Study of urban carbon dioxide equivalent (CO$_2$e) accounting based on the comparable GPC framework: a case of the underdeveloped city, Nanning, China

Junsong Jia$^{a,b}$, Zhihai Gong$^{b,c}$, Dongming Xie$^d$, Huiyong Jian$^{b,c}$ and Chundi Chen$^e$

$^a$Key Laboratory of Poyang Lake Wetland and Watershed Research, Ministry of Education, Jiangxi Normal University, Nanchang, China; $^b$School of Geography and Environment, Jiangxi Normal University, Nanchang, China; $^c$Graduate School of Jiangxi Normal University, Nanchang, China; $^d$Tourism College of Jiangxi Science & Technology Normal University, Nanchang, China; $^e$Key Laboratory of Reservoir Aquatic Environment, Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, Chongqing, China

ABSTRACT
It is innovative to account for the carbon dioxide equivalent (CO2e) of underdeveloped regions such as Nanning city of China. Meanwhile, the ‘Global Protocol for Community-scale greenhouse gas emission inventories (GPC)’ has been considered a worldwide comparable framework for calculating urban CO2e emission (CE). So, the CEs of Nanning were calculated during 1994–2015 by the GPC methodology in this paper. The results show the total CE of Nanning, containing the electricity CE of Scope 2, grew rapidly from 6.56 Mt in 1994 to 55.44 Mt in 2015, with an annual average increasing rate of 10.69% and amount of 2.33 Mt. The biggest three contributors were industrial energy consumption, transportation and industrial processes, which contributed 29.72–61.09, 10.75–41.87 and 7.40–14.99%, respectively, to the total CE. Almost always, more than 90.94% of Nanning's CE was related to coal. When considering only the CEs from coal, oil and gas, both these CEs per unit area and per GDP of Nanning were always greater than those of the world, although less than those of China due to the underdeveloped status of Nanning in most years. So, it was necessary for Nanning to pursue the pattern of low-carbon development, and some corresponding countermeasures were recommended.

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1. Introduction
Currently, climate change is damaging the environments around us (Lin et al. 2015), and cities have become the centres of people's social-economic lives (Yu et al. 2015). More than 3.6 billion people live in cities (Gouldson et al. 2015), and urban populations will pass 6.7 billion in 2050 (UNDESA 2014). With this urbanisation, more fuels will be used in cities. Therefore, the greenhouse gases (GHGs) or carbon dioxide equivalent (CO$_2$e) will also be
increasingly emitted into the sky, resulting in an acceleration of global warming (Wang et al. 2015). If we do not take any effective actions, the average global temperatures will increase approximately 5.8 °C over the next 100 years. This possibility poses a huge threat to global sustainable development (Ren et al. 2015). Furthermore, the Intergovernmental Panel on Climate Change (IPCC) estimates the consumed fuels within cities account for approximately 44% of global CO₂e emissions (CE) (IPCC 2014). When considering the final consumption of electricity, the emission shares of cities may reach approximately 71–76% or even higher (Satterthwaite 2008; Hoornweg et al. 2011; Feng et al. 2014). Therefore, to combat climate change, people have recently come up with methods of accounting for cities’ CE to record it more accurately and discuss the related adaptive measures more thoroughly (Dodman 2009).

These methods fall into three categories: from bottom to top (bottom-up), which calculates the emissions of different sectors separately and adds them to obtain an overall result; from top to bottom (top-down), which estimates the distributive value using the whole national or regional emissions and some divided factors; and a hybrid method, in which parts of emissions may be counted by the bottom-up method and the rest from the top-down or other methods (Table 1). IPCC 2006 is a typical bottom-up method that divides emission sources into four sectors: energy; industrial processes and product use (IPPU); agriculture, forestry and other land use (AFOLU) and waste. However, the method is mainly suitable for and often used in the national CE accounting (Guan et al. 2012, 2014; Liu et al. 2014; Liu, Guan, et al. 2015; Wang et al. 2014; Chen 2015). Similarly, the Greenhouse Gas Protocol (WRI/WBCSD 2004) is also bottom-up. It divides emissions into three scopes and is mainly suitable for corporate CE accounting (Ibrahima et al. 2012). Later, Kennedy et al. (2010) proposed a more specific accounting system. This system contained six sectors: electricity; heating and industrial fuels; ground transportation fuels; aviation and marine transportation; IPPU; and waste (Kennedy et al. 2009, 2014; Sugar et al. 2012; Singh and Kennedy 2015). Similarly, Bi et al. (2011) suggested another accounting framework. This framework also had six sectors but was different slightly from Kennedy and more suitable for calculating CE in China’s developed cities such as Nanjing (Wang et al. 2012). In 2014, the ‘Global Protocol for Community-scale greenhouse gas emission inventories (GPC)’ was published by the ICLEI, WRI (world resources institute) and C40 (a network of the world’s megacities committed to addressing climate change both locally and globally). The report provides a much more comprehensive, transparent and accurate set of guidelines than the bottom-up methods described such as the IPCC 2006; Therefore, the GPC has been considered a worldwide comparable framework for calculating urban CE (C40 et al. 2014).

Conversely, Dhakal (2009, 2010) adopted energy use per unit Gross Regional Product (GRP) as a key indicator to estimate divided city CEs in China, which can be described as a top-down method. Similarly, a more careful top-down allocation approach using 135-sector input–output (IO) tables was proposed (Zhang et al. 2015). In addition, some hybrid methods were suggested (Lin et al. 2013; Paloheimo and Salmi 2013; Zhang et al. 2014; Ru et al. 2015). For example, in 2014, the British Standards Institution (BSI 2014) proposed two methods in its Publicly Available Specification (PAS) 2070. One was called the direct plus supply chain method, which could be the equivalent of the GPC. Another used the IO table from the life cycle perspective and was called the consumption-based method.
Table 1. Comparison of current major methodologies for urban CE accounting.

