Chapter 2
China's National, Regional, and City's Carbon Emission Inventories

Consistent, comprehensive, and accurate estimates of carbon emissions from fossil fuel combustion and cement production are fundamental prerequisites to understanding the global carbon cycle and designing evidenced-based policies for reducing carbon emissions. Uncertainty in estimates of carbon emissions from fossil fuel combustion [1–6] arises from inconsistencies in data sources for both activity data (e.g., the amount of fuel burnt or energy produced) and emission factors (EFs, the amount of carbon oxidized per unit of fuel combusted, EF is the product of the net heating value v, net carbon content c, percent carbon content C_{ar}, and oxidization rate o).

2.1 Methodology for Emission Accounting

2.1.1 Calculation of Carbon Emissions from Fossil Fuel Combustion

Carbon emissions are calculated by using activity data, which are expressed as the amount of fossil fuels in physical units used during a production processes (activity data $_{\text{clinker}}$ is the amount of clinker produced) multiplied by the respective emission factor (EF).

$$\text{Emission} = \text{activity data} \times \text{emission factor (EF)} \tag{2.1}$$

Emissions from cement manufacturing are estimated as:

$$\text{Emission}_{\text{cement}} = \text{activity data}_{\text{ clinker}} \times \text{EF}_{\text{clinker}} \tag{2.2}$$

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If data on sectorial and fuel-specific activity data and EF are available, total emission can be calculated by:

$$\text{Emission} = \sum\sum\sum(\text{activity data}_{i,j,k} \times \text{EF}_{i,j,k}) \tag{2.3}$$

where i is an index for fuel types, j for sectors, and k for technology type. Activity data are measured in physical units (tons of fuel expressed as t fuel).

EF can be further separated into net heating value of each fuel v, the energy obtained per unit of fuel (TJ per t fuel), carbon content c (t C TJ^{-1} fuel), and oxidization rate o the fraction (in %) of fuel oxidized during combustion and emitted to the atmosphere. The values of v, c, and o are specific for fuel type, sector, and technology.

$$\text{Emission} = \sum\sum\sum(\text{activity data}_{i,j,k} \times v_{i,j,k} \times c_{i,j,k} \times o_{i,j,k}) \tag{2.4}$$

For the coal extracted in China (e.g., for the 4,243 coal mines analyzed in this study), net heating v and carbon content c values are not directly available, and a more straightforward emission estimate for coal emissions can be obtained using the mass carbon content (C_{ar} in t C per t fuel) of fuels defined by $C_{ar} = c \times v$ so that the total emission can be calculated as:

$$\text{Emission} = \sum\sum\sum(\text{activity data}_{i,j,k} \times C_{\text{ar}\ i,j,k} \times o_{i,j,k}) \tag{2.5}$$

The activity data can be directly extracted as the final energy consumption from energy statistics, or estimated based on the mass balance of energy, the so-called apparent energy consumption estimation:

$$\begin{aligned}&\text{Apparent energy consumption} = \text{domestic production} + \text{imports} - \text{exports}\\&+/-\text{change in stocks} - \text{non energy use of fuels}\end{aligned} \tag{2.6}$$

2.1.2 *Calculation of Carbon Emission from Cement Production*

The carbon emission from cement production is due to the production of clinker, which is the major component of cement. When clinker is produced from raw materials, the calcination process of calcium carbonate ($CaCO_3$) and cement kiln dust (CKD) releases CO_2:

$$CaCO_3 \rightarrow CaO + CO_2$$

The amount of emission can be calculated from the molar masses of CaO (55.68 g $mole^{-1}$) and carbon (12 g $mole^{-1}$) and the proportion of their masses in clinker production. Furthermore, the emission associated with CKD that is not recycled to the kiln is calculated using the CKD correction factor, CF_{cdk}.

Carbon emission from cement production can be calculated by clinker emission factor ($EF_{clinker}$) and clinker production.

$$\mathrm{Emission}_{\mathrm{cement}} = \mathrm{Activity\ data}_{\mathrm{clinker}} \times \mathrm{EF}_{\mathrm{clinker}} \tag{2.7}$$

$$\mathrm{EF}_{\mathrm{clinker}} = \mathrm{EF\,CaO} \times (1 + \mathrm{CF}_{\mathrm{cdk}}) \tag{2.8}$$

$$\mathrm{EF\,CaO}_{\mathrm{clinker}} = \mathrm{Fraction\,CaO} \times (12/55.68) = \mathrm{Fraction\,CaO} \times 0.2155 \tag{2.9}$$

Fraction CaO is the mass proportion of CaO per unit clinker (in %).

EF $CaO_{clinker}$ is the mass of total carbon emission released as CaO per unit of clinker (unit: t C per t clinker).

CF_{cdk} is the CKD correction factor (in %).

$EF_{clinker}$ is the mass of total carbon emission per unit of clinker (t C per t clinker)

Clinker is the major component of cement. However, data on clinker production are less widely reported than those of cement production. When the data of clinker production are not available, the clinker-to-cement ratio "$R_{clinker\text{-}cement}$" (in %) can be used for estimating the cement emission factor (EF_{cement}) and further estimate the emission based on cement production.

$$\mathrm{R}_{\mathrm{clinker\text{-}cement}} = \mathrm{activity\ data}_{\mathrm{clinker}} / \mathrm{activity\ data}_{\mathrm{cement}} \tag{2.10}$$

$$\mathrm{EF}_{\mathrm{cement}} = R_{\mathrm{cement\text{-}clinker}} \times \mathrm{EF}_{\mathrm{clinker}} \tag{2.11}$$

$$\mathrm{Emission}_{\mathrm{cement}} = \mathrm{EF}_{\mathrm{cement}} \times M_{\mathrm{cement}} \tag{2.12}$$

The IPCC default Fraction CaO (clinker) is 64.6 %, and the Fraction CaO (cement) is 63.5 %; thus, the IPCC default $EF_{clinker}$ is 0.1384 (t C per t clinker). In the IPCC 1996 guideline, the clinker-to-cement ratio is 95 %, which assumes that most cement is Portland cement and that the corresponding default EF_{cement} is 0.1360 (t C per t clinker). In the IPCC 2006 guideline, the clinker-to-cement ratio is 75 % when no direct clinker production data are available, and the corresponding default EF_{cement} is 0.1065 (t C per t clinker). In this study, the clinker-to-cement ratio is calculated using clinker production statistics and cement production statistics.

It should be noted that the non-energy use of fossil fuels and other industrial process such as ammonia production, lime production, and steel production will also produce carbon emissions. To keep consistent with the scope of international dataset we are comparing, those emissions are not included in this study. Based on the previous study, the total emission of these non-energy fuel use and industry processes was equivalent to 1.2 % of China's emissions from fossil combustion in 2008 [6].

2.1.3 Calculation of Carbon Emission from Industrial Process

Carbon emissions from industrial production refer to the CO_2 released from the physical–chemical process of transforming raw materials into industrial products. The fossil fuels used in this transformation stage are considered the carbon emissions from fossil fuel combustion performed by the industrial sectors and are not considered as the industrial process emissions. For example, emissions from the calcination of calcium carbonate ($CaCO_3 \rightarrow CaO + CO_2$) are considered industrial process emissions. By contrast, emissions from fossil energy usage during the calcination process are considered energy-related emissions.

According to the IPCC's Guidelines for National Greenhouse Gas Inventories, industrial process emissions result from several types of industrial production: Mineral Industry (2A), Chemical Industry (2B), Metal Industry (2C), Non-energy Products from Fuels and Solvent Use (2D), and Other Industry (2H). The detailed classifications are provided in Table 2.1.

In this study, we calculated the emissions from 5 types of major industry production processes. On the one hand, these emissions are not reported in existing emission datasets; on the other hand, the openly accessible data sources can be supported by the calculation.

The IPCC [2] suggested three basic methodologies to estimate industrial process emissions. The Tier 1 approach, also known as the reference approach, is an output-based approach that estimates emissions based on the production volume and the default emission factors. The emissions factors refer to the emission amounts per production unit, which amounts vary depending on the production processes; the global average emission factors will be used in the Tier 1 approach, and the emissions are estimated by the mass production amount and the mass of emissions per production unit (global average value). The Tier 2 approach is also an output-based approach, but estimates emissions based on production and country-specific information for correction emission factors. The calculation process in this approach is similar to the Tier 1 approach, except the global average emission factors are replaced by country-specific values. The Tier 3 approach is an input-based carbonate approach that estimates the emissions based on the carbon inputs. The calculation process requires a material flow analysis of the entire production supply chain. Hence, the Tier 3 approach requires the greatest volume of

Table 2.1 Electricity grid emission factors

Electricity grid emission factor: (kgCO_2/kWh)	
Northeast electricity grid:	0.9803
North China electricity grid:	1.0852
East China electricity grid:	0.8367
Central China electricity grid:	1.0297
Northwest electricity grid:	1.0001
South electricity grid:	0.9489

data. For the purpose of data feasibility, we adopted the Tier 1 approach. Our calculation is based accordingly on the following equation:

$$\text{Emission} = \text{Activity data}_i * \text{Emission factor}_i \tag{2.13}$$

Activity data are the amount of industry products at the national level (mass unit: tons). The emission factors (unit: ton CO_2/ton product) are the national average ratio of the amount of CO_2 released for each unit of product. The emission released during the production process of glass, soda ash, ammonia, calcium carbide, and alumina are listed as the following:

