

Review on Urban GHG Inventory in China

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Abstract: With the rapid urbanization progress of China, a study on an urban GHG inventory is of great significance. However, related studies in China are still in the exploratory stage. This paper firstly introduces three major urban GHG inventory accounting methods and related issues with regard to Chinese cities, and then reviews the published studies of urban GHG inventories in China in the past few years. Methodology frameworks, gas types, emission scopes, geographical boundaries are examined and compared. With great distinctions in the accounting methods and contents, there is no direct comparability between the research results. However, the following characteristics can still be found: the GHG emissions per capita and GHG emissions per unit of GDP are higher than the world average level, and the total GHG emissions maintains an increasing trend, although the GHG emissions per unit of GDP keeps declining. Currently, researches on the urban GHG inventory in China are mainly based on the non-urban-level IPCC Guidelines and Provincial-level guidelines. The release of urban-level GHG inventory estimation guidelines in China is expected to provide unified standards for related studies in the future.

1. INTRODUCTION

Greenhouse gas (GHG) emissions, also called carbon emissions, mainly consist of CO₂ and as a result, the word carbon is usually applied for representing GHGs ([Hu and Yang, 2011](#)). The Intergovernmental Panel on Climate Change (IPCC) ([2014](#)) stated explicitly in their Fifth Assessment Report (AR5) released in 2014 that the average surface temperature of the earth increased by 0.85°C from 1880 to 2012, and it might be mainly caused by human activities. To realize the temperature control target for alleviating climate changes, GHG emissions need to be reduced profoundly. Urban areas are concentrated areas of energy consumption and certainly become the hotspots of emissions ([Cai, 2014b](#)). Urban areas only cover about 2.4% of the land area of the earth, but contribute nearly 67% - 80% of all GHG emissions ([Chen, et al., 2010](#)). The world's urbanization rate had already increased to 53.6% in 2014 from less than 30% in 1950 and it is predicted to reach 66% in 2050. Meanwhile, since its reform and opening-up, under the context of rapid social and economic development, China has undergone a rapid urbanization process and the urbanization rate of China reached 54.77% in 2014 ([United Nations, 2015](#)). With rapid urbanization process, urban carbon emissions studies attract more and more attention. The estimated urban-level GHG inventory will feature the status of urban GHG

emissions and provides scientific support to the formulation of plans by local government, which will be of great significance for the construction of a low-carbon city. At present, a few cities in the world have carried out calculation of a GHG inventory and substantial scholars launched related studies aiming at the calculation of an urban GHG inventory ([Dodman, 2009](#); [Crocì, et al., 2011](#); [Hoorneweg, et al., 2011](#); [Chavez and Ramaswami, 2013](#)). However, related studies started later in China and the estimation of GHG emissions is still in the preliminary exploration stage. In this study, recent studies on GHG inventory are reviewed and compared by referring to related pre-stage comprehensive research achievements based on the introduction of the main methods and key issues of the urban GHG inventory ([Chen, et al., 2010](#); [Gu, et al., 2014](#); [Li, et al., 2013](#); [Cong, et al., 2012](#); [Bai, et al., 2013](#)).

2. URBAN GHG INVENTORY METHODS AND KEY ISSUES

2.1 Main methods of GHG inventory

Currently, there are two mainstream methods of accounting for a GHG inventory. The first calculates the inventory within a geographical boundary. Guidelines such as the *IPCC Guidelines for National GHG Inventories*, *China's Guidelines for provincial-level GHG Protocol* and the *Provincial-level Guidelines for GHG Inventory Estimation* belong to this type. The second method concerns the organizational boundary of an economic unit, which includes the *Guidelines for Enterprise GHG Inventory*, *ISO 14064 Series of Standards* and so on ([Gu, et al., 2014](#); [Bai, et al., 2013](#)). The former is more popular as the mainstream method of inventory estimation for Chinese cities. Three methods using the geographical boundary will be introduced in this paper:

2.1.1 IPCC Guidelines for National GHG Inventories

The Parties under the UNFCCC (United Nations Framework Convention on Climate Change) are required to submit their National Communication on Climate Change. For guiding and standardizing the accounting of GHG inventories, IPCC has issued two editions of *IPCC Guidelines for National GHG Inventories* (shortened as IPCC Guidelines): one published in 1996 and the other in 2006. Currently, all countries apply the IPCC Guidelines (Edition 2006) for the estimation of a GHG inventory. The basic principle of the guideline is: to combine the information (activity data) of human activities and coefficient (emission factor) of quantizing the emission or elimination by unit activities, and the product of the two shall be the estimated value of the GHG emissions ([IPCC, 2006](#)):

$$E = AD \times EF$$

In which, E is the total GHG emissions estimated value, AD is the activity data, and EF is the emission factor of the activity. IPCC Guidelines mainly start with basic methods and carry out the GHG emissions' accounting in two ways, the top-down and bottom-up methods ([Bai, et al., 2013](#)). The top-down method means that the data of GHG inventories are

aggregated and analyzed with the upper-level government statistics, while the bottom-up method describes data collected and processed at the local level ([U.S. Department of Agriculture, 2015](#)). Although the IPCC Guidelines aim at the GHG emissions accounting at the national level rather than the urban level, the general methods, computational equation and emission factors are generally referred to by studies on urban GHG inventory estimation, and it is of strong guiding significance.

2.1.2 China's Guidelines for Provincial-level GHG Protocol

The NDRC (National Development and Reform Commission) released the *China's Guidelines for provincial-level GHG Protocol (Trial)* (Provincial-level Guidelines for short) in 2011, for the launch of GHG inventory estimation in regions selected for low-carbon pilots. The Provincial-level Guidelines are mainly based on the IPCC Guidelines and its GHG emissions accounting is similar to the IPCC Guidelines in basic principle, with the top-down method as the main accounting method. However, it adjusts the emission factors and computational formulas according to practical conditions in China ([NDRC, 2011](#)). Although the Provincial-level Guidelines are originally for the provincial-level administrative regions rather than the urban-level, it is much more practicable at urban level because of the low accessibility of higher level data, and therefore has been widely applied to studies on urban GHG inventories in China.

2.1.3 Global Protocol for Community-Scale Greenhouse Gas Emission Inventories

WRI (World Resource Institute), C40 and ICLEI ([2014](#)) released the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories* (GHG Protocol for short), and it was the first globally tested accounting standard of an urban GHG inventory. In addition, the *International Local Government GHG Emissions Analysis Protocol* released by ICLEI ([2009](#)) (ICLEI Protocol for short) can be deemed as the predecessor to the GHG Protocol. Although the inventory estimation method targets the urban level, it can also be applied to other administrative regions below the national level. The ICLEI Protocol has been applied to the estimation of GHG inventories around the world and meanwhile, the GHG Protocol draft has been implemented in several cities throughout the world since its promotion. Similar to the calculation methods of IPCC Guidelines, the basic method of equating GHG emissions with the product of activity data and the emission factor is still employed in the GHG Protocol and ICLEI Protocol. The main accounting method is from the bottom to the top, which may have a higher level of precision and can get closer to the actual GHG emission status of the city. To make it convenient for the estimation of an urban GHG inventory, WRI customized an urban GHG accounting tool for China based on the GHG Protocol in 2015.

2.2 Key issues of urban GHG inventory

Direct comparisons of GHG emission inventories of different cities and researchers may not have any significant meaning due to different inventory accounting methods, greenhouse gas types and inconsistent emission scope.

Emission scope division is always based on an urban geographical boundary, and urban boundary definitions of different countries or regions are also diverse. Difference of gas types, emission scope and urban boundaries make it difficult to compare inventories.