| Method               | Author (Year)   | Category | Summary or assessment                                                                 |
|----------------------|-----------------|----------|---------------------------------------------------------------------------------------|
| The Greenhouse Gas Protocol | WRI/WBCSD (2004) | bottom-up | (1) Divided emission into three scopes  
(2) Several sectors: energy, metals, chemicals, minerals, waste, pulp and paper, et al.  
(3) Mainly used in corporate CE accounting |
| IPCC                 | IPCC (2006)     | bottom-up | (1) A guidance on emission factor, data and equation, et al.  
(2) Four sectors: Energy, IPPU, Waste and AFOLU  
(3) Mainly used in national CE accounting |
| Dhakal               | Dhakal (2009)   | top-down | (1) Adopted energy use per unit GRP as a key indicator to estimate divided city CEs  
(2) Emission factors were from IPCC 2006 |
| Kennedy              | Kennedy et al. (2010) | bottom-up | (1) Adopted three scopes proposed by WRI/WBCSD  
(2) Six sectors: electricity, transportation, IPPU & waste, et al. |
| Bi                   | Bi et al. (2011) | bottom-up | (1) Also six sectors but different slightly from Kennedy  
(2) The earliest case of a developed city in China |
| Lin                  | Lin et al. (2013) | hybrid   | (1) Calculated the emissions from three scopes  
(2) Scopes 1 and 2 were estimated using the IPCC 2006; and Scope 3 was calculated using the life cycle analysis (LCA) |
| GPC                  | C40 et al. (2014) | bottom-up | (1) Contained three scopes and five sectors  
(2) Based on IPCC 2006; but more comprehensive, transparent and accurate, and specifically suitable for cities |
| PAS 2070             | BSI (2014)      | hybrid   | (1) Direct plus supply chain method was equal to GPC  
(2) Consumption-based method used the IO models from a life cycle perspective |
| Zhang                | Zhang et al. (2015) | top-down | (1) Adopted 135-sector IO tables  
(2) The others were the same as Dhakal |
China, the world’s largest developing country, has already become one of the top energy consumers as well as the top CO$_2$ emitter in the world (IEA 2013; Liu et al. 2013; Chen and Lin 2015; Yang et al. 2015). The country has promised a series of targets to decrease CE since it joined the Kyoto Protocol in 1998, e.g. decreasing the carbon intensity of 17% to below 2010 levels by the year 2015 and 40–45% below 2005 levels by the year 2020 (Cong and Wei 2010; Liu, Liang, et al. 2015). Academically, some benchmarks or methods of urban CE accounting (Ramaswami et al. 2008; Finnveden et al. 2009; Hillman and Ramaswami 2010) that are suitable for Chinese developed cities such as Xiamen and Nanjing have also appeared (Bi et al. 2011; Lin et al. 2013). However, these methods often cannot be used directly in other cities, especially for underdeveloped cities such as Nanning, because of disparities in the statistical indexes or missing data. To calculate this CO$_2$ emission of Nanning city, the top-down method lacks enough information, e.g. the IO table of energy use at the city scale, to complete the computation. Therefore, the latest bottom-up method (worldwide comparable GPC framework) was used. First, we complete the CE calculation of Nanning based on the available data. Then, we suggest some countermeasures for this city's low-carbon future or sustainable development after careful analysis. The rest of the context is as follows. Detailed descriptions of the regional outline, CE accounting framework and data are in Section 2. The analysis of the results and discussion are in Section 3. Conclusions and specific suggestions for this city’s low-carbon strategies are given in Section 4.

2. Methodology

2.1. Outline of the study area

The studied area, Nanning, is located at 22°13’–23°32’ N and 107°45’–108°51’ E and has an administrative area of 22 112 km$^2$. As the capital of Guangxi Province, it is a typical city in the western region of China. With the development of China’s economy, Nanning has also a rapid increase in social wealth and related energy consumption. For example, in this city, a coal storage and transportation base (CSTB) had been built in 2012, which was used to purchase and supply crude coal for power generation. This fact might cause some waste of energy consumption. Thus, it is necessary for Nanning to pursue the path of a low-carbon economic transformation to take efficient action to decrease its energy intensities and CEs. In addition, according to the standard of ‘developed’ put forward by the World-Bank (GDP per capita no less than $12476, https://data.worldbank.org.cn/) in 2015, Nanning is an obviously underdeveloped city. However, this city has been drawing increasing attention from the outside world because of its special economic policies. For example, it was just approved to have a comprehensive bonded zone in its ‘High-Tech Industrial Development Zone’ in 2015. This policy enabled Nanning to have more opportunities to transform its developing pattern. Even so, some fundamental information has not been found from the public approach, such as an accounting framework or method for analysing the urban CE of Nanning.

2.2. Accounting sectors based on the GPC framework

Generally, the calculation sectors were classified into three scopes (Kennedy et al. 2010). Scope 1 contained the stationary and mobile fuel combustion that occurred only within the
urban geographical boundary. Based on Scope 1, Scope 2 contained the emissions associated with electricity used within the city boundary but generated outside it. Emissions from life cycle perspective were added to Scope 3. As shown in Figure 1, the specifically calculated sections of this paper were clearly included in the dotted rectangle by the GPC accounting framework. The dotted and shadow rectangle meant the omitted sections, which contained the CEs of agriculture, forestry and other land-use (AFOLU) types as well as other CEs of Scope 3. AFOLU emissions were not considered because of their high uncertainties and typically small contributions to total city CEs (Kennedy et al. 2010; Bi et al. 2011). For example, the share of AFOLU emissions to total city CEs was calculated as only 3.48% in Xiamen city of China (Lin et al. 2013). Another reason was that the original data of Nanning city for AFOLU emissions’ estimation were also not available over 1994–2015. Emissions from Scope 3 were omitted because enough of the related data were also not available, such as Nanning’s energy IO table.

Overall, it can be seen that seven sectors are included in the dotted rectangle: industrial, household and commercial energy consumption; transportation; industrial processes; waste landfill; and wastewater treatment. The first four sectors arose directly from energy use, while the last three sectors were process related. The $\text{CO}_2\text{e}$ signified $\text{CO}_2$, $\text{CH}_4$, $\text{N}_2\text{O}$, $\text{CF}_4$, and $\text{C}_2\text{F}_6$. They can be transferred into $\text{CO}_2\text{e}$ by multiplying global warming potential (GWP) parameters, which were 1, 28, 265, 6630 and 11,100, respectively, as recommended by the IPCC (2014). Based on the available Nanning Statistics Yearbook from 1995 to 2016 (http://www.shujuku.org/statistical-yearbook-of-nanning.html), the time series’ data in 1994–2015 were chosen for the estimation of Nanning’s CE.

### 2.3. Stationary energy

#### 2.3.1. Industrial energy consumption

The CE of industrial energy consumption shows the emissions arising directly from all kinds of industrial energy combustion, for example, the paper-making industry. We can calculate them using the following equation:

$$C_i = \sum_i \sum_j E_{ij} \cdot f_j$$

(1)

where $C_i$ denotes total CE arising from industrial departments in the unit tonnes-$\text{CO}_2\text{e}$ ($\text{t-}\text{CO}_2\text{e}$), $i$ denotes different subsectors of industrial departments (e.g. leather and paper making), $j$ denotes the energy type (e.g. washed coal, liquefied gas and coke oven gas), $i$

![Figure 1. Accounting sectors (included in dotted rectangle) of Nanning’s CE based on the GPC framework.](image-url)
denotes fuel combusted in i subsectors of industry and in the form of energy type j, and \( f_j \) denotes the emission factor of different energy types. We obtain energy-use data from the Nanning Statistical Yearbook, which is published yearly by the local government. Then, based on a suggestion from IPCC, the emission factor can be gotten (listed in Table A1). Using the calorific value, the emission factor of heat can be calculated as 0.11t-CO\(_2\)/GJ. Last, Nanning's emission factors of electricity are taken from the average values of China. These factors can be obtained directly from the International Energy Agency (IEA) statistics 2011–2016 (listed as Table A2).

