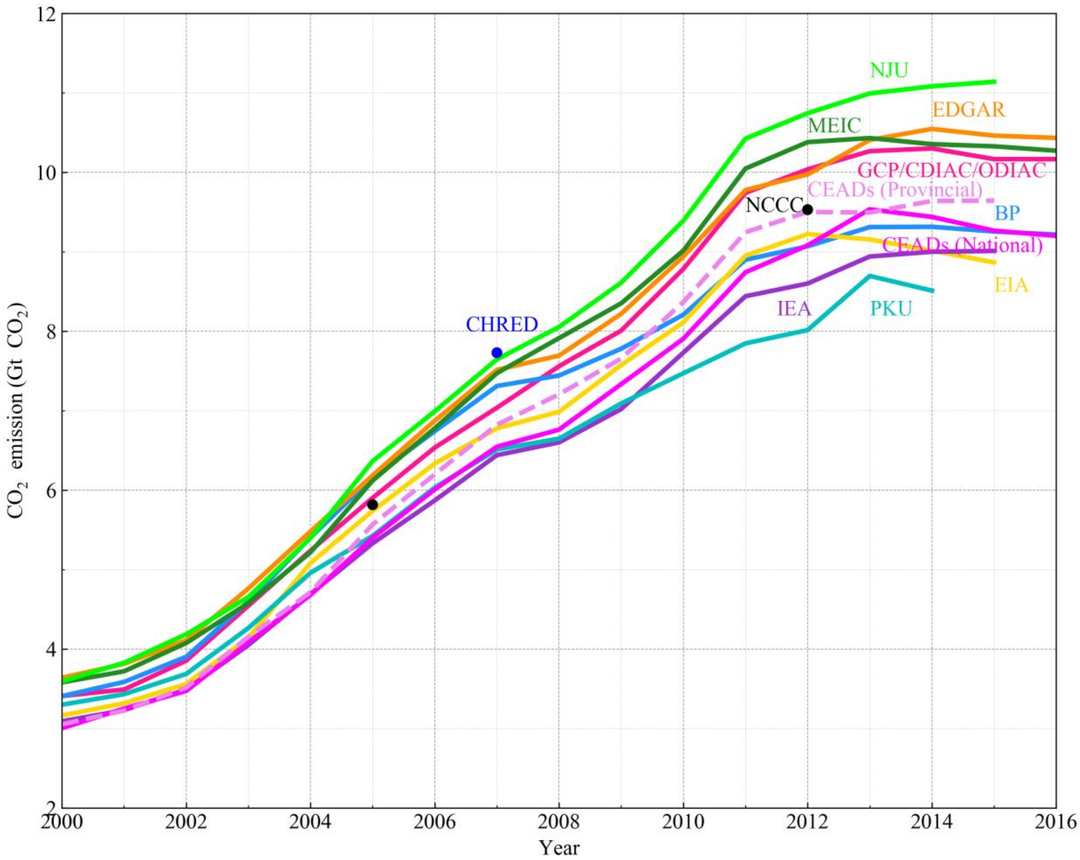

Fig. S1 China's total $FFCO_2$ emissions from 2000 to 2016. The emissions are from combustion of fossil fuels and cement production from different sources (IEA, EIA and BP estimates do not include cement production. EDGARv4.3.2_FT2016 includes international aviation and marine bunkers emissions). The values for 6 gridded emission inventories are tabular data provided by data developers before spatial disaggregation (e.g. (Oda, 2018)). For GCP data prior to 2014, it was from CDIAC and 2015-2016 was calculated based on BP data and fraction of cement production emission in 2014(Le Quéré, 2018).