(1) **Glass production**: When glass raw materials have been melted, the limestone ($CaCO_3$), dolomite $Ca(CO_3)$, $Mg(CO_3)$, and soda ash (Na_2CO_3) produce CO_2:

$$CaCO_3 \rightarrow CaO + CO_2 \tag{2.14}$$

$$MgCO_3 \rightarrow MgO + CO_2 \tag{2.15}$$

(2) **Soda Ash production**: Soda ash comprises primarily sodium carbonate (Na_2CO_3). CO_2 is emitted during the production of Na_2CO_3; thus, the carbon emissions can be estimated by multiplying the quantity of soda ash consumed by the default emission factor for sodium carbonate:

$$2Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O = 3Na_2CO_3 + 5H_2O + CO_2 \tag{2.16}$$

(3) **Ammonia production:**
Ammonia (NH_3) in the form of major industrial chemical products is synthesized by hydrogen and nitrogen, while both the production processes will release CO_2 as a by-product:
Hydrogen production:

$$CH_4 + H_2O \rightarrow CO + 3H_2 \tag{2.17}$$

$$CO + H_2O \rightarrow CO_2 + H_2 \tag{2.18}$$

Hydrogen and nitrogen production:

$$CH_4 + \text{air} \rightarrow CO + 2H_2 + 2N_2 \tag{2.19}$$

Ammonia synthesis:

$$N_2 + 3H_2 \rightarrow 2NH_3 \tag{2.20}$$

(4) **Calcium Carbide production**
Calcium carbide (CaC_2) is created by heating calcium carbonate ($CaCO_3$) to produce calcium oxide (CaO) and the carbonization process of calcium oxide (CaO). Both processes will release CO_2.

$$CaCO_3 \rightarrow CaO + CO_2 \tag{2.14}$$

$$CaO + 3C \rightarrow CaC_2 + CO \tag{2.21}$$

$$2CO + O_2 \rightarrow 2CO_2 \tag{2.22}$$

(5) **Alumina production**
During the alumina production process, CO_2 is emitted from the consumption of carbon anodes while transforming alumina oxide into alumina metal:

$$2Al_2O_3 + 3C = 4Al + 3CO_2 \tag{2.23}$$

2.2 Emission Factors

International fossil fuel emission datasets such as The International Energy Agency (IEA) [7], Carbon Dioxide Information Analysis Center (CDIAC) [8], British Petroleum (BP) [9], Emission Database for Global Atmospheric Research (EDGARv4.2) [10], Regional Emission inventory in Asia (REAS) [11], and Lawrence Berkeley National Laboratory-China Energy Group [12] also give a range of emission estimates for China (spanning 0.3 Gt C for 2008). A key research gap is the lack of transparent comparisons of the EF used for estimating China's emissions in these different datasets. Specific measurements of the EF are seldom conducted for the fuels (especially the coal) typically used in China. These critical parameters also vary with time and space, following the shifts in the exploitation of different coal mines, or changes in the origin and amount of imported coal. In 2012, for instance, 8 % of the coal used in China was imported compared to only 0.1 % in 1990 [13].

We provide new estimates of EF of coal based on an unprecedented dataset from coal mines and coal samples. China has 12,200 coal mines in total [14]. We collected percent carbon content (C_{ar}, in %) data of raw coal for 4,243 state-owned mines (Fig. 2.3). The total annual production of these 4,243 mines is 1.24 Gt-coal (36 % of the 2011 national total production), and the total reserve for these mines is 86.24 Gt-coal (37.5 % of national total reserve [15]). The average C_{ar} of these 4,243 mines is 58.45 % ($2\sigma = \pm 44$ %), and the production-weighted C_{ar} is of 53.34 % (Fig. 2.1a). The standard deviation here represents real spatial variability across mines and not data uncertainty.

We also conducted independent chemical composition measurements of C_{ar}, v (in TJ t^{-1} coal), and c (t C TJ^{-1}) in 602 coal samples from 100 main coal mining areas in China. The total annual production of these 100 mining areas is 3.53 Gt-coal (99 % of the 2011 national production). The average C_{ar} for the group of 602 samples (Fig. 2.1b) is 55.48 % ($2\sigma = \pm 44$ %), and the production-weighted average is 54.21 %. The average c (Fig. 2.1c) of our 602 coal samples is 26.59 t C TJ^{-1} ($2\sigma = \pm 11$ %) and 26.32 tC TJ^{-1} when weighted by production. The

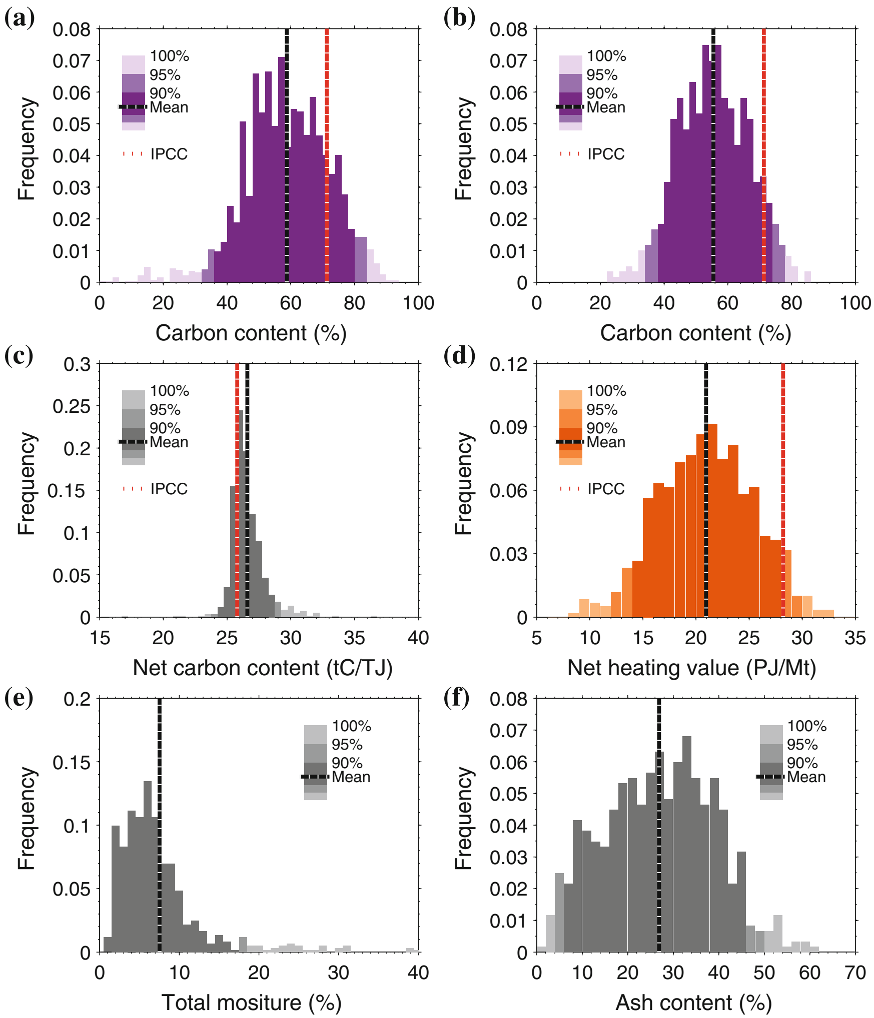

Fig. 2.1 Histograms of Chinese coal properties. Total carbon content of 4243 coal mines (**a**) and 602 coal samples (**b**). *Dashed lines* show mean, and *shading* indicates 90 and 95 % intervals. **c** and **d**, show net carbon content (**c**) and net heating values of the 602 coal samples, respectively. Carbon content for coal mines (**a**) and samples (**b**) is significantly lower than IPCC value, which is mainly because of the lower heating values, *v*, of China's coal (**d**), net carbon content is close to the IPCC value (**c**). Total moisture (**e**) and ash content (**f**) further proved the low quality of China's coal, which is in general with high ash content but low-carbon content

average v (Fig. 2.1d) is 20.95 PJ Mt^{-1} ($2\sigma = \pm$ 42 %) and this becomes 20.6 PJ Mt^{-1} when weighted by production. Here as well, the standard deviation represents real spatial variability across samples and not data uncertainty. When collocating samples and mines data on a 1°-by-1° grid, their regression shows a slope close to one (Fig. 2.4), indicating that samples and mines both capture the same (large) spatial variability of C_{ar} across China.

Overall, the coal mine and sample data give consistent average C_{ar} values (58.45 % for mines and 55.48 % for samples) that are also spatially consistent across