### 2.3.2. Household energy consumption

In daily life, coke oven, natural and liquefied natural gases (LNGs) as well as electricity are used in the household consumption sector. These fuels may arise from both primary and secondary energies. These CEs can be calculated:

\[
C_H = \sum_j (E_j \cdot f_j)
\]

(2)

where \( C_H \) denotes the CE of energy consumption in the household sector (t-CO\(_2\)e), \( E_j \) denotes the energy consumption of category j obtained from yearly statistical data and \( f_j \) denotes the same emissions factors as in 2.3.1 above.

### 2.3.3. Commercial energy consumption

The energy consumption of the commercial sector is in the form of electricity. Its CEs are:

\[
C_{CO} = E_e \cdot f_e
\]

(3)

where \( C_{CO} \) denotes the electricity consumption CE of the commercial sector (t-CO\(_2\)e), \( E_e \) denotes the quantity of the electricity consumption \( (10^4\ kWh) \) obtained directly from government statistical data and \( f_e \) denotes the emission factor of electricity (Table A2).

### 2.4. Transportation

The transportation sector usually includes road, water and air transport. Road transport is the main contributor. The other two parts account for no more than 30% of the total transport CE (Bi et al. 2011). Therefore, we only calculate the CE of road transport based on the available data. For road transport, many kinds of vehicles exist, such as motorcycles, trucks (heavy, medium, light and micro), taxis, buses and passenger cars. These CEs are calculated:

\[
C_T = \sum_k \left( N_k \cdot VMT_k \cdot FE_k f_{g/d} \right) \times 10^{-6}
\]

(4)

where \( C_T \) denotes the total CE of energy consumption in the road transportation sector (t-CO\(_2\)e), \( k \) denotes the category of vehicle fleets, \( N_k \) denotes the number of vehicle fleet k, \( VMT_k \) denotes the annual average number of mile-metres travelled by vehicle fleet k (km/vehicle/year), \( FE_k \) denotes the fuel economy of vehicle fleet k (L/km) and \( f_{g/d} \) denotes the emission factor of gasoline or diesel (g-CO\(_2\)/L). The number of vehicles is obtained from the Nanning Statistical Yearbook, and VMT information is obtained from the article (Wang et al. 2012). Finally, we sum the different CE categories of vehicle fleets to get the total amount (\( C_T \)).
2.5. Waste

According to the IPCC (2006), CH₄ emitted from the solid waste landfill accounts for 97% of the total CE in the whole waste treatment sector. Solid waste consists of both industrial and municipal solid waste. The recommended method of the First-Order Decay Model (FODM) was used to calculate solid waste CE. Ideally, the FODM needs at least 20 years of data from the solid waste landfill. Fortunately, we can get the related data for industrial and municipal solid waste from the Statistical Yearbooks, Bulletins or collections of the local government. The related data are from 1994 to 2015, and the time series is 21 years. Thus, the FODM is suitable for this study.

\[
C_{\text{WASTE}} = 28 \times \left[ \sum \left( \text{CH}_4, t - R_t \right) \right] \cdot (1 - OX_t)
\]  

where \(C_{\text{WASTE}}\) denotes the CE of solid waste treatment (t-CO₂e), \(\text{CH}_4, t\) denotes CH₄ production output of waste type 1 during inventory year t (tonnes), \(R_t\) denotes CH₄ recovery number for inventory year t (tonnes) and \(OX_t\) denotes oxidation ratio for inventory year t (%).

Similarly, wastewater treatment CE consists of both industrial and domestic wastewater. The related data of industrial and domestic wastewater can be obtained from local statistical materials. The recommended methods follow:

\[
C_{\text{IWWATER}} = 28 \times \sum \left[ (\text{TOW}_i - S_i) f_i - R_i \right]
\]  

where \(C_{\text{IWWATER}}\) denotes the CE arising from industrial wastewater treatment (t-CO₂e), \(i\) denotes the industrial subsectors as in 2.3.1, \(\text{TOW}_i\) denotes the total amount of biodegradable organic matter from i subsector industry in the inventory year (tonnes), \(S_i\) denotes the organic part discharged by the sludge for the inventory year (tonnes), \(f_i\) denotes the emission factor of the industrial subsector i and \(R_i\) denotes the methane amount recovered during the inventory year (tonnes).

\[
C_{\text{DWWATER}} = 28 \times \left\{ \left[ \sum_{m,n} (U_m \cdot T_{m,n} \cdot f_n) \right] \cdot (\text{TOW} - S) - R \right\}
\]  

where \(C_{\text{DWWATER}}\) denotes the CE arising from domestic wastewater treatment (t-CO₂e); \(m\) denotes different income groups such as low, middle and high; \(n\) means different systems of disposing domestic wastewater for the inventory year; \(U_m\) denotes the population percentage of group m; \(T_{m,n}\) denotes the degree of system n used by group m; \(f_n\) denotes the emission factor of system n; \(\text{TOW}\) denotes the total amount of biodegradable organic matter from domestic wastewater (tonnes); S denotes total organic matter discharged by sludge for the inventory year (tonnes); and \(R\) denotes the total methane recovered during the inventory year (tonnes).

2.6. IPPU

The industrial processes are the chemical or physical transformation courses of materials during industrial production. This sector's CE also has many categories. However, the basic
data on these categories are scarce, so we focus on three major categories for this sector’s CE calculation: the mining, chemical and metal industries. We can get the related production data from yearly statistical materials and the emission factors from IPCC report.

Mining industry: The mining industry is the largest CE source of the industrial processing sector. According to the IPCC, the mining industry contains cement, lime and glass production. The three are the major CE sources of mining industry, among which cement production has the greatest contribution. The corresponding CEs are

\[
C_{CE} = (M_{pr} \cdot p - M_{im} + M_{ex}) \cdot f_{cl}
\]

where \(C_{CE}\) denotes the CE during cement production (t-CO\(_2\)), \(M_{pr}\) denotes the yield of cement production (tonnes), \(p\) denotes the ratio of the cement clinker (default value is 0.65), \(M_{im}\) denotes the imported cement clinker (tonnes), \(M_{ex}\) denotes the exported clinker (tonnes) and \(f_{cl}\) denotes the emission factor of the clinker (t-CO\(_2\)/t-clinker, default value is 0.52).