Figure S2

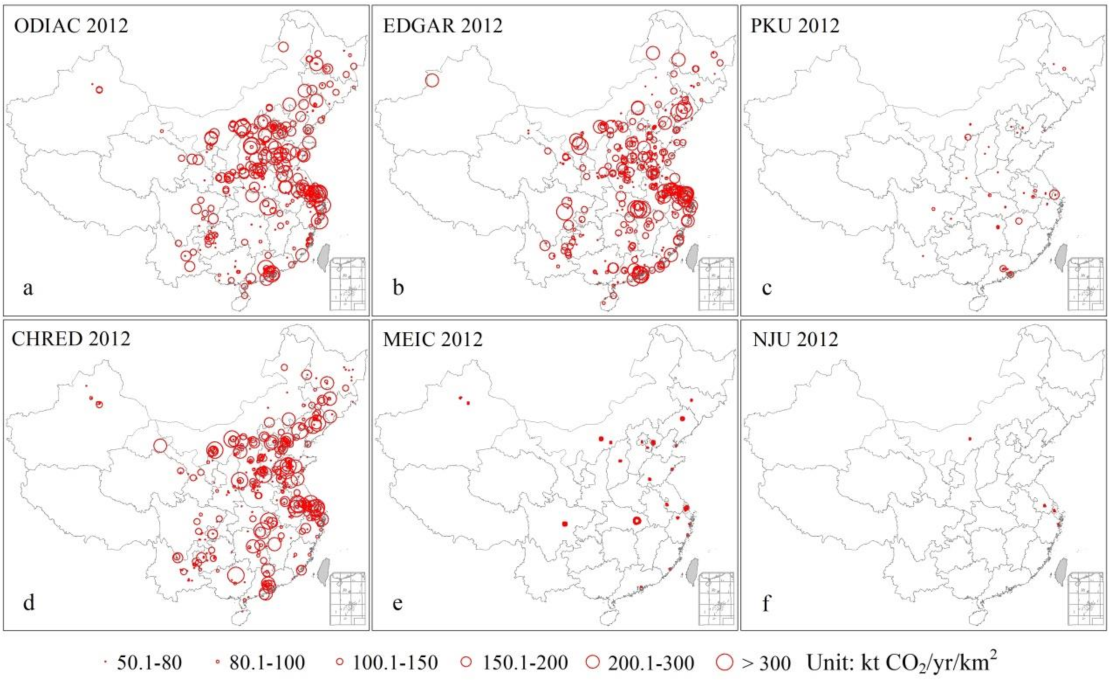

Figure S2 High-emitting grids bubble plots for ODIAC, EDGAR, PKU, CHRED, MEIC and NJU in 2012 at 10 km resolution.

Figure S3

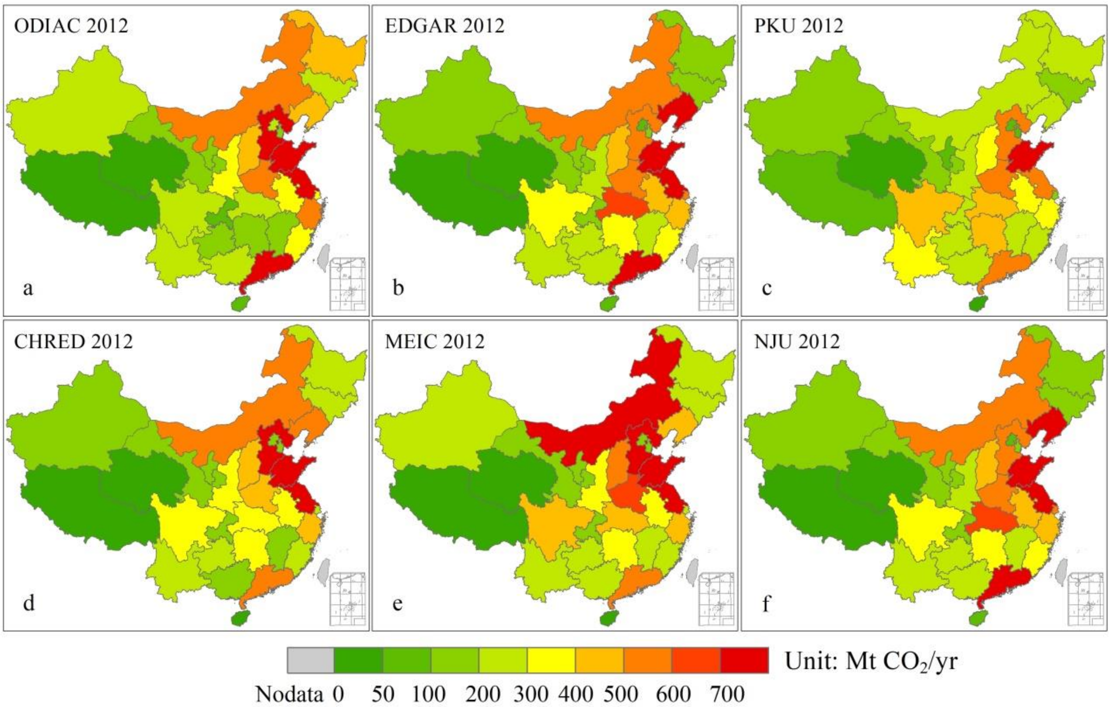

Figure S3 The spatial distribution of provincial total emissions for ODIAC, EDGAR, PKU, CHRED, MEIC and NJU in 2012.

Table S1

Table S1 Summary of total emission estimates*

Data	ODIAC2017	EDGARv432	PKU	CHRED	MEIC	NJU	CEADs
Emission estimates	Global & National	National	Subnational	Provincial	Provincial	Provincial	National, provincial, city
Emissions sectors:							
Power;	√	√	√	√	√	√	√
Industry;	√	√	√	√	√	√	√
Transportation;	√	√	√	√	√	√	√
Residential and commercial;	√	√	√	√	√	√	√
Cement production;	√	√	√	√	√	√	√
Other industrial processes;	√	√	√	√	√	√	
Intern. aviation and bunkers;		√					
Agriculture;		√	√	√			
Waste;		√	√	√		√	
Natural (Wild fire)			√				