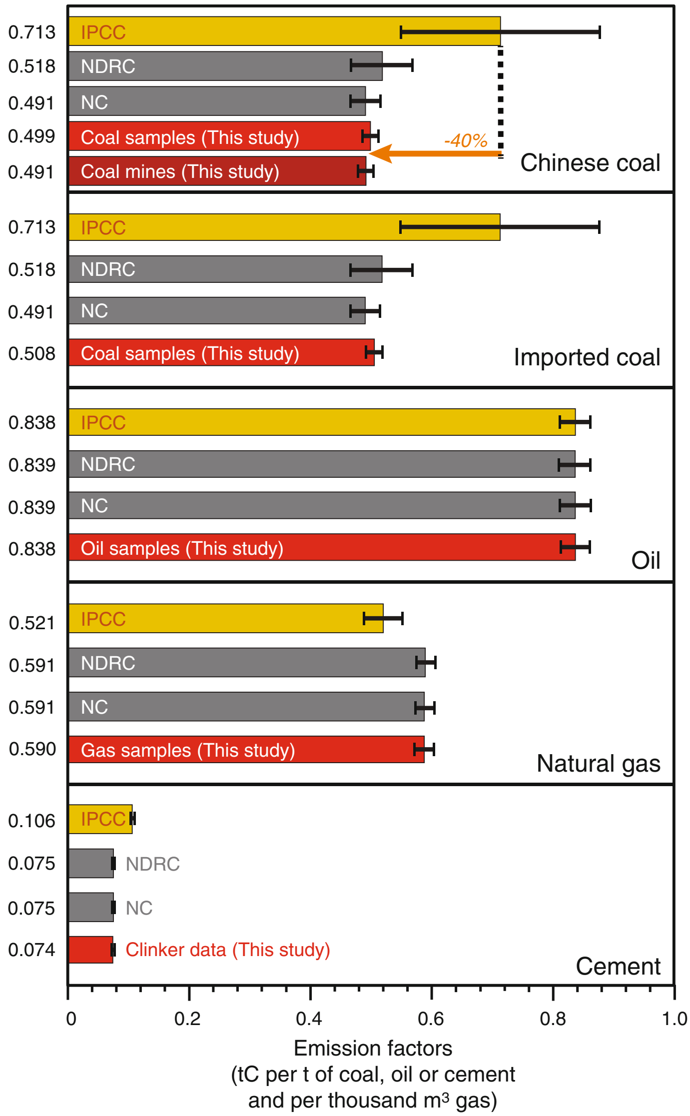

Fig. 2.2 Comparison of emission factors. (in 2012). *IPCC* default value from IPCC guidelines for national emission inventories (1996, 2006). *NDRC* value reported by National Development and Reform Commission (NDRC) in 2008 [20]. *NC* China's National Communication (NC) that reported to UNFCCC (2012 for value in 2005) [23]

the country's very large range of C_{ar}. The mean C_{ar} values are significantly lower than the IPCC default value (71 %) for coal. The C_{ar} for mines and samples show consistent in spatial distribution (Fig. 2.4), indicating the robust of data quality. Decomposing C_{ar} into the net average carbon content (c) and heating values (v), from the coal samples data, we found v = 20.95 PJ Mt^{-1} which is very close to the v reported by NBS (20.91 PJ Mt-$coal^{-1}$) but significantly less than the default IPCC value (28.2PJ Mt-$coal^{-1}$) and the average of US coal value [16] (26.81PJ Mt-$coal^{-1}$). The c of coal (26.59 tC TJ^{-1}) in within 2 % of the IPCC (1996, 2006) default value (25.8tC TJ^{-1}), and NC values reported in 1994 (26.1tC TJ^{-1}).

Because of the average low quality of coal, the v of coal extracted in China is much lower than the global average. This is also reflected by the high-level ash content of China's coal [17, 18]. The average ash content of the 602 coal samples was 26.91 %, significantly higher than the average ash content of US coal samples (14.08 %) [16]. This high ash content is an indirect evidence for a lower EF of coal combustion, but implies larger emissions of particulates containing minerals per unit of coal burned (such as PM 2.5 and fly ash) if fly ash is not removed in power plants, with subsequent effects on air quality [19].

Technology efficiency, reflected in the oxidization rate parameter o defining the fraction of coal consumed that is actually oxidized into CO_2, is another factor that

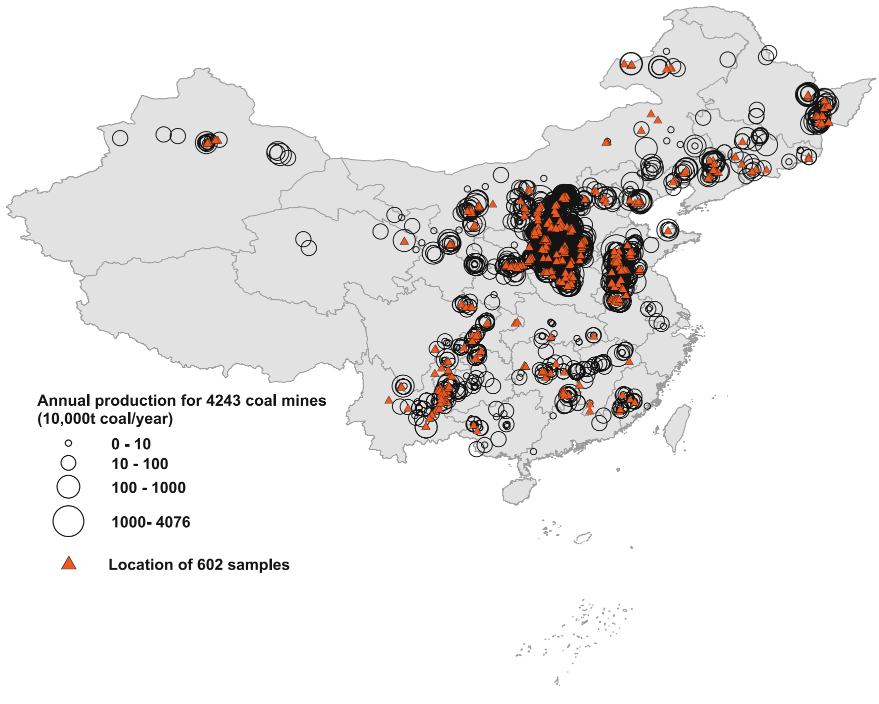

Fig. 2.3 Location of 4243 coal mines (with annual production) and 602 coal samples. The coal samples and mines are consistent with spatial distribution

contributes to EF. To our knowledge, until now there has been no international dataset using China's national-specific *o*. The *o* value varies with the combustion technology and economic sector. We collected data on specific *o* values of energy consumption for 15 major sectors in China with 135 different technologies of fossil fuel combustion based on the national level investigation by NDRC in 2008 [20]. By considering the share of each fuel type for each sector, the weighted average *o* for coal in our calculation is 92 %, lower than the IPCC default value of 98 %, but consistent with China-specific values reported by NDRC (94 %), NC (91.5 %) as well as by Peters et al. [21]. The investigated *o* of oil (98 %) and natural gas (99 %) are close to IPCC default value (within 1 %).

Based on the investigation of C_{ar}, *c*, *v*, and *o*, we updated the EFs (Fig. 2.2) of coal, crude oil, and natural gas combustion in China. The final EF expressed in t C per t-coal in 2012 show that EF from coal mining data (0.4907 t C tcoal^{-1}) and coal samples (0.4987 t C t^{-1}) are nearly identical each other and 40 % lower than the IPCC default value (0.713 t C t tcoal^{-1}), but close to the specific value reported by NDRC (0.5180 t C t^{-1}) and by NC (0.4910 t C t^{-1}). The value of NDRC and NC is both based on the national investigation of about 1700 government-owned coal mines in 1994 [22] (NDRC has updated *o* in 2005); thus, the results show time

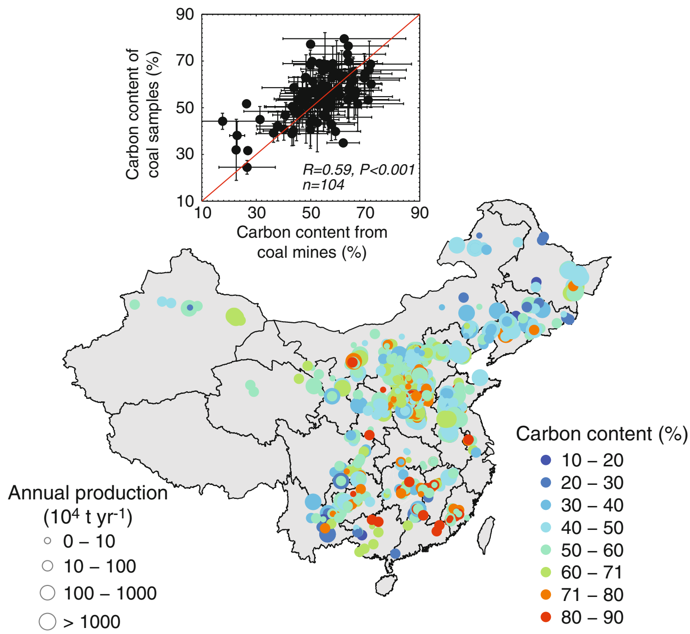

Fig. 2.4 Total carbon content and production of coal mines. The *inset* shows the comparison between carbon content from 602 coal samples and 4243 coal mines ($R = 0.59$, $P < 0.001$, $n = 104$). Each *dot* in the *inset* indicates the average of carbon content from 602 coal samples and 4243 coal mines in the same 1°-by-1° grid. The nearly one-to-one correlation indicates that samples and mines capture the same spatial variability of coal carbon content across China

consistency of EF. The EF of China's natural gas is 11 % higher than the IPCC value. The difference of emission factors for crude oil and cement production process is within 5 % of IPCC (Figs. 2.2, 2.3, and 2.4).

All error bars are 2σ errors.

2.3 China's National Carbon Emission Inventories

2.3.1 Carbon Emission from Energy Combustion

China's carbon emissions from fossil fuel burning and cement production were 8.50 $GtCO_2$ in 2012, making it the country with the largest emissions in the world. China's carbon emissions were only 5.46Mt CO_2 in 1950; thus, the total emissions increased more than 100-folds during those 60 years. Carbon emissions are mainly the result of fossil fuel combustion (90 %) and cement production (10 %). In 2012, 90 % of China's energy consumption was primarily derived from fossil fuel combustion (Fig. 2.5): 68 % from coal consumption, 13 % from oil, and 7 % from gas.

Among the industrial sectors, the emissions are mainly produced by the manufacturing and power generation sectors (see Fig. 2.6). In 2012, manufacturing accounted for 47 % of China's total carbon emissions, while thermal power generation contributed 32 %, and the transportation sector accounted for only 6 %. Such patterns differ with each sector's proportion of emissions from other major emitters, especially from the developed countries where the emissions are mainly from the transportation and household sectors. For example, in the USA, the transportation sector produces 32 % of the total carbon emissions while the industrial sector only accounts for 17 %.