Chemical industry: In the chemical industry subsector, many production processes exist, e.g. ammonia, nitric acid and carbon black production, all of which emit CEs, according to the IPCC. Based on the available data, we can only account for the CE from the ammonia production process:

\[
C_{AM} = \left(M_{am} \cdot FD_{am} \cdot CC_{am} \cdot CO_{am} \times \frac{44}{12} - R_{CO_2}\right) \times 10^{-3}
\]

where \(C_{AM}\) denotes the CE emitted from the ammonia production process (t-CO\(_2\)), \(M_{am}\) denotes ammonia production (tonnes), \(FD_{am}\) denotes the fuel demand coefficient (GJ/t-ammonia), \(CC_{am}\) denotes the carbon content coefficient (kg C/GJ), \(CO_{am}\) denotes the carbon oxidation rate (default factor is 100%), and \(R_{CO_2}\) denotes CO\(_2\) recovery in urea production (kg-CO\(_2\)).

Metal industry: Many production processes that emit CEs also exist in the metal industry, e.g. steel, metallurgical coke, iron alloy, aluminium and magnesium. The emissions emitted from these production processes include not only CO\(_2\) but also CH\(_4\), CF\(_4\) and C\(_2\)F\(_6\). We can account for them easily by multiplying the metal production number by the matching emission factors.

3. Results and discussion

3.1. Sectoral CE

3.1.1. Industrial energy consumption CE

It can be easily seen that an obvious CE’s increase in the industrial subsector PHPS (power, heat production and supply) existed, which was from 0.16 million tonnes (Mt) in 2011 to 4.44 Mt in 2012. Before 2012, the CEs of PHPS changed between 0.02 Mt and 0.56 Mt, and their shares in the whole industrial CE could almost be neglected during 1994–2011. However, over 2012–2015, the CEs of PHPS had become a very important component. The reason might arise from the fact that the CSTB, which was used to supply coal for power generation, had been built in 2012.

From 2012 on, the largest eight departments were the industrial subsectors NMMP (non-metallic mineral products), PHPS, FSFP (farm and sideline food processing), CMPM
(chemical materials and product manufacturing), PMPP (paper making and paper products), WBRP (wood, bamboo, rattan, palm and straw products), MB (manufacture of beverages), and MRP (manufacture of rubber and plastics). In 2012–2015, the eight subsector CEs contributed 89.00–92.67% to the whole industrial CE. The average contribution was 91.40%. The first two subsectors (NMMP and PHPS) contributed more than a half (53.45–60.36% > 50%). The four subsectors NMMP, PHPS, FSFP and CMPM contributed more than three-fourths (75.84–77.56% > 75%). All the CEs from the eight industrial subsectors had the whole increasing trends, but with different variation rate in 1994–2015. For instance, MB had the largest annual variation rate of 15.19%. However, CMPM had the least annual variation rate of 3.29%.

On the whole, CEs from all the industrial subsectors in Nanning increased from 3.87 Mt in 1994 to 19.01 Mt in 2015 (Figure 2). But they could also be divided obviously into two stages: 1994–2013 and 2014–2015. In the first stage, CEs from all industrial subsectors increased almost stably, only had little recession in a few years such as 1996, 1998, 1999 and 2005. However, in the second stage, they had an obvious recession (Figure 2). The main reasons were the follows. In the first stage, with the development of urban and social economy, real estate and other infrastructure construction grew quickly in Nanning. People ignored improved energy efficiency and focused only on GDP growth. Therefore, the corresponding energy consumption and economic pattern became unreasonable and all the industrial subsectors gained a large growth. However, in recent years, people began to pay attention to the low-carbon economy and managed to improve energy efficiency. For example, people preferred to exploit renewable energy, develop energy-saving technologies and remove inferior (energy-intensive or polluting) industries. The inferior CMPM contribution to the whole industrial CE decreased from 13.69% in 2011 to 7.07% in 2015.

![Figure 2](chart.png)

**Figure 2.** Accumulative results of energy consumption CE from all industrial subsectors.
3.1.2. Household and commercial energy consumption CEs

It can be easily seen that household CE had an increasing trend on the whole. In 1994, the household CE was 0.23 Mt and it reached 3.97 Mt in 2015 with an annual average increasing rate of 14.54% and amount of 0.18 Mt (Figure 3(a)). Similarly, commercial sector CE had also a whole increasing number from 38.68 \times 10^3 tonnes in 1994 to 1.26 Mt in 2015 with an annual average increasing rate of 18.06% and amount of 0.06 Mt (Figure 3(b)). The growing steadily trends indicated that the standard of people's daily life had a real improvement over 1994–2015, which was consistent with the fact.

3.1.3. Transportation CE

Five kinds of traffic tools are considered: passenger vehicles, trucks, simple motors, motorcycles and steering wheel-type tractors (Figure 4). Total CE in the transportation sector grew rapidly, with an annual rising rate of 16.48% from 1994 to 2015. Among five traffic tools, passenger vehicle CE had the biggest growth rate of 20.15%. It was also the largest contributor in transportation sector. Truck CE was the second biggest contributors. In 2015, they accounted for 84.95% and 12.76% of the total transport CE, respectively. From 1994 to 2015, the sum of these two tools' CE had always a large share (>78.65%, Figure 4), so we could almost neglect the contributions of the other three tools.

The main three types of passenger vehicles were private cars, taxis and buses (Figure 5). Private car CE had the largest increase from 37.40 \times 10^3 tonnes in 1994 to 6.52 Mt in 2015. The increase was 6.49 Mt, more than 172 times that in 1994 and with an annual increase of 27.86%. In 1995, taxi CE’s share increased because of the great growth in taxis’ number in the official statistics (Figure 5(b)). However, after 1995, the growth of private cars was much faster than that of taxis, so taxi CE’s share started to decline gradually until 2015. Overall, average shares of private cars, taxis and buses were 89.04, 6.49 and 4.47%, respectively.

3.1.4. Waste CE

As shown in Figure 6, with the growths of people and artificial objects in Nanning, the emissions of municipal solid waste landfill increased stably with an average annual rising rate of 16.31% from 1994 to 2015. However, the CE of industrial solid waste landfill presented a slightly decreasing trend after 2008. This change was because of improvements in production technologies and comprehensive use percentage increases in solid waste. Similarly, the CE of industrial wastewater treatment showed also an obviously decreasing trend after 2008.

![Figure 3. CO2e emissions from household (a) and commercial (b) energy consumption.](image)
In addition, the CE of domestic wastewater treatment had no obvious change in 1994–1999 and only a slightly increase over 2000–2015, perhaps because of the relatively stable patterns of social and economic development and the consumption habit of local residents.

Figure 4. Accumulated CEs of different traffic tool types.

Figure 5. CO₂e emissions from private cars, taxis and buses (a) and their respective shares (b).