Emission calculation method	Apparent consumption	Sectoral approach	Apparent consumption	Sectoral approach	Sectoral approach	Sectoral approach	Apparent consumption
Fuel data used	UN statistics (Boden, 2016), and (BP, 2016)	(IEA, 2014), (BP, 2016)	(IEA, 2014)	FCPSC (2011); (Wang et al., 2014)	(NBS, 2018)	(NBS, 2016)	(NBS, 2016)
Emission factor for raw coal (tC per t of coal)	0.746	0.713	0.510	0.518	0.491	0.518	0.499

Emission factor for oil (tC per t of oil)	0.850	0.838	0.758	0.839	0.829	0.820	0.829
Emission factor for natural gas (tC per thousand m^3 of natural gas)	0.521	0.521	0.651	0.591	0.584	0.590	0.584
Emission factor for cement production (tC per t of cement)	0.131	0.104	0.147	0.075	0.187	0.095	0.074
Uncertainty	17.5% (95% CI)	±15%	±19% (95% CI)	±8%	±15%	7-10% (90% CI)	-15% - 25% (95% CI)

Notes	Estimates are based on CDIAC. Uncertainty estimate is based on (Andres et al., 2014)	Uncertainties for non-Annex I countries from (Olivier et al., 2015)	Monte Carlo simulations of 1000 times on all grids for the activity data and emission factors' PDFs	The uncertainty of activity data and emission factors is no more than 6% and 5%	Monte Carlo simulations of 10,000 times for input parameter PDFs	7-10% (90% CI)	Monte Carlo simulations of 100,000 times for the activity data and emission factors' PDFs

* CI: Confidence interval; PDFs: Probability density functions.

Table S2

Table S2 Summary of spatial disaggregation approach*

	Data	ODIAC	EDGAR	PKU	CHRED	MEIC	NJU	CEADs
	Spatial resolution	1 km	0.1 degree	0.1 degree	10 km	0.25 degree	0.25 degree	national, provincial, city scales
Point source	Data	CARMA2.0	CARMA3.0	CARMA2.0	FCPSC	CPED	CEC;ACC;CC TEN	N/A

	Notes	Geolocation and emission estimates for 720 point sources in China	1706 point sources for China	715 in year 2000 and 1007 in 2007 for China	1.58 million industrial enterprises	A unit-based 2320 power plants data	240-824 PP+CP during 2000-2016	N/A
Line source	Data	N/A	the OpenStreetMap and OpenRailwayMap (using different weighting factors), Int. aviation and bunker	N/A	The national road, railway, navigation network, and traffic flows	Transport networks	N/A	N/A

Area source	Data	Nighttime light	Population density, nighttime light	Vegetation and population density, nighttime light	Population density, land use, human activity	Population density, land use	Population density, GDP	N/A
Notes		Street light might help for line sources (Oda, 2011); 1km data do not include int. aviation and bunker	INP includes CP, iron and steel, non-ferrous metals and various chemicals	INP includes CP, coke, brick and aluminum production	INP includes CP, lime production, iron and steel production, glass production, and ammonia production.	N/A	INP includes cement and glass, chemical, and metal productions	INP only include CP (75% of total INP)

* INP: Industry process; CP: Cement production; PP: Power plants; N/A: Not available

Methodology and source data of main data sets

1. ODIAC-The Open-source Data Inventory for Anthropogenic CO_2

The Open-source Data Inventory for Anthropogenic CO_2 (ODIAC) is a global monthly high-resolution (1x1km) gridded fossil fuel CO_2 emission data product(Oda, 2018;Oda, 2011). This high-resolution emission dataset was originally designed for high-resolution atmospheric CO_2 tracer transport model simulations and flux inversions.

ODIAC is primarily based on country emission estimates made by the Carbon Dioxide Information Analysis Center (CDIAC) at the Oak Ridge National Laboratory. The CDIAC emission estimates are made by fuel types such as coal, gas, oil (e.g. Marland and Rotty, 1984(Marland and Rotty, 1984)). CDIAC estimates also include emissions from cement production, gas flaring and international bunker. Emissions for the recent years are projected using BP. Major improves than previous ODIACv1.7 includes: (1) the use of the CDIAC emissions estimates instead of our own estimates, (2) the use of multiple spatial emissions disaggregation methods to distribute CDIAC national emission estimates, and (3) the inclusion of temporal variations. We extrapolated the 2013 CDIAC emissions to years 2014 and 2015 using the 2016 version of the BP global fuel statistical data(BP, 2016). We simply used the same fractions of emissions from cement production and gas flaring in 2013 (approximately 5.7 and 0.6 % of the global total; Boden et al., 2016(Boden, 2016)). International bunker emissions were scaled using changes in national total emissions.