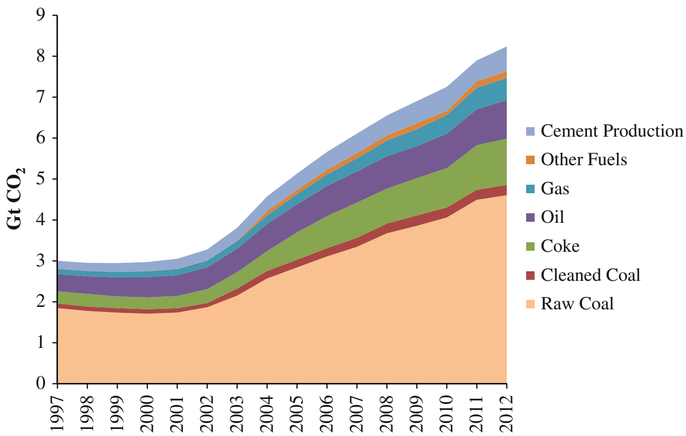

Fig. 2.5 China's national CO_2 emissions by fuels (unit: Mt CO_2)

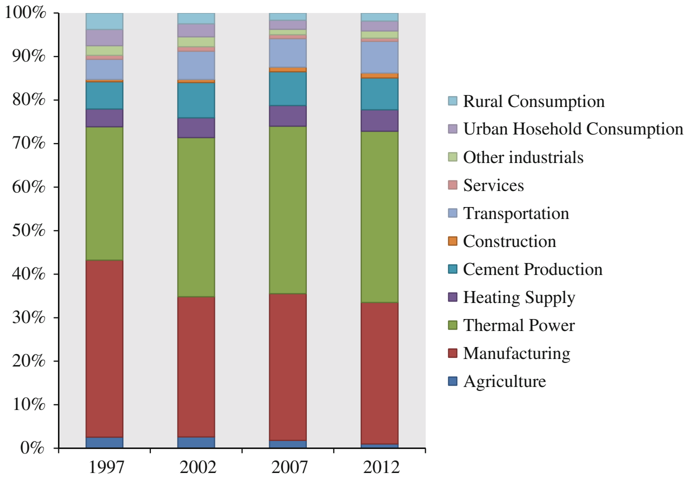

Fig. 2.6 China's national CO_2 emissions by sectors (unit: Mt CO_2)

2.3.2 Carbon Emission from Cement Production Process

Cement process emissions account for about 9 % of China's total carbon emissions [10]. Carbon emissions associated with cement production in China are about half of the global total. CO_2 is emitted during calcining of limestone to produce clinker, which is combined with other ingredients to produce cement. We calculated China's emissions from cement production based on clinker production and EF. We found that carbon emissions of cement production in China were 0.62 Gt CO_2 yr-1 ($2\sigma = \pm 3$ %) in 2012 compared to 0.024 Mt CO_2 yr-1 in 1978. The cement emissions are lower than those reported by international sources. For example, cement emissions are 1.1 Gt CO_2 yr-1 in CDIAC and 0.88 Gt CO_2 yr-1 in EDGARv4.2 (data for 2012).

The large differences in cement carbon emissions are because CDIAC and EDGAR estimated clinker production as a fraction of total cement production, whereas we collected original clinker production data. To calculate the cement process emission, it is more appropriate to use the specific amount of clinker production rather than the total cement production. China's clinker production was not directly reported by national statistics. Therefore, the IPCC proposed a method to estimate it by using a fixed cement-to-clinker ratio, and this method is used by CDIAC and EDGAR. This ratio is estimated to be 95 % in the IPCC 1996 Guidelines [1], which assumed that most cement in China was Portland cement. The more recent IPCC 2006 Guidelines [2] suggested a 75 % cement-to-clinker ratio for developing countries. We found that both IPCC 1996 and 2006 default values result in an overestimation of China's clinker production when compared with official clinker statistics from China Cement Association [24]. These data suggest that the cement-to-clinker ratio was only 58 % in 2012, which is also

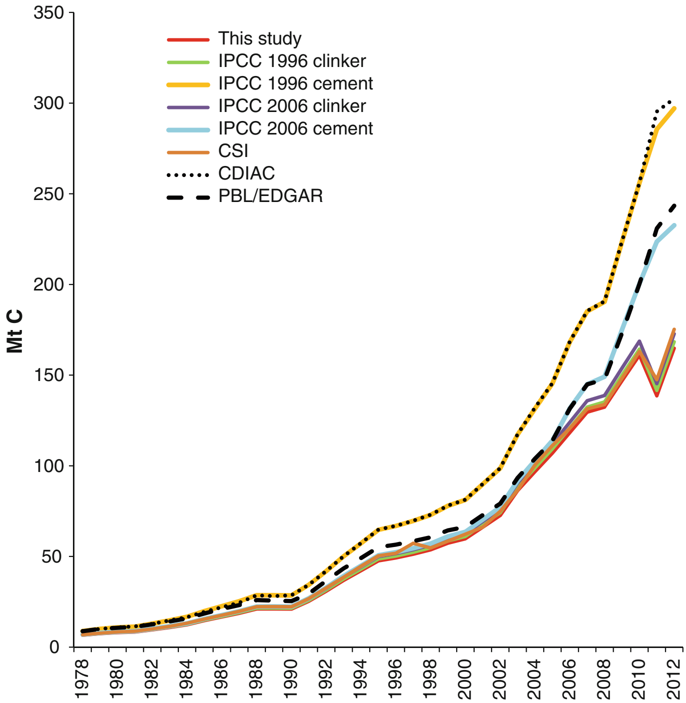

Fig. 2.7 Emission estimates of China's cement production emissions by different sources (1C = 3.6642 CO_2)

consistent with factory-level investigations [25] and other recent studies [26–29]. As a result, our estimation of emissions from cement production (0.62 Gt CO_2 yr-1) is 45 % lower than CDIAC (1.1 Gt CO_2 yr-1) and 32 % lower than that of EGDARv4.2 (0.88 Gt CO_2 yr-1) (Fig. 2.7).

2.3.3 Emission from Industrial Process

The total CO_2 emissions from the production of alumina, plate glass, soda ash, ammonia, and calcium carbide totaled only 43 Mt CO_2 in 1990 but 233 Mt CO_2 in 2013. The cumulative industrial emissions of manufacturing the 5 products are also significant, and during the 1990–2013 period, it measured approximately 2.5 Gt CO_2, exceeding the total annual emissions of India. Annual 233 Mt CO_2 emissions are equivalent to approximately 25 % of the total emissions from cement production. However, such emissions are not reported by current international emission datasets or by China's national emission inventories that are reported to the UN.

The emissions from the production of ammonia and alumina constitute the highest proportion of total emissions from the 5 industrial processes. In 2013, emissions from ammonia and alumina contributed 42 and 31 % of total industrial process emissions, respectively. Emissions from calcium carbide production constituted the third largest contribution, constituting 24 % of total industrial process emissions. The contributions from glass production and soda ash production are relatively small, namely 1.7 and 1.4 %, respectively. For the 1990–2013 period, the industrial emissions of all five production processes increased rapidly. In particular, the emissions from alumina production increased substantially from 12 Mt CO_2 in 2004 to 73 Mt CO_2 in 2013, a sixfold increase within ten years. The trend of increasing emissions from ammonia production is relatively smooth compared with that from the production of the other four products. This finding may be due to the long history of Chinese agricultural development, and the associated demand for ammonia as a fertilizer has been relatively stable because of the scale and status of China's agriculture system. Additionally, the emissions from the production of alumina, calcium carbide, and ammonia fluctuated around the year 2008, which can be explained as the impact on the production processes of the global economic crisis [30]. After 2008, the emissions from these processes continued their rapid growth trends. China initiated a 4,000 billion RMB economic stimulus plan in 2008 to counteract the effects of the global economic crisis and invested most of the capital in infrastructure construction, which stimulated industrial production [31]. For example, the emissions from alumina production doubled during the period 2008–2013. This doubling can be explained by the rapid development of heavy industries after 2008 (Fig. 2.8).

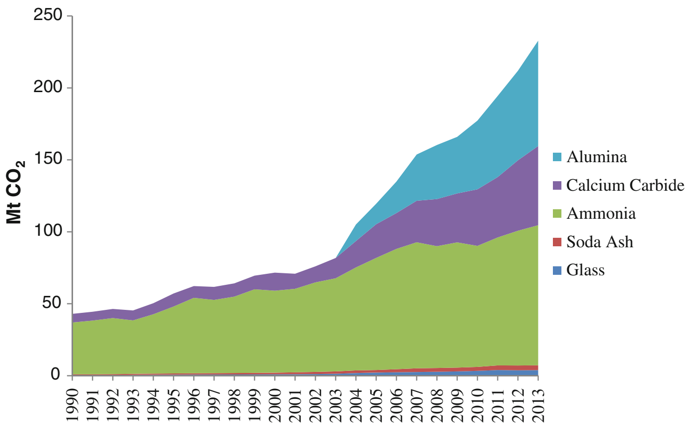

Fig. 2.8 Industrial process emissions from the production of alumina, plate glass, soda ash, ammonia, and calcium carbide in 1990–2013

2.4 China's Provincial Carbon Emission Inventories

2.4.1 Methods

The inventories include carbon emission from energy consumption of 30 provinces, excluding Tibet, Taiwan, Hong Kong, and Macau Special Administrative Region. Data were obtained from National Energy Statistical Yearbook and Provincial Energy Balance Sheet.

The compilation steps are the following:

Determine the energy consumption data of different sectors.
Determine the sectorial emission factor.

Different from national carbon accounting, provincial carbon emission calculation should take cross-regional electricity transmission into consideration. This study adopted the accounting method from a consumption perspective rather than production perspective.