Figure 6. CO₂e emissions from solid waste landfill (a) and wastewater treatment (b).
3.1.5. Industrial process CE

Obviously, CE from the industrial process sector increased from 1994 to 2015. It was 7.93 Mt in 2015 and was 13.25 times more than that in 1994 (0.56 Mt). The average yearly rising rate and amount were 13.49% and 0.35 Mt, respectively. Steel, cement and synthetic ammonia had the biggest shares in this sector’s CE. The three shares contributed to more than nine-tenths of total industrial process CE (>94.05%). They reached the largest number of 99.11% in 2004. These shares’ situation indicated that the industrial productions were mainly consisting of infrastructure construction in Nanning. The share of aluminium was 0.92% in 1994 and it reached 5.95% in 2015, with an average annual rising rate of 9.30%. The share of pig iron was always less than 1.04% in 1994–2015 (Figure 7).

3.2. CE of different types’ energies

Figure 8 shows CEs arising from different types of energies such as crude coal, washed coal, other washed coal, coke, coke oven gas, natural gas, diesel and electricity. Other fuel
emissions were small and omitted. It can be found that an obvious CE’s increase in crude coal existed, especially from 8.49 Mt in 2011 to 12.90 Mt in 2012. This CE grew unceasingly to the largest 14.38 Mt in 2013. Before 2011, it had a whole slowly increase and even little recession (e.g. 1999). However, the crude coal's CE had an extremely decrease over 2013–2015. The reason for the first growth of crude coal’s CE might, like the CE of industrial energy consumption, also arise from the built CSTB in 2012, which was used to supply coal for power generation. Similarly, in recent years, people began to pay attention to the low-carbon economy and managed to improve energy efficiency, which, in turn, caused the great decline of coal consumption and the corresponding CE.

The share of crude coal’s CE to the total CE from different fuel types was the biggest and between 54.26 and 68.66%. The second largest component was the electricity’s CE, which was between 24.98 and 38.24%. The share of other coal’s CE was between 0.49 and 3.88%. Therefore, we could add the shares of crude coal, other coal and electricity to obtain the following result. More than 90.94% of Nanning’s CE was always related to coal because in China most electricity arose from coal burning from 1994 to 2015.

### 3.3. Total CE of Nanning

Figure 9 shows the total CE and different subsector CEs of Nanning. In it, we can find the total CE increased steadily with a slight decrease only in 1995–1996. The total CE of Nanning city was 6.56 Mt in 1994, and it grew rapidly to 7.76 Mt in 1995. However, then it decreased to 7.42 Mt in 1996. After 1996, it stabily increased again to 55.44 Mt in 2015. The rising rate was 18.28% from 1994 to 1995 and average annual rising rate was 11.16% in 1996–2015. Industrial energy consumption CE (1) accounted for 29.72–61.09% of total CE. Transportation energy consumption CE (2), household energy consumption CE (3), commercial energy consumption CE (4), industrial process CE (5), solid waste landfill CE (6) and wastewater treatment CE (7) accounted for 10.75–41.87, 3.49–7.77, 0.50–2.49, 7.40–14.99, 1.06–4.68 and 2.02–13.36%, respectively. Overall, the shares of (1) and (7) declined because the shares of the other five sectors increased.

Therefore, we can easily find that industrial energy consumption CE (1) was the biggest contributor to total CE. Further, (1) emissions still had a steady growth (Figures 2 and 9) from

![Figure 9. Total CE and different subsector CEs in Nanning city.](image)
1994 to 2013 although their share was always declining in the whole period 1994–2015. Transportation energy consumption CE (2) was the second contributor, and industrial process CE was the third. The former three contributors accounted for more than 70.65% of the city’s whole CE. Therefore, it can be concluded that we should pay much more attention to the CEs of these three subsectors when we study Nanning’s low-carbon future and design for this city’s sustainable development.

3.4. CE intensities

Table 2 shows the total CE of Nanning city, CEs per unit area, population, CEs per capita, GDP, CEs per GDP and the shares of the primary, secondary and tertiary industry in 1994–2015. It can be easily seen that the CE intensities (CE per GDP) decreased obviously from 16.58 t-CO$_2$/10$^4$$^3$ in 1994 to 6.92 t-CO$_2$/10$^4$$^3$ in 2015. The decline percentage was 58.26%. The reason might be the improvements in industrial technology. However, per capita CEs increased from 2.44 t to 7.54 t during the study period. Total CE decreased from 1995 to 1996, but it grew almost 7.4 times more than before. This fact might be due to the improvements in living standards and the prosperity of the real estate construction in recent years. Similarly, from 1994 to 2015, the CE per unit area increased from 0.30 to $2.51 \times 10^3$ t-CO$_2$/km$^2$, an increase of 7.4 times. In addition, the GDP itself, similar to the total CE, increased stably during the study period. The only difference in CEs was that the GDP still had an increase from 1995 to 1996. All in all, the GDP was positively related with the total CE.

The economic structure of Nanning had an obvious change from 1994 to 2015. The share of secondary industry had a decreasing trend in 1994–2001 and thereafter an increasing trend. Overall, it had only a slight rise of no more than 4% during 1994–2015 (Table 2). However, the share of primary industry decreased almost stably from 26.23 to 10.88%. In addition, the share of tertiary industry increased on a whole from 37.71 to 49.67%. These trends indicate that the economic development in Nanning relied increasingly on tertiary industry. This fact might explain why the economic recession of secondary industry from 1995 to 1996 did not impact Nanning’s GDP growth but did cause the total CE to decrease.

3.5. Comparison with China and the world

It should be noted that total CE of Nanning city contained electricity CE from Scope 2. This electricity was used within the city’s geographical boundary. The related CE could be called as electricity consumption-related CE or consumption-based CE (ECCE). For Nanning city in this paper, we could determine only three types of ECCEs based on the available data: industrial, household and commercial. The three ECCEs were included in industrial energy consumption CE, household energy consumption CE and commercial energy consumption CE, respectively. In contrast, many cities in China have coal-fired power plants located within their geographical boundaries to generate and sell electricity to the national power grids (Bi et al. 2011). These emissions from power stations (production-based view) were mixed in the industrial energy consumption CE. The mixed sub-industrial name was PHPS (power, heat production and supply). In PHPS, the share of heat production and supply was very small. However, we could still not differentiate it from PHPS because of the hybrid nature of the statistical data. In other words, the electricity production-related CE or production-based CE (EPCE) was included in PHPS CE and was the major portion of PHPS CE. But, we could not...
Table 2. Total CE, CEs per unit area, population, CEs per capita, GDP, CEs per GDP and the shares of primary, secondary and tertiary industries in Nanning city.