The ODIAC spatially distributes emissions in two steps. First, the power plant emissions are mapped using the geolocation and emission estimates of point sources taken the Carbon Monitoring for Action (CARMA2.0)(Wheeler and Ummel, 2008). We might have less point sources than others with CARMA 2.0 and 3.0 as we eliminated some of the point sources with wrong geolocations after visual inspection (720 point sources in China left). The number of the point sources remains the same across years, and emission magnitude was scaled by national totals. The spatial distributions of the rest of the emissions (the total emission minus point source emissions) are then estimates using the nighttime light data collected from the Defense Meteorological Satellite Program (DMSP) satellites(Oda, 2018;Oda, 2011). We used a product that does not have an instrument saturation issue rather than a regular nighttime light product(Ziskin, 2010). The improved nighttime light data have mitigated the underestimation of emissions over dimmer areas seen in ODIAC v1.7(Oda, 2010).We separately distributed CDIAC gas flare emissions using a 1×1 km nighttime light-based gas flare maps(Elvidge et al., 2009). We identified and excluded bright gas flare pixels before distributing emissions using a global nighttime light product that was specifically developed for gas flares by NOAA, National Centers for Environmental Information (NCEI, formerly National Geophysical Data Center, NGDC)(Oda, 2011).

The year 2017 version was used of the ODIAC data product (ODIAC2017(Tomohiro Oda, 2015)) that covers from 2000 to 2016. The data product is available from the Center for Global Environmental Research (CGER, http://db.cger.nies.go.jp/dataset/ODIAC/).

2. EDGAR-The Emission Database for Global Atmospheric Research (EDGAR) V4.3.2

Overview

The Emissions Database for Global Atmospheric Research is a comprehensive global gridded emission dataset that indicates greenhouse gases and atmospheric pollutants. The first version of EDGAR (EDGAR v2) was firstly published by Olivier et al. (1996)(Olivier, 1996) (http: //edgar.jrc.ec.europa.eu/index.php#) and has been heavily used in the atmospheric chemistry and carbon cycle researches. In this study, we used the most updated version of EDGAR (EDGAR v4.3.2, -2014)(Janssens-Maenhout, 2017). The data are available from the EDGAR official website http://edgar.jrc.ec.europa.eu/overview.php?v=432_GHG&SECURE=123.

Emission calculations

The emissions are calculated based on the latest scientific knowledge and best available global statistics, following methods defined by IPCC (2006)(IPCC, 2006). Emission factors are technology-specific for different processes. Emissions reported by countries, such as UNFCCC, are not used to keep internal consistency and impartiality in the database. In EDGAR, country total CO_2 emissions (E) are calculated using the following equation:

$$E=\sum_{i,j,k}[AD_i * TECH_{i,j} * EOP_{i,j,k} * EF_{i,j} * (1 - RED_{i,j,k})] \quad (1)$$

where i is a given sector, AD refers to activity data, j is technology (TECH), k represents (end-of-pipe) abatement measure (EOP) installed with share k for each technology j, EF refers to uncontrolled emission factor and RED is relative reduction by abatement measure k. The activity data include consumed energy (TJ) of a certain fuel, the amount of products manufactured, etc. CO_2 emissions are mainly driven by the carbon content of the fuel in the combustion process. Technology-specific EFs are applied to different infrastructures (e.g. different distribution networks) or management processes. EDGAR v4.3.2 has monthly time step (http://edgar.jrc.ec.europa.eu/overview.php?v=432_GHG&SECURE=123).

Definitions of source sectors

The source sectors are defined according to the codes used in the 1996 IPCC guidelines, but with updates to the 2006 IPCC guidelines (IPCC, 2006)(IPCC, 2006) with all sectors related to fuel consumptions considered. By contrast, the Land-Use, Land-Use Change and Forestry sector is not included due to data limitation. Therefore, biomass burning (wild fire) is not included in this new version. For the CO_2 fluxes result from forests biomass, we use results from Petrescu et al. (2012)(Petrescu, 2012). This version is mostly based on international statistics such as IEA (2014)(IEA, 2014) and FAOSTAT (2014)(FAOSTAT, 2014), and raw data was preprocessed for completeness and consistency, such as removing outliers and filling holes with a linear interpolation for near year data. The national data from the Chinese Bureau for statistics is consulted to make sure the quality of activity data with consumption of fuels (fossil and biofuel) and of products (such as cement, metals, chemicals and solvents). To ensure consistency and comparability, CO_2 emission factors are selected from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 2006)(IPCC, 2006).

The input datasets for point, line and area sources were processed using GIS techniques for conversion, resampling and aggregation on a 0.1° × 0.1° grid resolution.

Emission factors and Activity data

Energy statistics:

Data for the annual energy content of fossil fuel consumption was derived from the IEA energy balance statistics (IEA, 2014)(IEA, 2014) for 1970-2012. This dataset comprises 64 fuel types and 94 fuel use activities. The biofuel data for China are supplemented with the data from USDA (2014)(USDA, 2014).