Calculation formula is

$$CO_2 \text{ electricity} = (\mathrm{EF}_e \times \mathrm{Activity}_e) \tag{2.25}$$

where

EFe: electricity grid emission factor ($kgCO_2/kWh$)
Activitye: consumption of electricity

National electricity grid can be divided into northeast, north China, east China, central China, northwest, and south regional electricity grid, not including the Tibet Autonomous Region, Hong Kong SAR, Macau SAR, and Taiwan.

The coverage of each regional electricity grid is shown below.
Northeast electricity grid: Liaoning, Jilin, and Heilongjiang

North China electricity grid: Beijing, Tianjin, Hebei, Shanxi, Shandong, and Inner Mongolian Autonomous Region

East China electricity grid: Shanghai, Jiangsu, Zhejiang, Anhui, and Fujian

Central China electricity grid: Henan, Hubei, Hunan, Jiangxi, Sichuan, and Chongqing

Northwest electricity grid: Shaanxi, Gansu, Qinghai, Ningxia Autonomous Region, and Xinjiang Autonomous Region

South electricity grid: Guangdong, Guangxi Autonomous Region, Yunnan, Guizhou, and Hainan

2.4.2 Carbon Emissions from 30 Provinces in 1995–2010

Figure 2.9 shows China's provincial carbon emission patterns in 2010. It is clear that the pattern coincides China's industrial center distribution. It is shown in Tables 2.2 and 2.3 that there was a nation-wide dramatic increase in provincial energy-related carbon emission between 1995 and 2010, especially in underdeveloped areas such as Xinjiang and Inner Mongolia, who mainly relied on heavy and energy-intensive industries.

Industry and thermal power generation are the predominant energy consumers. Among all energy types, the increase in coal consumption represents 80 % of the total increase. The summation of provincial increasing trend is the same as national increasing trend.

It is worth noticing that there was a 5–20 % error between the provincial sum of carbon emission and the national carbon emission based on National Balance Sheet. In 2010, the absolute value of the error is as high as 1.4 billion tons of carbon dioxide, equivalent with the total emission of Japan in the same year. Comparisons between carbon accounting by different organizations reveal that the uncertainty of China's energy-related carbon emission is inevitable under different data sources and choices of emission factors. Possible reasons for this uncertainty are:

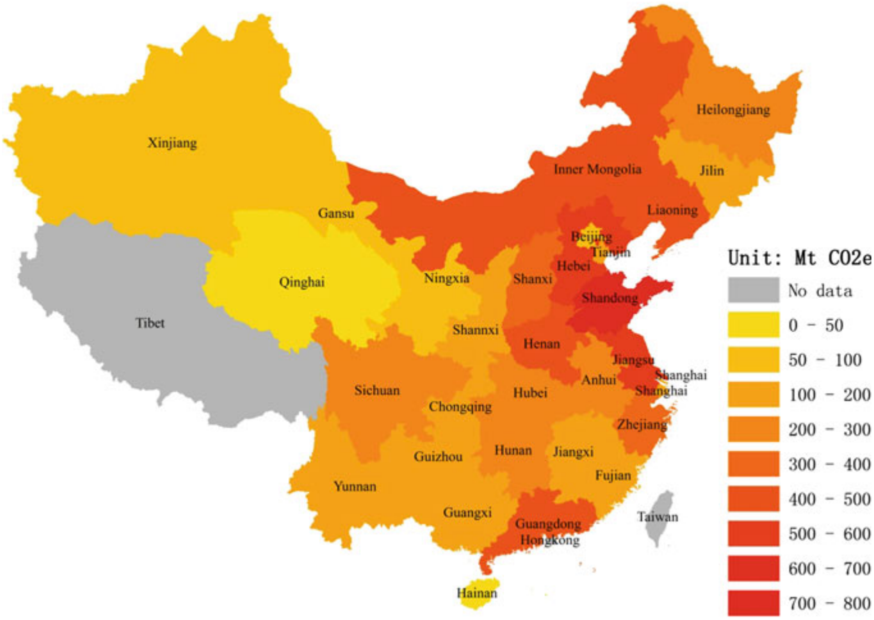

Fig. 2.9 China's provincial CO_2 emissions in 2010 (unit: Mt CO_2)

Table 2.2 China's provincial CO_2 emissions in 1997–2003 (unit: Mt CO_2)

	1997	1998	1999	2000	2001	2002	2003
Beijing	60.75	62.73	66.21	67.35	76.99	76.38	80.91
Tianjin	53.26	54.93	56.09	59.80	62.04	71.75	71.55
Hebei	208.74	232.01	218.91	233.42	248.07	278.96	322.19
Shanxi	148.12	146.93	144.88	147.81	184.29	221.10	245.88
Inner Mongolia	98.79	94.10	98.71	106.98	116.48	127.64	122.24
Liaoning	203.60	197.76	185.59	215.95	190.82	215.62	237.28
Jilin	100.94	86.58	88.06	82.77	87.96	91.06	99.00
Heilongjiang	134.40	134.83	125.79	130.26	126.16	118.50	122.45
Shanghai	108.86	115.92	127.89	125.76	138.17	145.08	155.41
Jiangsu	189.23	191.25	193.01	204.17	196.91	212.72	234.63
Zhejiang	111.43	109.36	113.46	123.81	134.16	144.65	162.44
Anhui	105.11	107.15	109.45	115.77	122.88	128.95	145.01
Fujian	41.20	44.56	56.27	53.51	52.82	64.40	78.41
Jiangxi	50.49	49.64	48.96	50.47	54.93	58.04	70.89
Shandong	177.66	196.42	196.55	173.65	210.87	236.80	313.19
Henan	145.09	145.30	146.17	166.94	168.56	171.04	190.26
Hubei	132.26	130.52	133.64	134.31	126.70	150.45	158.67
Hunan	94.89	95.82	77.14	73.26	71.86	83.40	95.24
Guangdong	160.39	179.25	180.34	189.81	198.45	213.42	241.25
Guangxi	45.81	46.47	47.08	50.59	48.86	48.67	58.70
Hainan	6.73	13.79	7.18	7.75	8.14	No data	14.98
Chongqing	53.39	61.16	66.49	68.03	61.25	65.66	57.94
Sichuan	116.88	116.58	101.97	96.93	99.46	114.23	145.52
Guizhou	72.19	94.36	75.92	79.19	79.05	82.62	105.80
Yunnan	54.38	53.67	51.54	49.88	58.35	69.32	85.07
Shaanxi	63.11	59.94	54.82	54.59	56.27	69.71	74.79
Gansu	47.21	47.59	47.91	51.01	52.60	55.79	63.72
Qinghai	11.58	11.51	13.56	11.92	14.46	15.20	17.46
Ningxia	16.57	17.36	17.14	No data	No data	No data	50.83
Xinjiang	62.67	63.88	62.10	64.67	67.78	63.73	74.09
Industrial process emissions	255.1	267.2	285.64	297.6	329.53	361.41	429.75
Total emissions	3,130.87	3,228.56	3,198.46	3,288.00	3,444.86	3,756.30	4,325.57

China's energy consumption and carbon emission have been accelerating as a result of its rapid economic development, but the statistical technology and management standards lagged behind, not being able to accomplish large-scale quantification and accounting.

Table 2.3 China's provincial CO_2 emissions in 2004–2010 (unit: Mt CO_2)

	2004	2005	2006	2007	2008	2009	2010
Beijing	86.62	91.18	95.86	102.73	98.10	99.14	103.05
Tianjin	82.19	94.35	100.54	109.55	116.47	128.62	134.36
Hebei	366.01	453.87	478.10	515.17	541.16	558.12	663.18
Shanxi	260.21	276.61	306.30	334.19	367.52	371.27	403.45
Inner Mongolia	197.49	230.01	266.97	339.26	412.42	443.29	474.35
Liaoning	255.40	281.84	323.18	358.15	367.64	405.89	456.38
Jilin	108.49	143.52	158.55	170.16	175.93	179.02	198.36
Heilongjiang	133.57	161.01	178.06	189.16	198.00	201.72	217.38
Shanghai	171.53	174.62	202.71	217.10	218.65	200.98	211.26
Jiangsu	306.23	394.21	427.87	453.04	476.90	495.25	555.56
Zhejiang	199.57	235.97	269.29	304.26	310.86	316.54	337.48
Anhui	150.24	147.20	166.43	185.60	213.91	236.86	247.75
Fujian	96.66	117.21	128.19	153.04	157.31	176.81	187.30
Jiangxi	82.58	88.40	99.33	116.46	118.01	126.34	134.84
Shandong	387.01	545.98	590.31	658.49	696.63	718.99	769.12
Henan	225.63	295.72	338.25	409.10	415.01	428.77	490.92
Hubei	176.03	183.83	217.87	242.55	247.93	266.75	319.61
Hunan	109.10	169.15	192.56	212.36	214.75	224.10	243.02
Guangdong	286.92	329.18	353.17	384.73	397.99	421.20	443.59
Guangxi	79.16	88.15	103.93	117.36	118.64	135.39	155.79
Hainan	14.09	15.52	17.34	21.25	25.22	25.67	25.82
Chongqing	63.72	76.77	84.22	92.51	119.54	125.06	124.86
Sichuan	165.36	158.12	165.47	195.20	218.71	245.03	270.10
Guizhou	118.35	136.84	160.43	168.86	160.23	179.14	182.36
Yunnan	53.82	127.86	143.54	153.74	155.99	176.21	183.64
Shaanxi	93.62	102.63	111.77	135.05	153.90	170.55	202.27
Gansu	73.48	81.49	87.58	95.52	101.75	98.33	123.44
Qinghai	18.72	19.54	23.93	25.27	29.78	29.96	28.88
Ningxia	58.53	48.25	56.02	66.81	71.43	79.04	91.11
Xinjiang	92.27	109.13	118.80	129.26	138.97	155.95	166.75
Industrial process emissions	481.96	532.82	616.53	678.54	709.64	819.52	938.13
Total emissions	4,994.56	5,911.00	6,583.09	7,334.49	7,749.00	8,239.51	9,084.10

As most regions of China regard fast economic development as successful political achievement, the local government would conceal the real statistical values, which results in the larger value for provincial sum estimate.