| Year | CE (10^4 t-CO\textsubscript{2}e) | CE Per unit area (10^3 t-CO\textsubscript{2}e/km\textsuperscript{2}) | Population (10^4 person) | CE Per-capita (t-CO\textsubscript{2}e/person) | GDP (10^8 $) | CE Per GDP (t-CO\textsubscript{2}e/10^4 $) | The primary industry (%) | The secondary industry (%) | The tertiary industry (%) |
|------|-------------------|-------------------|-----------------|-----------------|--------|-----------------|----------------|----------------|----------------|
| 1994 | 656               | 0.30              | 269             | 2.44            | 39.6   | 16.58           | 26.23          | 36.06          | 37.71          |
| 1995 | 776               | 0.35              | 273             | 2.84            | 48.08  | 16.15           | 26.09          | 34.26          | 39.65          |
| 1996 | 742               | 0.34              | 278             | 2.67            | 55.61  | 13.35           | 25.84          | 31.66          | 42.5           |
| 1997 | 752               | 0.34              | 281             | 2.68            | 66.29  | 11.35           | 25.81          | 30.29          | 43.9           |
| 1998 | 762               | 0.34              | 285             | 2.68            | 76.09  | 10.02           | 24.57          | 29.37          | 46.06          |
| 1999 | 799               | 0.36              | 286             | 2.8             | 79.89  | 10.01           | 23.88          | 28.57          | 47.55          |
| 2000 | 895               | 0.40              | 625             | 1.43            | 85.79  | 10.43           | 23.19          | 27.88          | 48.93          |
| 2001 | 949               | 0.43              | 630             | 1.51            | 97.78  | 9.7             | 21.7           | 27.06          | 51.24          |
| 2002 | 1079              | 0.49              | 635             | 1.7             | 107.14 | 10.07           | 20.37          | 27.11          | 52.52          |
| 2003 | 1675              | 0.76              | 642             | 2.61            | 111.45 | 15.03           | 19.11          | 29.2           | 51.69          |
| 2004 | 1906              | 0.86              | 649             | 2.94            | 123.69 | 15.41           | 17.39          | 31.23          | 51.38          |
| 2005 | 2012              | 0.91              | 660             | 3.05            | 143.76 | 14              | 17.07          | 31.76          | 51.17          |
| 2006 | 2231              | 1.01              | 672             | 3.32            | 175.43 | 12.72           | 16.4           | 33.78          | 49.82          |
| 2007 | 2603              | 1.18              | 684             | 3.81            | 214.72 | 12.12           | 16.34          | 34.18          | 49.48          |
| 2008 | 2786              | 1.26              | 692             | 4.03            | 263.42 | 10.57           | 15.38          | 34.68          | 49.94          |
| 2009 | 2975              | 1.35              | 698             | 4.26            | 321.93 | 9.24            | 13.93          | 34.59          | 51.48          |
| 2010 | 3381              | 1.53              | 707             | 4.78            | 375.09 | 9.01            | 13.58          | 36.21          | 50.21          |
| 2011 | 3748              | 1.69              | 711             | 5.27            | 433.34 | 8.65            | 13.82          | 37.51          | 48.67          |
| 2012 | 4681              | 2.12              | 713             | 6.56            | 524.82 | 8.92            | 12.9           | 38.38          | 48.72          |
| 2013 | 5257              | 2.38              | 724             | 7.26            | 617.39 | 8.52            | 11.84          | 38.95          | 49.21          |
| 2014 | 5353              | 2.42              | 730             | 7.34            | 693.43 | 7.72            | 11.27          | 39.75          | 48.98          |
| 2015 | 5544              | 2.51              | 740             | 7.54            | 769.47 | 6.92            | 10.88          | 39.45          | 49.67          |

Note: The GDPs were converted to the PPP $ based on constant 2011 international values.
acquire definitive data for EPCE. As shown in Figure 10, the PHPS CE column was empty in 1995, 1999–2003 and 2005–2011 because of the lack of corresponding PHPS data, and the total ECCE (commercial, household and industrial) had a stably increasing trend from 1994 to 2015. Nevertheless, the EPCE (included in PHPS CE) had an obvious recession in 2014–2015 which perhaps arising from the fuel’s decline of crude coal (Figure 8). In this paper, we accounted for the CEs from both the electricity use and its production end, which might contain double counting and cause some deviations. Therefore, in the latter comparison of Nanning, China and the world, electricity CE was excluded.

As discussed above, we compared Nanning’s CE arising only from coal, oil and gas consumptions with those of both China and the world. The corresponding results were shown in Table 3. It can be easily found that the CEs per GDP of Nanning were smaller than those of China in most years. However, they were always bigger than those from the world. Thus, it was increasingly urgent and necessary for us to save energy and improve energy efficiency in Nanning from the global perspective. A similar result could also be gotten from the CE per unit area. In particular, these CEs per unit area of Nanning have been always more than those of both China and the world since 2011 (Table 3).

In contrast, the per capita CE of Nanning was only 1.40 t in 1994, which was less than contemporaneous China (2.53 t) and the world (4.11 t). Until 2014, the per capita CE of Nanning (4.52 t) was the closest to the world (4.89 t) and the difference was −0.37 t. In 2015, the difference was −0.38 t. Overall, the per capita CEs of Nanning were always less than those of China and the world (Table 3). Moreover, these accumulative CEs per capita of Nanning were also always less than China and the world from 1994 to 2015 (Figure 11). These results mainly arose from the underdeveloped status of Nanning compared with cities in developed countries or some developed cities in China such as Beijing and Shanghai.

3.6. Uncertainties

Some common sources of errors or uncertainties exist for calculating the CO$_2$e emission of any place such as a city, town or country. For example, errors may exist in calculation processes caused by the rounding method or in emission factors caused by real-world emission

![Figure 10. Electricity consumption-based CE (ECCE) containing commercial, household and industrial portions; electricity production-based CE (EPCE) was included in PHPS CE.](image)
variability. In the article, the main uncertainties in the CE calculation of Nanning may be rooted in the following places. First, the emission factors of different kinds of energies/products may have some inherent uncertainties. For example, we adopt directly the related data of China in the IEA statistics or the IPCC. The emission factors of the electricity are directly from the IEA. The other factors are mainly from the IPCC. Especially in industrial processes, solid waste landfill and wastewater treatment, default emission factors are often used. Second, the calculation model may have some unpredicted and systematic errors, such as the IPCC-recommended FODM. This method is used to calculate solid waste CE from the

Table 3. Differences in four emission indicators in Nanning (NN), China (CN) and the world (WD).