Fossil fuel production statistics

Based on the World Coal Association (2016)(association, 2016), the hard coal and brown coal production data have been separated into surface and underground mining. For gas transmission and distribution, the leakage rate is assumed proportional to the pipelines length and determined by its construction material. Pipeline length and 2012 material statistics are mainly taken from reports on Europe by the Eurogas (2010)(Eurogas, 2010) report and Marcogaz (2013)(Marcogaz, 2013) technical sheet, UNFCCC National Inventory Reports (2014)(UNFCCC, 2014). The total amount of natural gas flared from 1994 onwards is primarily determined from the NOAA satellite observation of the intensity of flaring lights (Elvidge et al. 2009)(Elvidge et al., 2009).

Industrial processes statistics

CO_2 from cement production is based on the Tier 1 EF for clinker production, whereas clinker production is calculated from cement production reported by USGS (2014)(USGS, 2014) using clinker to cement ratio from the China Cement Almanac. Iron and steel production is further split into technologies using data of WSA (2014)(WSA, 2015). For other CO_2 sources such as lime, soda ash and ammonia production, we combine USGS (2014)(USGS, 2014) and the UNFCCC (2014)(UNFCCC, 2014) data. Urea production data is from IFA (2015)(IFA, 2015), which considers the fossil carbon in CO_2 from ammonia production.

Agricultural statistics

Following IPCC (2006)(IPCC, 2006) methodology we apply FAO crop and livestock data and IPCC (2006) emission factors for CO_2. Livestock numbers are combined with estimates for animal waste per head to estimate the total amount of animal waste produced. The fraction of crop residues removed from and burned in the field is estimated using data of Yevich and Logan (2003)(Yevich and Logan, 2003) and UNFCCC (2014)(UNFCCC, 2014) for the fraction burned in the field by Annex I countries.

Spatial modeling of emissions

The spatial distribution of EDGAR is based on disaggregation of country sectoral total emissions. As an important input to global atmospheric transport and inversion models, EDGAR v4.3.2 disaggregates CO_2 emissions over a 0.1x0.1 grid. The emissions can be emitted either from a point source or a linear source or an area source. The line and area sources are distributed over the grid cells with the proxy data covering the globe entirely or partially, whereas the point sources are allocated to individual grid cells using geographical coordinate (lat and lon). A detailed description for spatial mapping is available in the EDGAR gridding manual(Janssens-Maenhout, 2013). A key proxy dataset is the gridded world population provided by the Center for International Earth Science Information Network (CIESIN) for the years 1990, 1995, 2000, 2005, 2010 and projected to 2015(CIESIN: Center for International Earth Science Information Network - CIESIN - Columbia University et al., 2005). Industrial activities are mainly located at the plant location coordinates on the point source grid-maps. Power plant emissions have been distributed according to the CARMAv3.0 (2012)(CARMAv3.0, 2012) point source distribution. CARMA's point sources with low intensity are used to allocate emissions from auto-producing power or heat plants. A specific proxy was mainly developed for cement and lime for China based on the plant locations and annual throughput of the facility listed by the CEC (2014)(CEC, 2014, 2015) for China. Because of the incompleteness of the list of cement factories, annual emission estimates per facility were applied. For the major coal producers, the coordinates of coal mines from the World coal association (2016)(association, 2016) are used to distribute emissions. Coal mine locations for China have been updated and extended with the data of Liu et al. (2015)(Liu et al., 2015). Line sources are exclusively used to describe emissions from the transport sector. For example, road maps can tell you where the roads are located, but the real question is how to distribute emissions on to the road map. So different proxy data layers for three road types worldwide (highways, primary and secondary, residential and commercial roads) obtained from the OpenStreetMap of Geofabrik (2015)(Geofabrik, 2015) are used with different weighting factors for the emission distribution, depending on road types. Similar data from OpenRailwayMap are used for railways. For inland waterways the maritime traffic lines (for ships and ferries) are composed from the navigable parts of rivers and lakes, using the hydrology map of Lehner et al. (2011)(Lehner et al., 2011). Wang et al. (2008)(Chengfeng et al., 2008) is used for international shipping. The spatial proxy for the aviation sector is derived from International Civil Aviation Organization(ICAO, 2015) flight information. Input data regarding airports and routes are taken from "Airline Route Mapper". It should be noted that point sources are jointly constrained by the country total. Line sources are correlated one-dimensionally along the lines within the length of the total network. For more detailed considerations of uncertainty grid-maps we refer to Andres et al. (2016)(Andres et al., 2016). The total estimate data was from EDGARv4.3.2_FT2016. The annual spatial data of EDGARv4.3.2

used in this study was from 2000 to 2012 with a resolution at 0.1 × 0.1 degree.

3. PKU-CO_2

The PKU-CO_2 data set was constructed for 64 fuel sub-types in 5 categories and 6 sectors, in addition to cement production(Wang, 2013). Due to differences in data sources and data processing methods, the 64 fuel sub-types were classified into 8 groups, namely (1) wildfires, (2) aviation/shipping, (3) power stations, (4) natural gas flaring, (5) agricultural solid wastes, (6) non-organized waste incineration, (7) dung cakes, and (8) others. County-level fuel consumptions in China were determined based on the provincial fuel consumption(NBS, 2008) and a set of provincial-data-based regression models(Zhang et al., 2007).