As a result of widespread cross-regional electricity and primary energy transmission, energy consumption may be calculated for several times. For example, raw coal is included as primary energy consumption in its place of production, while washed coal is again included in its place of consumption, leading to errors from duplication.

Uncertainty analysis is crucial to the compilation of carbon inventories, but the quantification of uncertainties is out of the scope of this study. The study of energy-related carbon emission is based on international references, and the uncertainty is +10 %.

2.5 Difference of China's Carbon Emission Estimates Between National and Provincial Statistics

The uncertainty associated with carbon emissions in China comes from both uncertainties regarding activity data and emission factors. The Chinese National Bureau of Statistics (NBS) is the only official source for the data on energy consumption and cement production. NBS reports the national energy consumption data that been used by international organizations such as the United Nations or the World Bank. However, a conspicuous error in energy consumption data, reported by the NBS since 2000s, is that the provincial aggregated energy consumption data are 20 % higher than the national energy consumption data [32]. Therefore, there is significant uncertainty regarding which of the two numbers are more accurate.

China implements a top-down statistics system—the compilation of energy statistics in China occurs under the aegis of the National Bureau of Statistics (NBS) at the central government level which oversees and coordinates the corresponding statistical departments at provincial and county level [33]. The NBS designs and publishes survey principles and reporting formats that are applied to all regional and local statistical department for collecting energy data and information from firms and households. The NBS publishes both national and provincial 'Energy Balance Sheets' annually in China's Energy Statistical Yearbook [34], which provides detailed energy inventory and final energy consumption for the country and each province. In principle, the national energy statistics should be identical to the provincial ones.

In 2009, China's national energy consumption was 3,066 million tons standard coal equivalents (SCE), but the sum of all the provinces was 17 % higher, i.e., 3,572 million tons SCE. The energy data discrepancy between the national total and the sum of the data provided by the provinces has been increasing since the 1990s. The discrepancy was less than 2 % in 1995, but the difference kept increasing to 17 % in 2009. The "official" explanation offered by the NBS is: "as [different] conversion factors [are applied in converting to standard unit of energy consumption], the sum of the data by region is not equal to the [national] total" [34].

If only the conversion factor is to be blamed, then the amount of energy consumed in physical units should still be identical. The amount of raw coal consumption in 2009 from the national Energy Balance Sheet is 2,966 million tons, while aggregated figure from provincial sheets is 3,560 million tons. The discrepancy of coal consumption is 20 %, while the discrepancies of other types of final energy consumption are relatively small (see Fig. 2.10). Furthermore, the difference is due to factors in energy transformation and final energy consumption. For example, the difference of coal washing during energy transformation process between the two data sources can contribute 33 % of the total discrepancy of 594 million tons in raw coal consumption while manufacturing contributes 42 % of the discrepancy.

As a result, China's estimated CO_2 emission from provincial aggregation was 14 % higher than the figure calculated based on the national statistical data in 2010. The discrepancy of 1.4 Gt accounts for about 3 % of the world's total and is larger than Japan's total emissions, which can be ranked as the 5th largest emitter in the world. If we compare the CO_2 emissions from the provincial aggregation with data from other international statistical agencies, the gap ranges from 0.09 Gt (the equivalent of Maldives total emissions [35]) to 1.2 Gt (Japan's total [35]) in 2008.

We conduct analysis to show the uncertainty range of China's emission estimates based on emission factors (EFs) reported in the literature. We collected 12 sets of EF data for fossil fuel combustion from the six following official sources:

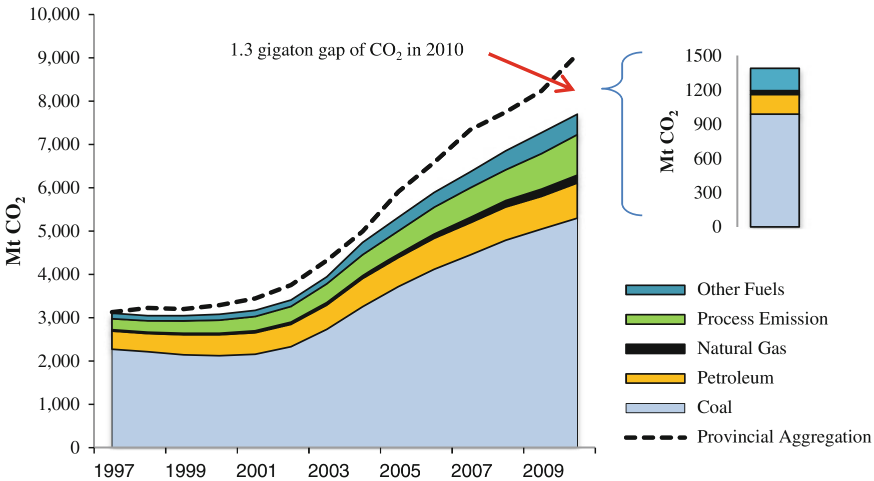

Fig. 2.10 The sources of China's CO_2 emissions by fuel types during 1997–2010. The *left side* "*area chart*" illustrates the increases of CO_2 emissions calculated from the national energy statistics since 1997 breaking down with different fuel type: coal—*light blue*; petroleum—*yellow*; natural Gas—*black*; process emission—*purple*; and other fuels (e.g., coke oven gas, other gas, other coking products, LPG, refinery gas, and other petroleum products)—*dark blue*. The *dash line* represents the aggregated CO_2 emissions calculated from the provincial energy statistics 1997–2010. The *right side* "*column chart*" presents the 1.4 Gt emission gap in 2010 between national and provincial statistics and the pattern of different fuel types in contributing the emission gap

IPCC (1996, 2006) [1, 2], China National Development and Reform Commission (NDRC) [36], UN Statistics (UN) [37], China National Communication on Climate Change (NC) [23], China National Bureau of Statistics (NBS) [13], and Multi-resolution Emission Inventory for China (MEIC) [38]. There are 3 sets of EF in the NDRC data, corresponding to 3 tiers of fuel classifications, 4 sets in NC and 2 sets in UN. We combined these 12 sets of EF with 2 sets of energy statistics derived from national and provincial data [13, 39]. This yielded 24 possible inventories for China's carbon emissions of fossil fuel combustion for 1997–2012. The underlying data used in the commonly used datasets (IEA, CDIAC, BP, EDGAR) are either listed in this data assembly (NBS and IPCC) or not publically available.

The mean value of 24 possible inventories is 2,490 MtC in 2012, and the standard deviation is 372 MtC (15 %). The 2σ standard deviation range suggested by 24 possible inventories is 30 %, which is larger than the reported range of 10 % by current emission datasets such as EDGAR.

A Monte Carlo approach was adopted to assess the distribution range of the emissions by assuming that all reported EF values have the same probability (values have been randomly selected with equal probabilities and calculated for 100,000 times). The mean value of the 24 members' ensemble is 2.43 Gt C in 2012 (95 % confidence interval is +20 %, −11 % and max–min range of +27 %, −15 %). The uncertainty is attributed to the activity data (about 40 % of total uncertainty) and EF (60 %). The variability of EF for coal dominates the total uncertainty (55 % for total uncertainty and 90 % for the uncertainty by EF), whereas the EF for other fuels are more comparable. Different EF values for coal mainly reflect variation in v and hence C_{ar} ($C_{ar} = v \times c$) values, whereas the variation of c and o is comparatively smaller (less than 10 %).

The distribution range of the emissions is listed in Fig. 2.11.

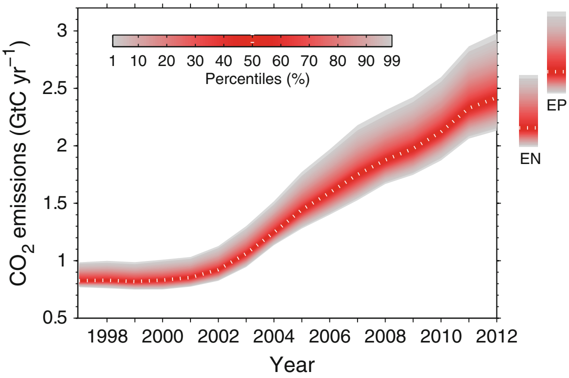

Fig. 2.11 Uncertainty distribution of Chinese CO_2 emissions 1997–2012. Monte Carlo simulations of the Chinese carbon emissions based on a blended activity dataset where national and provincial data are assigned equal probabilities (n = 100,000). Chinese carbon emissions based on national energy activity data (EN) and provincial activity energy data (EP) in 2012 are shown on the *right bar*

We assumed the equal possibility for various EF when conducting the Monte Carlo analysis, and this will expand the uncertainty range. However, both the standard deviation of 24 possible inventories and the Monte Carlo analysis show the significant uncertainty range, implying the considerable system error of the emission estimates by using reported EF; thus, it is critical to perform the emission estimates based on measurement-based EF.

2.6 City's Carbon Emission Inventories

2.6.1 Methodology

The urbanization process has been considered as the major driver for China's development in the coming decades. Cities play an essential role in China's carbon emissions, for example, 85 % of China's direct carbon emissions are from cities [40].