| Year | CE (Mt) | CE per capita (t-CO₂/ person) | CE per GDP (t-CO₂/10⁴$) | CE per unit area (10³t-CO₂/km²) |
|------|---------|-------------------------------|------------------------|-------------------------------|
|      | NN      | CN   | WD   | NN     | CN   | WD   | NN     | CN     | WD   | NN     | CN   | WD   | NN     | CN     | WD   |
| 1994 | 3.76    | 3029 | 23101 | 1.40  | 2.53  | 4.11  | 16.58  | 29.55  | 4.58  | 0.17   | 0.31  | 0.16  |
| 1995 | 4.83    | 3228 | 23564 | 1.77  | 2.67  | 4.13  | 16.15  | 25.90  | 4.52  | 0.22   | 0.34  | 0.16  |
| 1996 | 4.21    | 3323 | 24185 | 1.51  | 2.72  | 4.18  | 13.35  | 23.21  | 4.47  | 0.19   | 0.34  | 0.16  |
| 1997 | 4.02    | 3314 | 24423 | 1.43  | 2.68  | 4.16  | 11.35  | 19.16  | 4.34  | 0.18   | 0.34  | 0.16  |
| 1998 | 4.03    | 3312 | 24510 | 1.41  | 2.66  | 4.12  | 10.02  | 17.42  | 4.25  | 0.18   | 0.34  | 0.16  |
| 1999 | 3.65    | 3423 | 24853 | 1.28  | 2.72  | 4.12  | 10.01  | 16.96  | 4.16  | 0.18   | 0.36  | 0.17  |
| 2000 | 4.11    | 3514 | 25501 | 1.41  | 2.66  | 4.12  | 10.01  | 15.51  | 4.08  | 0.19   | 0.36  | 0.17  |
| 2001 | 4.46    | 3674 | 25825 | 0.71  | 2.88  | 4.17  | 9.70   | 14.25  | 4.03  | 0.20   | 0.38  | 0.17  |
| 2002 | 5.00    | 4025 | 26436 | 0.79  | 3.13  | 4.21  | 10.07  | 14.38  | 4.02  | 0.23   | 0.42  | 0.18  |
| 2003 | 7.73    | 4723 | 27718 | 1.21  | 3.65  | 4.36  | 15.03  | 16.19  | 4.06  | 0.35   | 0.49  | 0.19  |
| 2004 | 9.09    | 5521 | 29143 | 1.40  | 4.25  | 4.53  | 15.41  | 17.20  | 4.05  | 0.41   | 0.57  | 0.20  |
| 2005 | 9.83    | 6326 | 30279 | 1.49  | 4.84  | 4.65  | 14.00  | 17.23  | 4.02  | 0.44   | 0.66  | 0.20  |
| 2006 | 10.97   | 6926 | 31187 | 1.63  | 5.27  | 4.73  | 12.72  | 15.96  | 3.93  | 0.50   | 0.72  | 0.21  |
| 2007 | 13.74   | 7518 | 32307 | 2.01  | 5.69  | 4.84  | 12.12  | 14.23  | 3.86  | 0.62   | 0.78  | 0.22  |
| 2008 | 14.56   | 7663 | 32597 | 2.11  | 5.77  | 4.82  | 10.57  | 12.13  | 3.78  | 0.66   | 0.80  | 0.22  |
| 2009 | 16.32   | 8037 | 32004 | 2.34  | 6.02  | 4.68  | 9.24   | 11.01  | 3.72  | 0.74   | 0.83  | 0.21  |
| 2010 | 18.91   | 8472 | 33471 | 2.67  | 6.32  | 4.83  | 9.01   | 9.94   | 3.70  | 0.86   | 0.88  | 0.22  |
| 2011 | 21.88   | 9206 | 34413 | 3.08  | 6.83  | 4.91  | 8.65   | 9.70   | 3.66  | 0.99   | 0.96  | 0.23  |
| 2012 | 28.54   | 9415 | 34819 | 4.00  | 6.95  | 4.91  | 8.92   | 8.41   | 3.58  | 1.29   | 0.98  | 0.23  |
| 2013 | 32.14   | 9674 | 35312 | 4.44  | 7.11  | 4.92  | 8.52   | 7.58   | 3.52  | 1.45   | 1.00  | 0.24  |
| 2014 | 32.95   | 9761 | 35499 | 4.52  | 7.14  | 4.89  | 7.72   | 6.97   | 3.42  | 1.49   | 1.01  | 0.24  |
| 2015 | 33.13   | 9848 | 35686 | 4.48  | 7.16  | 4.86  | 6.92   | 6.35   | 3.33  | 1.50   | 1.02  | 0.24  |

Note: The CO₂ emissions of China and the world were taken from the BP Statistical Review of World Energy, BP Global 2016.

Figure 11. Accumulative CE per capita of Nanning, China and World.
global point of view. However, the decay speed and mode of the solid waste may vary as the influencing factors change, such as time, place and climate. In other words, the model may be different from the actual situation in Nanning. Third, the lack of some data sources may make the calculated result of Nanning smaller than the reality. For example, we calculate the CE of only five industrial processes: steel, pig iron, cement, aluminium and synthetic ammonia production. The result may be less than the real emissions from all industrial processes in Nanning. Similarly, we only calculate the CE of electricity consumption in the commercial energy consumption sector, which may also make the results less than reality. Last, AFOLU emissions were not considered because the original data for emissions’ estimation were not available, although these emissions’ contributions were typically small (3.48%, Lin et al. 2013). And, emissions of SF$_6$ and from Scope 3 were also omitted because enough of the related data were not available, such as Nanning’s energy IO table. These omissions may also make the calculated result of Nanning’s CE smaller than the reality.

4. Conclusions

Currently, we must account for city CE to combat climate change. In reality, people have suggested many urban CE accounting frameworks (bottom-up, top-down and hybrid methods) for case studies regarding some typical developed cities globally such as London, Los Angeles, Xiamen and Nanjing. However, these cases and methods often cannot be used directly in underdeveloped cities, e.g. those in the Guangxi Province in western China, because of disparities in statistical indexes or lacking data. Therefore, taking Nanning (an underdeveloped city) as an example, we complete the urban CE calculation based on the available data and the latest GPC method, which is considered a globally comparable framework. The particular calculated sectors are industrial energy consumption, transportation, household energy consumption, commercial energy consumption, industrial processes, waste landfill and wastewater treatment.

The results showed Nanning’s CE grew rapidly from 6.56 Mt in 1994 to 55.44 Mt in 2015, with an annual average increasing rate of 10.69% and amount of 2.33 Mt. The biggest three contributors were industrial energy consumption, transportation energy consumption and industrial processes, which contributed 29.72–61.09, 10.75–41.87 and 7.40–14.99%, respectively, to the total CE. The CE intensities (CEs per GDP) decreased from 16.58 t-CO$_2$/10$^4$ to 6.92 t-CO$_2$/10$^4$ from 1994–2015 because of the improvement in industrial technology. Per capita CEs have increased from 2.44 t to 7.54 t due to the improvements in living standards and the prosperity of real estate construction in recent years. Because most electricity originated from coal burning in China, we could add the shares of crude coal, other coal and electricity to get the result that more than 90.94% of Nanning’s CE was almost always related to coal from 1994 to 2015. According to the GPC framework, the total CE contained the electricity CE from Scope 2. Therefore, we accounted for CEs from both electricity use and its production end. However, these results might include double counting and cause some deviations due to the hybridity of data in Nanning. Thus, we only considered the CEs from coal, oil and gas (excluding electricity) when comparing the results with those of China and the world. The results showed these accumulative CEs per capita of Nanning were always less than those of China and the world from 1994 to 2015 because Nanning was still underdeveloped. However, these CEs per GDP and per unit area of Nanning were always bigger than that of the world, although less than those of China due to the underdeveloped status.
of Nanning in most years. Thus, from the global view, we must save energy and improve the energy efficiency of Nanning.