Based on PKU-FUEL data, CO_2 emissions were calculated using CO_2 emission factors (EFC) and the combustion rates for different fuel types. EFC for all combustion processes were derived as the means of data collected from the literature. Specially, EFC for oil consumed inpetroleum refinery industry was from Nyboer et al. (2006)(Nyboer, 2006), and EFC for oil consumed by 7 ship types and 5 types of biomass burning were collected from Wang et al. (2008)(Wang, 2008) and van der Werf et al. (2010)(van der Werf, 2010). For the remaining fuel types, EFC were collected from URS (2003)(URS, 2003), IPCC (1996)(IPCC, 1996), US Department of Energy (2000)(Energy, 2000), API (2001)((API), 2001), and US EPA (2008)((USEPA), 2008). Fixed combusted rates of 0.990, 0.980, 0.995, 0.980, 0.901,0.887, 0.789, 0.919, and 0.901 were applied to petroleum, coal, natural gas, solid municipal and industrial waste fuel, biomass burned in the field, firewood burned in cook stoves, firewood burned in fireplaces, crop residue burned in cook stoves, and open burning of agriculture waste, respectively(Lee, 2005;Johnson, 2008;Oda, 2011;Zhang, 2008). CO_2 emissions from cement production were also compiled. These are based on cement production data in 155 countries (USGS, 2010)((USGS), 2010) and CO_2 emission factors from the literature(Andres, 1996). Country-level reported CO_2 emissions from cement production were disaggregated to 0.1°×0.1° grids using the industrial coal consumption map from PKU-FUEL as a proxy, hence making the assumption that cement manufactures are co-located with coal consumption.

Accuracy of the location of the power plants were examined(Wang, 2013). The locations for 100 randomly selected power plants for China were checked one by one in Google imagery. It was found that 45 % of the stations are located in the same grid points (0.1°×0.1°) as reported in the CARMA v2.0 database, and that the remaining 42% stations are actually located in grids adjacent to the one listed in CARMA v2.0. This suggests that the accuracy of the CARMA v2.0 power plant spatial localization errors in China are relatively large for 0.1°×0.1° resolution mapping. Thus, the authors suggest that location of power plants is expected to be updated when an improved version of CARMA product is available. The monthly PKU-CO_2-v2 inventory data was used for evaluation over the periods 2000—2014.

4. CHRED-China High Resolution Emission Database

The CHRED CO_2 data covers emissions from energy combustion, industrial processes, transportation, agriculture, households and services. Details about the emission estimation and spatial disaggregation methods can refer to previous work(Cai et al., 2012;Wang et al., 2014;Cai et al., 2016a;Cai et al., 2016b;Cai and Zhang, 2014). The CHRED uses a bottom-up method to calculate total emissions which is based on the data of each individual enterprise. Emissions from transportation, agriculture, and services are estimated based on proxy data. Specifically, emissions from the transport are calculated based on provincial data for energy consumption of the transport sector(Cai et al., 2012). We spatialized the total transport emissions using two datasets: 1) data for the national road network, railway network, navigation network, and air-port locations; 2) and traffic flows of these networks. We disaggregated provincial agricultural emissions to each grid based on farmland spatial distribution at the 30 m × 30 m spatial resolution. Moreover, we disaggregated emissions from services at the province level to each grid based on spatial distribution of built-up areas. CHRED contains a core account and an extension account. The core account contains emissions by industries, and the extended account contains socioeconomic data (e.g., land uses, population, and human activity data) which are supplemental to emission data.

The total emission for year 2007 was summed from the gridded data. The spatial data of year 2012 used in this study was rescaled from the 2007 emissions provided by Cai et al., (2018)(Cai et al., 2018) by a factor according to the CO_2 emission inventory in 2012 from NCCC.

5. MEIC-Multi-resolution Emission Inventory for China

Overview

The Multi-resolution Emission Inventory for China (MEIC) is a bottom-up emission inventory framework developed and maintained by Tsinghua University, which uses a technology-based methodology to calculate air pollutant and CO_2 emissions for more than 700 anthropogenic sources for China from 1990 to the present. With the detailed source classification, the MEIC model can represent emission characteristics from different sectors, fuels, products, combustion/process technologies, and emission control technologies. The MEIC model improved the bottom-up emission inventories developed by the same group(Zhang, 2009), with major improvements of a unit-based power plant emission database(Liu, 2015), a high-resolution vehicle emission modeling approach(Zheng, 2014), an explicit NMVOC speciation assignment methodology(Li, 2014), and a unified, online framework for emission calculation, process, and download (available at http://www.meicmodel.org). In this study, we used the most updated version of MEIC 1.3(Zheng, 2018), and derived emissions data between the years 2000 and 2016.