It is difficult to define a city's boundary for carbon emission accounting due to lots of cross-boundary carbon emissions caused by urban metabolism. Cross-boundary exchange of goods, services, commuter travel, and aviation has posed challenges in developing a holistic accounting of emissions associated with human demands for energy and materials in cities. Direct use of primary energy through industrial activity leads to the direct carbon emissions within territorial boundary, and these emissions are usually defined as scope 1. Cities also consume lots of purchased electricity generated by upstream power plant, and the corresponding emissions are defined as scope 2. The consumption of products leads to the emissions from upstream production through supply chain, which is defined as scope 3. Various boundary definitions arouse uncertainties of cities' carbon inventories and then become barriers for the comparability of cities' carbon emission status at global scale.

To undertake quantitative analysis on carbon emissions from Chinese cities is necessary. Practically, China's regional "low-carbon development" strategy mainly targeted in cities. For example, several cities have already initiated their low-carbon development plans, such as Baoding, Shanghai, Guiyang, Hangzhou, Wuxi, Jilin, Zhuhai, Nanchang, and Xiamen [41]. National Reform and Development Commission (NDRC, a ministry leveled agency responsible for national economy planning) initiated national low-carbon demonstration projects in August 2010, in which eight cities were chosen as pilot cities, including Tianjin, Chongqing, Shenzhen, Xiamen, Hangzhou, Guiyang, and Baoding. Academically, studies on carbon emissions in Chinese cities increased sharply, such as Shanghai [42], Shenyang [43], Nanjing [44–46], and Suzhou [45, 47]. Both "top-down" and bottom-up" approaches have been applied, and most of the carbon emissions were calculated based on the IPCC method for national carbon inventory [48]. For example, Dhakal estimated energy consumption and CO_2 emission in 35 cities and analyzed historical changes in Beijing, Tianjin, Shanghai, and Chongqing by using a "top-down" approach [40]. Xi et al. [43] and Bi et al. [44] developed a bottom-up accounting approach with sectoral detailed carbon emissions. These studies created opportunities for global comparison, but a comparison study among different cities from spatial–temporal perspective is still missing, especially between different emission scopes.

Calculation of city's carbon emissions from different scopes:

(1) Direct carbon emission (scope 1) accounting
In this study, we analyzed the scope 1 and scope 2 emissions for Chinese mega cities. The scope 1 emission includes emissions from industrial energy consumption, cement manufacturing process, residential consumption and transportation. Emission from industrial energy consumption can be calculated by the quantity and type of final energy consumption. Emission from cement manufacturing process can be calculated according to the production quantity and the respective emission factor. Car ownership, density of road network, population density, transportation volume, and the provincial emission data can be used to estimate transportation emission. Emission from waste disposal can be calculated by waste disposal quantity and the life cycle emission database. Remote sensing results and GIS technology are used to calculate the carbon emission from changes in land usage.
(2) Cross-regional electricity transmission carbon emission (Scope 2) accounting
The scope 2 emission can be calculated based on electricity production and supply, and the purchase and output of electricity. Here, we calculated the scope 2 emission by using the cross-regional electricity (imported electricity) multiplied by the emission factors (emission per unit of electricity consumption).
(3) Embodies carbon emission (Scope 3)
Scope 3 inventories require detailed information on materials and energy flux and should be calculated through the use of national and regional input–output (IO) models. The scope 3 carbon emission can be calculated according to the consumption quantity of major products, LCA emission database, and the Global Trade Analysis Project (GTAP) [49].

2.6.2 Carbon Emissions in Chinese Megacities: Case Study in Beijing, Tianjin, Shanghai, and Chongqing

Beijing, Tianjin, Shanghai, and Chongqing are four municipal cities directly accountable to the central government (politically equal to one province) in China. The definition of the total population of these four cities is 70 million, about 1 % of global population, and their total GDP counts for 10 % of the whole country in

2009 [50]. Beijing is the capital of China which locates in the northern part of the North China Plain. It covers 16, 808 km^2 area and has a population of 17.6 million and a gross domestic product (GDP) of 1, 215 billion Yuan (RMB) in 2009. Tianjin is east to Beijing, approximately 160 km from Beijing. It covers an area of 11, 920 km^2, with a population of 9.69 million and a GDP of 752 billion Yuan in 2009. Shanghai is an economic center located in Yangtze delta area, with an area of 6340 km^2, a population of 19.2 million, and a GDP of 1, 505 billion Yuan in 2009. Chongqing is located along the upper reaches of the Yangtze River, straddling the region that connects the central and western parts of China. It covers an area of 82, 400 km^2 and has a population of 28.6 million and a GDP of 653 billion in 2009. Therefore, here we performed the scope 1 and scope 2 carbon emission accounting for the aforementioned four municipalities as examples.

The total population of Beijing, Tianjin, Shanghai, and Chongqing is over 70 million, accounting for approximately 1 % of the global population. The total GDP of four municipalities accounts for 10 % of the national GDP. The total GDP, population, and area of the four municipalities in 2009 are shown in Table 2.4.

The calculation of carbon emission is based on the sectorial energy consumption, the quantity of cross-regional electricity supply, and electricity consumption from 1995 to 2010.

Calculation results:

All the four cities have rapid growth of total (scope 1 + scope 2) emissions from 1995 to 2009 (for Chongqing from 1997 to 2009), in which Beijing increased from 81 million tons of CO_2 in 1995 to 155 million tons of CO_2 in 2009, Tianjin increased from 65 million tons of CO_2 in 1995 to 176 million tons of CO_2 in 2009, Shanghai increased from 100 million tons of CO_2 in 1995 to 218 million tons of CO_2e in 2009, Chongqing increased from 58 million tons of CO_2 in 1997 to 144 million tons of CO_2 in 2009, respectively. In total, four big cities emitted approximately 700 million tons of CO_2 in 2009 and contribute to about 2 % of global anthropogenic GHG emissions. In particular, scope 2 contributes significantly to the total amount of carbon emissions and shows a considerable increase both in Beijing and Shanghai. The proportion in Beijing increased from 17 % in 1995 to 32 % in 2009, accounting for 50 million tons of CO_2 in 2009. Shanghai had no input cross-boundary emissions in 1995 and then had 13 % of cross-boundary emission proportion in 2009, accounting for 28 million tons of CO_2 in 2009. The

Table 2.4 Population, GDP, area, and urbanization level of Beijing, Tianjin, Shanghai, and Chongqing

	Population (million)	GDP (billion RMB)	Area (km^2)	Urbanization rate (%)
Beijing	17.6	1215.3	16,410.5	78.2
Tianjin	12.3	721.2	11,917.3	60.9
Shanghai	19.2	1504.7	6,340.5	88.3
Chongqing	28.6	653.0	82,402.9	30.0

fractions of cross-boundary emissions both in Tianjin and Chongqing in 2009 are relatively small with 9 % (15 million tons of CO_2) in Tianjin and 4 % (6 million tons of CO_2) in Chongqing.

Figures 2.12 and 2.13 show the sectoral carbon emission distribution of four municipalities in 1995 (1997 for Chongqing) and 2009. It is clear that industries, thermal electricity generation, and external electricity purchase are the major carbon emission contributors, followed by transportation and heat supply. Emission from

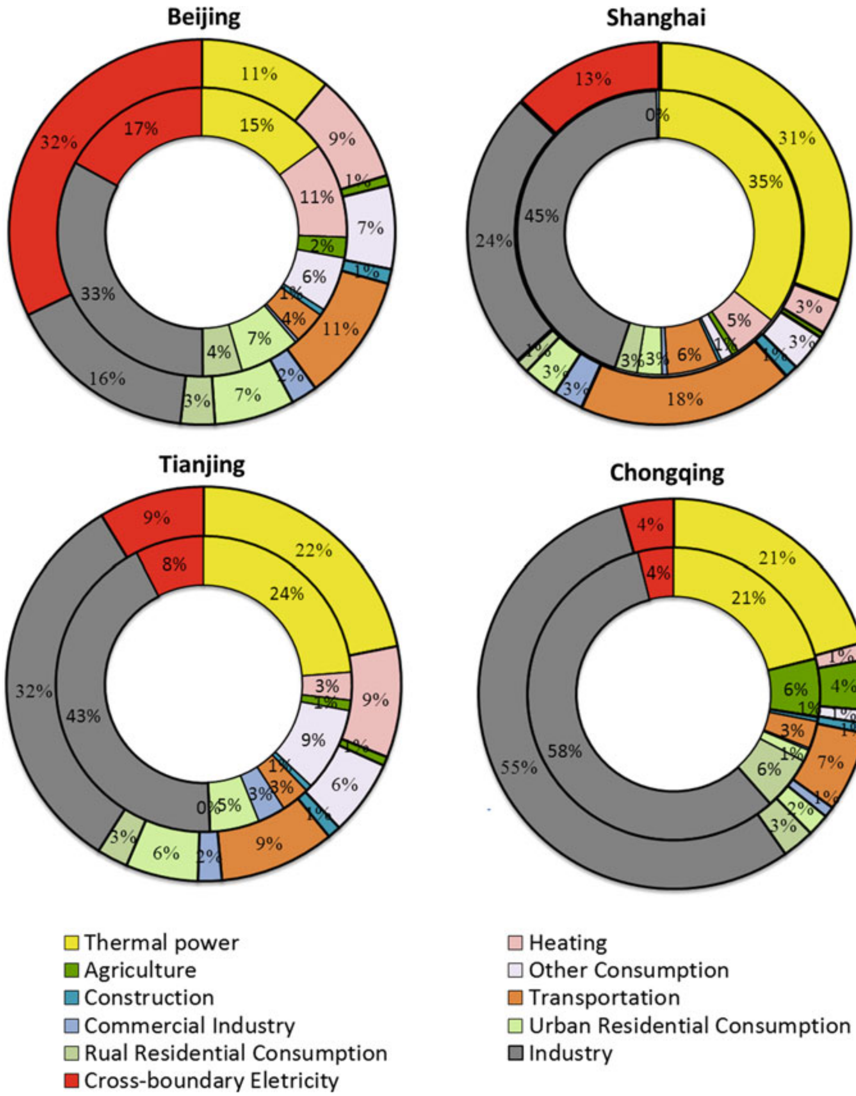

Fig. 2.12 CO_2 emission from different sectors (*inner* year 1995; *external* year 2009)

external electricity purchase (scope 2 emission) represents a large proportion of the total emission and experienced an accelerating increase. For example, emission from external electricity purchase in Beijing accounted for 17 % of the total emission, and the figure increased to 32 % (20 million tons) in 2009. There was no external electricity purchase in Shanghai in 1995, while the proportion rose to 13 % in 2009. The percentage of external electricity in Tianjin and Chongqing was minimal, with 9 and 4 % for Tianjin and Chongqing, respectively. It is manifested that the proportion of scope 2 emission represents the developing and urbanization level of a city to some extent.

