Methods for Estimating Energy-related CO2 Emissions and Gridding of Energy Consumption and Carbon Emissions Data

1. Estimation Method for Energy related CO_2 Emissions

Estimation method for energy related CO_2 emissions is mainly derived from the classical material balance method, i.e., to estimate CO_2 emissions based on activity data of various energy and carbon emission factors, which is particularly express as:

$$\mathrm{E} = \sum_{g} AD_{i,j,g} \times EF_{i,j,g} \times R$$

Where E is CO_2 emissions; AD is activity data; I is energy of various types; J is various facilities using various energy types; g is various grids; EF is carbon emission factors; and R is carbon oxidation rate, which is set as 1 in this research.

In the estimation, the energy types (i) mainly include 4 types, including coal, oil, natural gas and imported electricity. On the basis of various facilities (j), coal can be further divided into 8 types, including coal for electricity, coal for heating, coking coal, Pulverized coal used for injection(PCI), feed coal, lump coal, steam coal used in other industries, and coke; oil divided into 7 types, including gasoline, diesel, fuel oil, kerosene, liquid petroleum gas (LPG), refinery gas, and other petroleum products; and natural gas divided into 2 types, including natural gas for electricity and natural gas for other use. The heating values and carbon emission factors are different even for the same type of energy used in various facilities. See Table 1 for more details.

Table 1. Net heat value and related carbon emission factors of various energy types.

		Net Heat value MJ/kg、MJ/m³	Emission factors kg-C/MJ
coal	coal for electricity	21.41	26.78
	coal for heating	20.54	26.78
	coking coal	27.71	25.21
	PCI	26.14	27.39
	Lump coal	25.68	26.86
	feed coal	24.89	26.29
	steam coal used in other industries	21.74	26.29
	Coke	28.43	29.20
Oil	gasoline	43.07	18.92
	diesel	43.51	20.22
	kerosene	43.07	19.12
	fuel oil	41.82	21.12
	LPG	50.18	17.22
	refinery gas	46.00	15.72
	other oil products	35.43	20.02
Natural gas	Natural gas used by power plants	34.71	15.32
	Natural gas used by other sectors	36.30	15.32

Data source: net heat value and carbon emission factors of oil and natural gas are from [25]; coal related data are from authors' estimation.

2. Method of Gridding of Energy Consumption and Carbon Emissions Data

2.1. Point Emission Sources

Point source data means energy consumption and carbon emissions with specific longitude and latitude locations within Shanghai. In 2010, Shanghai point sources for energy consumption and carbon emissions cover 26 power plant, which further divided into 20 coal-fired power plants, 4 gas-fired power plants and 2 oil-fired power plants; 8 centralized heating enterprises; 4 iron and steel production sets; 7 chemical enterprises and chemical industry parks; 3 gas plants and over 3,000 middle and small coal-fired boilers. In addition to the above point sources, other energy and emission data that specific locations cannot be identified will be disaggregate in the area source data.

2.2. Line Sources

Line source data means traffic line emission sources bearing traffic oil consumption and associated CO_2 emissions, including on-road transportation, waterway transportation and air transportation. This research mainly focuses on oil consumed by on-road transportation and associated CO_2 emissions. Other relevant data related to waterway transportation and air transportation is exclude.

Methods of estimating on-road transportation related oil consumption and associated CO_2 emissions are usually divided into "bottom-up" and "top-down" two approaches. The "bottom-up" approach estimates based mainly on the parameters of vehicle types, volume, driving distance and fuel economy of vehicles. The "top-down" approach estimates based mainly on the oil consumption of transportation sector and the follow-up subdivision according to various vehicles with various oil consumption. Currently, the data of driving distance and fuel economy of various vehicles in Shanghai possesses higher uncertainty, while the oil consumption statistic data is relatively more accurate and reliable, with lower uncertainty. Hence, we apply the "top-down" approach to estimate on-road transportation related energy consumption and total associated CO_2 emissions. Then we distribute the on-road traffic energy consumption and related CO_2 emissions into each grid with the consideration of traffic flow by road types in different urban regions. Specific estimating method is as below:

(1) To re-calculate and obtain the on-road transportation oil consumption in accordance with Shanghai energy statistic data and the division method of oil consumption sector. Shanghai energy statistic data counts oil consumption based on legal entities, instead of ultimate utilization. Hence, in Shanghai Statistical Yearbook on Energy, oil consumed by the "traffic, transportation and storage" sector only include oil consumed by the public transportation sector, excluding oil consumed by private traffic sector. To reveal the actual traffic oil consumption, oil consumed by other sectors will be disassembled and incorporated into the transport sector. Given the China oil statistical system and Shanghai's oil consumption features, and considering pertinent literatures and empirical data from statisticians, oil consumed by on-road transportation is disassembled in the following methods and principles that: (a) all the oil consumed by the transportation, storage and mail industries are subsumed into oil consumption of the transport sector; (b) all the oil consumed by the residents is subsumed into oil consumption of the transport sector; (c) all the gasoline and half of the diesel consumed by the wholesale, retrial, accommodation and catering industries is subsumed into oil consumption of the transport sector; (d) half of the gasoline and diesel consumed by industry sector is subsumed into oil consumption of the transport sector; (e) all the oil consumed by the primary industry is subsumed into oil consumption of the transport sector; (f) oil consumed by transport sector is further disassembled into on-road traffic, waterway traffic and air traffic based on the features of petroleum products. The kerosene consumed by the transport sector is subsumed into air traffic oil consumption. Fuel oil and 10% of diesel consumed by the transport sector is subsumed into waterway traffic oil consumption; all the rest oil consumed by the transport sector is subsumed into on-road traffic oil consumption.

(2) To identify Shanghai's daily turnover volume of vehicles in terms of regions and road types according to the data of Shanghai daily turnover of motor vehicles by regions, motor vehicle volumes and traffic capacity by road types, developed by Shanghai City Comprehensive Transportation Planning Institution (CCTPI), and then to disassemble the traffic oil consumption by regions and by road types according to such weights.

Among these, in the light of Shanghai spatial configuration, the urban regions are divided into five regions, which are Puxi inside the Inner Ring Viaduct (Pxii), Pudong inside the Inner Ring Viaduct (Pdii), Puxi between the Inner Ring Viaduct and the Outer Ring Viaduct (Pxio), Pudong between the Inner Ring Viaduct and the Outer Ring (Pdio), and areas outside Outer Ring Viaduct (Aoo). Road types are divided into four grades, namely the fast road (including expressway), main road, secondary main road and local roads. See Table 2 for more detailed and ultimate confirmed proportion of Shanghai daily turnover volume of motor vehicles by various regions and by various road types.

Table 2. Ratio of annual turnover volume of motor vehicles for Shanghai (by regions and road types)

Road types	Centre city				Suburb
	Pxii	Pdii	Pxio	Pdio	Aoo
Fast road	32.3%	27.9%	49.3%	49.7%	34.8%
Primary road	36.1%	39.7%	26.1%	23.5%	35.4%
Secondary road	17.0%	21.7%	11.4%	13.2%	17.5%
Local road	14.6%	10.7%	13.1%	13.7%	12.2%
Sum	100.0%	100.0%	100.0%	100.0%	100.0%

Data source: Author estimated based on report from CCTPI.

(3) To count the length of roads of various types via GIS, and then to calculate the corresponding oil consumption based on oil consumption intensity and length of roads by various regions and various types.

(4) To add up all the length of roads of various types in each grid, and then to calculate oil consumption of various oil types in each grid.

(5) To estimate associated CO_2 emissions of on-road transportation in various grids according to the oil consumption of various oil types in each grid.

2.3. Area Sources

Area source data means energy consumption whose geo-spatial locations cannot be identified. Such energy consumption is usually characterized by "low-quantity and wide-area diffused", such as energy consumed by commercial sector, residential sector and industrial enterprises below designated size. We make use of usage characteristics of various energy types in each area source data, taking socioeconomic data that can reflect such characteristics as proxy system, so as to indirectly obtain the gridded energy consumption and associated CO_2 emission data. The mentioned proxy system is mainly the GDP grouped by regions and by industries, Shanghai population distribution by streets, and Shanghai industrial concentration data. GDP data grouped by regions and by industries is from Shanghai statistical bureau, population distribution by streets is from China's sixth nationwide census data, and industrial concentration trend is represented by the concentration of middle and small sized boilers in each grid. See Table 3 for more detailed corresponding relationship between energy consumption and reference system.

Table 3. Proxies used for disaggregating energy and CO_2 emissions to grids.

Fuel type	Sectors	Proxy
Coal	middle & small coal fired boilers	Industry concentration
Oil	industrial enterprises below designated size	Industry concentration
	commercial sector	GDP of tertiary industry
	Resident sector	Population
	Agriculture	GDP of agriculture
Natural gas	industrial enterprises below designated size	Industry concentration
	commercial sector	GDP of tertiary industry
	Resident sector	population