Emission calculations

The MEIC model calculates CO_2 emissions for 31 provinces in mainland China using the technology-based method as follows:

$$Emis_{i,j} = A_{i,j} \times \sum_{m} \left(X_{i,j,m} \times EF_{i,j,m} \right)$$

Where i represents the province, j represents the emission source, m represents the technologies for manufacturing, A is the activity rate, X is the fraction of a specific manufacturing technology, EF is the CO_2 emission factor. The details of the technology-based approach can be found in Zhang et al. (2007, 2009)(Zhang, 2007, 2009), Lei et al. (2011)(Lei et al., 2011), and Li et al. (2017)(Li, 2017).

Emissions from power plants and on-road vehicles are calculated using more detailed methods that can achieve high spatial resolutions in emissions mapping. The unit-based method is developed to track emissions for each coal-fired power plant based on unit-specific parameters, including boiler type, fuel consumption, fuel quality, and electricity generation(Liu, 2015). Emissions from on-road vehicles are estimated using a county-level database developed by Zheng et al. (2014)(Zheng, 2014), which resolves the spatial distribution of vehicle ownership in each county as well as the vehicle kilometers traveled on different types of roads. Detailed documentation of the method and data for power plants and on-road vehicles can be found in Liu et al. (2015)(Liu, 2015) and Zheng et al. (2014)(Zheng, 2014), respectively.

Definitions of source sectors

The MEIC model covers more than 700 anthropogenic sources in China, including all the combustion sources and industrial processes that generate CO_2 emissions. For example, the MEIC calculates CO_2 emissions from the combustion of coal, oil, and natural gas used in stationary (i.e., industrial and residential facilities) and mobile (i.e., on-road and off-road) sources, as well as from the industrial processes of cement and lime production. All the detailed anthropogenic sources that emit CO_2 are classified into several sub-sectors and finally grouped into four source sectors used in the analysis of this study. The four sectors are power, industry, residential, and transportation, and their relations with IPCC source codes are as follows.

Table. The MEIC source sectors and IPCC codes

MEIC sub-sector	MEIC sector	IPCC codes
power	power	1A1a
industrial heating	industry	1A1bc
residential heating	residential	1A1bc
industrial boiler	industry	1A2
residential combustion	residential	1A4
iron and steel	industry	1A2, 2C
cement	industry	1A2, 2A
other industrial process	industry	2A, 2B, 2C, 2D, 1B
on-road vehicles	transportation	1A3b
motorcycles	transportation	1A3b

off-road	transportation	1A3c, 1A3d, 1A3e

Emission factors and Activity data

Activity rates of energy consumptions by fuel type, by sector, and by province are derived from China Energy Statistical Yearbook. The production of cement and lime in each province are achieved from China Statistical Yearbook. For the coal-fired power plants, we derive the unit-level activity data from the unpublished database owned by the Ministry of Ecology and Environment. These data are collected from each plant by local agencies, and then managed and verified by Ministry of Ecology and Environment. Emission factors of CO_2 in MEIC are based on Liu et al. (2015)(Liu et al., 2015).

Spatial modelling of emissions

The spatial modelling of emissions in MEIC is conducted for the point, nonpoint, and mobile sources, respectively. The point sources (i.e., coal-fired power plants) in MEIC have accurate geographical coordinates, which are visually checked using the Google Map and are used to locate the emissions for each point source. The nonpoint sources emissions are first estimated at the provincial level and then spatially allocated to each county and 30″×30″ grid cells according to spatial proxies such as urban or rural extents(Schneider, 2009) and population distributions((ORNL), 2013). The mobile source (i.e., on-road vehicles) emissions are estimated at the county level and allocated to grid cells according to the road map. The spatial modelling methods uses in MEIC are summarized in the following table. The 30″×30″ emissions map of MEIC are finally aggregated to 0.25×0.25 degrees when the data product published, because a finer resolution could induce large uncertainties due to the nonlinear relationship between emissions and spatial proxies(Zheng, 2017).

Table. Spatial modelling methods and proxies used in MEIC.

Sector	**Source**	**Province to county**	**County to grid**
Power	Coal-fired power plants	Point source (geographical coordinates)	
	Other power plants	Industrial GDP	Urban population
Industry	All	Industrial GDP	Urban population
Residential	Urban	Urban population	Urban population
	Rural	Rural population	Rural population
Transportation	On-road	/	Road network
	Motorcycle	Vehicle numbers	Road network

	Off-road: agriculture	Machine power	Rural population
	Off-road: construction	Total GDP	Urban population
	Off-road: other sources	Total population	Total population

In this study, we used the MEIC data from the latest version 1.3 excluding biofuel emissions specially prepared by Bo Zheng(Zheng et al., 2018) to increase comparability, and derived the 2000-2016 monthly CO_2 emissions from power, industry, residential, and transportation sectors at the spatial resolution of 0.25 × 0.25 degree.