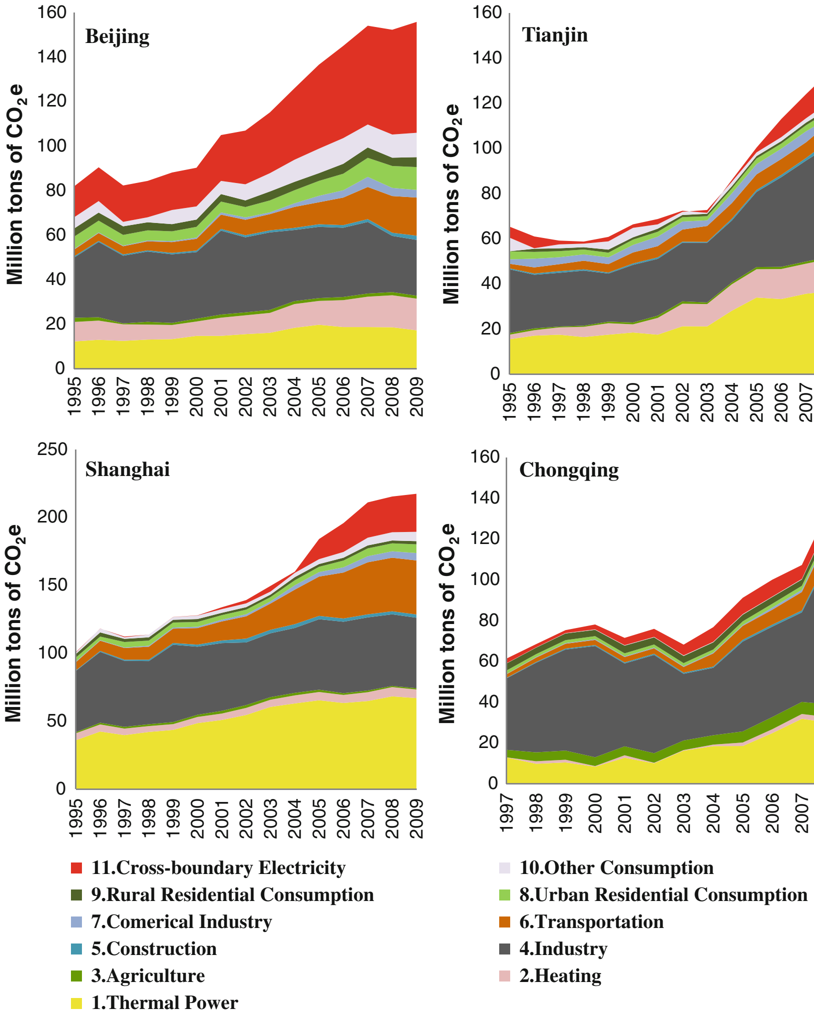

Fig. 2.13 Trajectory of GHG emission from Beijing, Tianjin, Shanghai, and Chongqing (1995–2009)

Apart from the external electricity purchase sector, industries and transportation are two other sectors whose carbon emission increased the most rapidly. The average increase in emission from industries has doubled over the period. Carbon emission from transportation increased from 4 % in 1995 to 32 % in 2009 for Beijing, 1 to 9 % for Tianjin, 6 to 18 % for Shanghai, and 3 to 7 % for Chongqing.

The carbon emission per capita is 8.9 tons, 12.2 tons, 11.3 tons, and 5.1 tons for Beijing, Tianjin, Shanghai, and Chongqing, respectively. The average carbon emission of Beijing, Tianjin, and Shanghai is similar to cities in developed countries, while the emission per capita is lower in Chongqing. As the urbanization level in Beijing and Shanghai has reached 80 %, while Chongqing is only 30 %, the average emission can reveal the economic development level to some extent.

Under the rocketing urbanization process, a great amount of population will surge to urban areas in the following decades. With increasing life quality and the development of infrastructure, the municipal carbon emission in China will further increase. Regions with similar carbon emission quantities as cities of developed countries could be key areas to implement energy conservation and emission reduction strategies.

From per capita point of view, the per capita carbon emissions in Tianjin, Shanghai and Beijing are among at the average international level (Fig. 2.14), while such a figure in Chongqing (5.1 tons of CO_2 per capita) is still low, indicating a potential increasing emission due to their further urbanization initiatives and improvements of citizens' living standards.

The scope 2 emissions from imported electricity use play a significant role in the evolution of the carbon emissions during 1995–2009. Beijing and Shanghai reversed their growth trends of carbon emissions when considering the indirect carbon emissions from imported electricity use since 2004. Besides, the proportion

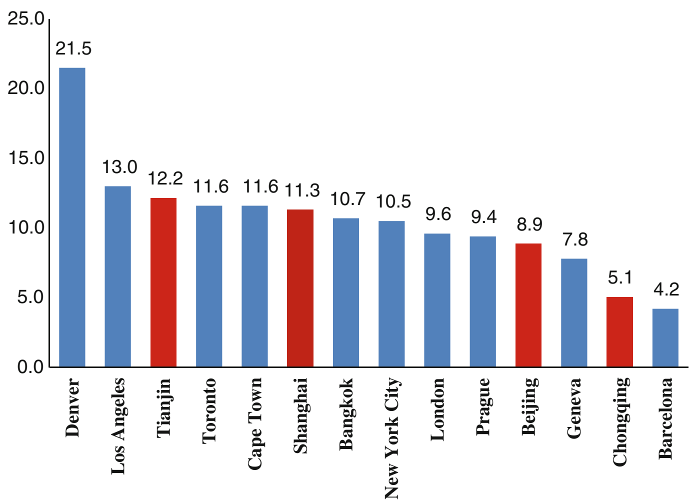

Fig. 2.14 Per capita CO_2 emission for global cities (tCO_2 per capita)

of carbon emissions from cross-boundary electricity keeps growing with city's development. It implies that with city's further development and industrial structure changes (such as more dependence on service-oriented industries), cross-boundary activities will further strengthen, and such cities will further rely on products, energy supply, and material supply from other regions.

2.6.3 Carbon Emissions from 150 Chinese Cities

We found the total carbon emissions from 150 Chinese cities (this is the number of cities for which the emissions data are available) are about 6,006 Mt CO_2 in 2010, which is higher than total emissions from the USA (the second largest emitter) and which accounts for 70 % of China's total carbon emissions. The per capita emissions show the significant variations of Chinese cities. The CO_2 emissions per capita in some Chinese cities are even higher than those of cities in developed countries. For example, the emissions in Tangshan city (in Hebei province), Suzhou city (in Jiangsu Province), Baotou city (in Inner Mongolia), and Zibo City (in Shandong province) are more than 20t CO_2 per capita—not surprisingly, these cities are important resource bases or manufacturing bases for China. However, in general, the per capita emissions in Chinese cities (about 7.5 t CO_2 emissions per capita) are much lower than the cities of developed countries and are approaching the level of global average. The emissions per capita in rural China are much lower than the emissions per capita in urban areas, mainly due to the less-developed infrastructure and a lower standard of living conditions in rural China (Fig. 2.15).

Fig. 2.15 CO_2 emissions in 150 largest Chinese cities in 2012

2.7 Summary

This Chapter compiled the national, provincial, and city's carbon emission inventories, based on the national and provincial Energy Balance Sheet, sectorial energy consumption, and Chinese emission factor by the internationally recognized greenhouse gas inventory compilation method. The national energy-related carbon emission more than doubled from 1990s to 2010s. There was a gradual increase during 1995 and 2001, while the increase has been faster since 2002. Among all fuel types, coal is the major contributor to carbon emission increase. Among all sectors, thermal electricity generation and industries make the greatest contribution, accounting for over 80 % of the total increase.

This chapter also calculated the scope 2 carbon emission of four Chinese municipalities (Beijing, Tianjin, Shanghai, and Chongqing) from 1995 to 2009 and compared the results to scope 1 emission and the per capita emission from other international cities. Because of "urban metabolism," urban areas consume more electricity and commodities from external sources. Scope 2 emission resulting from external purchase of electricity is more significant in more developed municipalities. For example, emissions from external electricity purchase account for 25 % of the total emission in Beijing and Shanghai. Moreover, due to the adjustment of economic structure and the change in heavy industry location, the scope 1 emission of municipalities gradually reaches a plateau or even decline. For instance, the scope 1 energy-related carbon emission of Beijing and Shanghai has decreased since 2008.

This chapter is an indispensible part of the whole research, as it provides strong data basis for the follow-up studies.

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