Based on these results, the following implications of strategies and management policies for combating climate change can be inferred:

First, for Nanning’s low-carbon future or sustainable development, we should pay much attention to develop some new industries using low-carbon energy sources such as the solar, instead of the traditional industries using high-carbon fuels such as petrol or coal. At the same time, in specific industrial subsectors, carbon mitigation countermeasures should be varied with their own realities. For example, we could conduct a cost-benefit comparison of CE reduction to determine developing priorities in industrial subsectors of NMMP, PHPS and FSFP, among others. Then, we should promote the spread of low-carbon related knowledge, policy, education and living patterns.

Second, from the perspective of transportation energy consumption, we should encourage city residents, especially private car owners, to drive less and to choose walking or public transportation methods such as the bus or subway to the greatest extent possible. Then, we should strive to develop some new low-carbon traffic tools that use new energies instead of traditional high-carbon fuels. Even so, transportation sector CE and share will likely increase rapidly because of the transformation or renovation of transportation infrastructure, the rise of wealth and traffic demands (Wang et al. 2012). Therefore, except for the new fuel tools and the guides of low-carbon lives mentioned above, we must comprehensively consider the other influencing causes when drawing up the low-carbon transportation policies in Nanning.

Third, considering only the CEs from coal, oil and gas, the accumulative CEs per capita of Nanning were always less than China and the world from 1994 to 2015. However, we still cannot say that promulgating the related strategies of energy saving or low-carbon development in Nanning is unnecessary because Nanning itself is still underdeveloped. With the acceleration of industrialisation, excessive CO₂ emissions and related problems will gradually and definitely emerge in the city. Thus, we should vigorously propel the related strategies and management policies of combating climate change in Nanning.

Fourth, for the first time, we have studied the CEs of underdeveloped cities. Therefore, the innovation is obvious, and the results show the worldwide comparable GPC framework has a strong generalisability. Thus, it is worthy of vigorous promotion and application in other similar underdeveloped cities, especially for other cities in Guangxi Province in western China. Moreover, the related conclusions and suggestions have a typical representative significance for all underdeveloped cities worldwide. For instance, more than 90.94% of the Nanning’s CE was generally related to coal during 1994–2015. A similar problem may exist in many other underdeveloped cities around the world, especially in China. Simply, the accounting using the GPC framework can give people more scientific data to justify related carbon-mitigation countermeasures and thus increase public understanding and trust in them.

Finally, as mentioned above, the lack of some data sources may make Nanning’s calculated CE smaller than the reality. Thus, it can be inferred that the local and central governments should vigorously improve the collection and sorting works of relevant index databases by the data-set requirements of the GPC framework. Furthermore, for the emission factors of some energy types in Nanning, people cannot get them directly from the related public literatures. Therefore, the government should also encourage the scientists to engage
actively into the related research work, and periodically, it could give enough funds to the related scientific research works, such as monitoring and verifying related emission factors.

Author contributions
Junsong Jia and Chundi Chen designed the research; Dongming Xie and Huiyong Jian performed it and analysed the result; Junsong Jia wrote almost all the text of first submission; Zhihai Gong revised it for the second submission. All authors read and approved the final manuscript.

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Appendix 1.

Table A1. CO$_2$e emission factors of different type’s energy.

| Energy type                  | Carbon content (kg/GJ)$^a$ | Carbon oxidation (%)$^a$ | Emission rate (kg-CO$_2$e/TJ)$^a$ | Net calorific value (TJ/Gg)$^a$ | Emission Factor (t-CO$_2$e/t) |
|------------------------------|----------------------------|--------------------------|-----------------------------------|-------------------------------|-------------------------------|
| Crude coal                   | 25.8                       | 100                      | 94600                             | 20.9                          | 1.977                         |
| Washed coal                  | 25.8                       | 100                      | 94600                             | 26.3                          | 2.488                         |
| Other washed coal            | 25.8                       | 100                      | 94600                             | 8.4                           | 0.795                         |
| Briquette                    | 26.6                       | 100                      | 97533                             | 17.6                          | 1.717                         |
| Coke                         | 29.2                       | 100                      | 107067                            | 28.2                          | 3.019                         |
| Coke oven gas                | 12.1                       | 100                      | 44367                             | 16726$^b$                     | 7.421$^c$                     |
| Natural gas                  | 15.3                       | 100                      | 56100                             | 38931$^b$                     | 21.840$^c$                    |
| Liquefied natural gas        | 17.5                       | 100                      | 64167                             | 44.2                          | 2.836                         |
| Crude oil                    | 20.0                       | 100                      | 73333                             | 42.3                          | 3.102                         |
| Gasoline                     | 20.2                       | 100                      | 74067                             | 43                            | 3.185                         |
| Kerosene                     | 19.5                       | 100                      | 71500                             | 44.1                          | 3.153                         |
| Diesel                       | 20.2                       | 100                      | 74067                             | 43                            | 3.185                         |
| Fuel oil                     | 21.1                       | 100                      | 77367                             | 40.4                          | 3.126                         |
| Liquefied petroleum gas      | 17.2                       | 100                      | 63067                             | 47.3                          | 2.983                         |
| Other petroleum products     | 20.0                       | 100                      | 73333                             | 40.2                          | 2.948                         |

Note: $^a$The value was the IPCC recommended value.
$^b$The unit was KJ/m$^3$.
$^c$The unit was t-CO$_2$e/10$^4$m$^3$.

Table A2. Emission factor of electricity (t-CO$_2$e/10$^4$kwh).

| Year  | 1994  | 1995  | 1996  | 1997  | 1998  | 1999  | 2000  | 2001  | 2002  | 2003  | 2004  |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Emission factor | 9.012  | 9.030  | 8.994  | 8.958  | 8.922  | 8.886  | 8.850  | 8.835  | 8.820  | 8.805  | 8.790  |
| Year  | 2005  | 2006  | 2007  | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  |
| Emission factor | 8.670  | 8.620  | 8.220  | 7.970  | 7.900  | 7.580  | 7.640  | 7.700  | 7.760  | 7.820  | 7.733  |