6. NJU-CO2

The Intergovernmental Panel on Climate Change (IPCC) sectoral approach (IPCC, 2006) was used to develop NJU-CO_2 emission inventories for 31 provinces in China (excluding Hong Kong, Macao and Taiwan) from 2000 to 2016. Total fossil fuel consumption data were calculated from a production perspective based on final energy consumption, plus energy used for transformation minus non-energy use. Emissions from fossil fuel consumption were further divided into three sub-sectors of industrial energy consumption (IEC), transportation energy consumption (TEC) and other energy consumption (OEC). Emissions from fossil fuel use for international bunker were not calculated here. Emissions from industrial processes (INP) referred to direct CO_2 emissions from chemical or physical transformation of materials during non-combustion industrial production (e.g., cement, steel, etc.) processes(Wang, 2012). Data on energy consumption for the whole of society and for each sector in provinces were derived from provincial energy balance tables in the China Energy Statistical Yearbook, with exception of transportation fuel consumption. For Tibet, CO_2 emissions from IEC and OEC have not been calculated due to data shortage. Fuel use by road transportation was calculated as the product of vehicle mileage traveled and the relevant fuel economy. Data on vehicle populations were taken from the statistical yearbooks(NBS, 2008, 2016) for each province. Vehicle mileage traveled (VMT) and fuel economy (FE) data were taken from previous studies(Wang, 2010, 2011). Industrial products were taken from the statistical yearbooks for each province and the China Cement Yearbook. The authors substituted cement production with clinker production in order to calculate CO_2 emissions from the cement industrial process. Activity data (AD), such as energy consumption and industrial production, are primarily from two sources: China's provincial statistics and national statistics, which do not match well. A triangular distribution function is assumed for AD data for limited samples(Brinkman, 2005;Wu, 2010). The national data point was set as the minimum value, and then the maximum value was calculated by adding up the provincial AD data and absolute difference between provincial and national statistics.

As power plants accounted for nearly 30 % of China's total emissions(Zhao, 2012) and cement production accounted for 60 % of emissions from INP, we mapped those emissions as large point sources (LPS) and identify their locations exactly by latitude and longitude. Power plants ranking in the top 80 % in terms of electricity production(CEC, 2014, 2015) and cement plants with capacity above1 Mt yr^{-1} were selected as LPS in this study. We derived the geographical coordinate of LPS by checking their addresses with Google Earth. Some LPS that could not be identified for lack of information were included in area emissions. The emissions from other sources (except LPS) were treated as area emission and allocated to each grid at 0.25° resolution via the proxies of population and/or GDP (gross domestic product). The 1 km×1 km gridded data of China's population and GDP densities(Liu, 2005;Yang et al., 2009) from 2000 to 2009 were developed and applied. Here we used the most up to date NJU-CO_2 version 2017 provided by data developer.

7. CEADs-China Emission Accounts and Datasets

CEADs provides time-series multi-scale CO_2 emission inventories for China, its provinces and cities. The national and provincial level emission inventories from 1997 to 2015 can be collected from the CEADs website(CEADs) or Figshare(Shan Y, 2018a). The inventory for 182 Chinese cities in 2010 can be collected in the same way as well(Shan Y, 2018b;Shan et al., 2018a).

CEADs CO_2 emissions were estimated with the IPCC administrative territorial-based scope which do not include emissions from international aviation and shipping(Barrett J, 2013). The CO_2 emissions include both fossil fuel- and process-related (cement) emissions. The emissions related to electricity and heat consumption are not considered as these parts belong to scope 2 indirect emissions. The emissions induced by electricity and heat generation are allocated to the power sectors instead. Meanwhile, the fossil fuel used as industrial materials (known as non-energy use) are excluded from the total consumption as well.

CEADs provides two approaches of fossil fuel consumption and CO_2 emissions: the sectoral approach and reference approach. The sectoral approach is calculated from the consumption perspective of fossil fuel, while the reference approach is calculated from the production side of three primary fuels. The sectoral emission inventories are constructed as 47 socioeconomic sectors, 17 fossil fuels, and the industrial process emissions.

The CO_2 emissions are calculated by Mass Balance Theory, they equal to activity data (fossil fuel consumption or industrial production) timed by emission factors. The fossil fuel consumption is collected based on Energy Balance Table (for national and provincial level). Restricted by the data quality at the city level, CEADs develops a series of methods to estimate the city level Energy Balance Table(Shan Y, 2017). In this way, the city level emission inventories are designed in the same way with the national and provincial inventories, making them consistent and comparable. Then the CEADs adopts the “crowd-sourcing” working mode to compile and verify the city level emission inventories. Emission factors used by CEADs datasets are collected from Liu, Guan’s previous studies(Liu et al., 2015) on China’s energy qualities. The factors are measured based on a wide survey of over 4000 coal mines in China, and are assumed to be more accurate than the IPCC default value. The factors are adopted by the Chinese governments in its third National Communications on Climate Change(NDRC, 2016).

Detailed information about CEADs emission inventories and their calculation methods can be found at Shan, Guan(Shan et al., 2018b). The annual CEADs at both national and provincial level emissions from 2000 to 2015 were used in the present study.

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