2.2.1 Types of greenhouse gas

Six types of greenhouse gases that were originally stipulated to be reported in the *Kyoto Protocol*. They are natural gases: Carbon Dioxide (CO₂), Methane (CH₄), Nitrous Oxide (N₂O) and artificial gases: Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulfur Hexafluoride (SF₆). Though a new type of GHG, Nitrogen trifluoride (NF₃), was included in the commencement of the second commitment period of the Kyoto Protocol from 2013, the three guidelines introduced above are all about the six types of greenhouse gases. CO₂ and CH₄ are the two most common greenhouse gases ([Cai, 2014b](#)). With CO₂ as the benchmark, the remaining different greenhouse gases have different global warming potentials (GWP) at different time-horizons. Centenary GWPs are generally adopted by each guideline ([IPCC, 2007](#)). GHG emission multiplied by its GWP of a specific time-horizon equals its carbon emission equivalent.

2.2.2 Scopes of GHG Emission

GHG emissions are further classified into three scopes by the WRI and WBCSD (2004). Scope 1 refers to all direct emissions inside the city, including GHG emissions produced by energy activities, industrial processes, agroforestry and land use change and waste within the city. Scope 2 includes all indirect energy-related emissions that have occurred outside the geographical boundaries of the city, including emissions produced by secondary energy such as purchased electricity and heating. Scope 3 includes other indirect emissions that have occurred outside the city which are caused by activities within the city, but that are not included in Scope 2, including the carbon emissions during intermediate links brought by items purchased outside the city ([Cong, et al., 2014](#)). The classification methods and ideas of WRI have been generally recognized by urban GHG emissions inventory researchers ([Cai, 2014b](#)). The current IPCC Guidelines only concentrate on direct emissions, while Provincial-level Guidelines and GPC Protocol cover indirect emissions.

2.2.3 Urban geographical boundaries

There are great differences in the geographical boundaries between cities in China and those of developed countries in terms of administrative division. Besides municipal districts in the city, prefecture-level cities have both jurisdictions over counties that are mainly rural areas, and representative jurisdiction over county-level cities that include both urban areas and rural areas. As for land use, cities in China include urban built-up areas as well as massive rural land. At present, geographical boundaries of urban GHG inventories in China are primarily based on urban administrative regions. According to Cai ([2013](#)), the urban built-up area is a reasonable geographical boundary for urban GHG inventories. In consideration of statistical data accessibility, he defined four types of urban geospatial boundaries: city administrative boundary (UB1), city district boundary

(UB2), city built-up area (UB3) and urban proper (UB4). He thought that urban proper (UB4), as determined by method of the Organization for Economic Co-operation and Development (OECD), is the most appropriate urban boundary of China to that of developed countries. The method developed by the OECD is a widely accepted way to classify local units into two types: urban area and rural area, based on the population density. For that reason, Cai developed a reasonable population density threshold for the identification of urban boundaries based on the urban definition method by China's Fifth National Population Census.

3. STUDY ON THE URBAN GHG INVENTORY IN CHINA

3.1 GHG emissions in China

Ever since its reform and opening-up, China has undergone over 30 years of high-speed development with the rapid process of urbanization. In accordance with the *China Statistical Yearbook* and statistical statement of the national economy and social development, China's domestic gross product (GDP) increased from 521.2 billion dollars to 10,240.9 billion dollars, while the total energy consumption converted to standard coal units increased from 1.18 billion tons to 4.26 billion tons in two short decades from 1994 to 2014. Meanwhile, the urbanization rate also increased to 54.77% from 28.62%, reaching the point at which the urban population surpassed the rural population. However, China is still in an extensive development stage. Its rapid economic growth and urbanization progress rely on the substantial consumption of energy and resources, which may result in the drastic growth of GHG emissions. Liu (2014) estimated the GHG emissions from 1997 to 2011 and found that China's total GHG emissions had reached 10.664 billion tons in 2011, which increased by 216.83% compared to 1997, where the coastal area accounts for 43.62% of the country. The report released by PBL (2015) displayed that China's GHG emission in 2013 was about 10.3 billion tons, which had grown by 4.2% when compared with 2012. Moreover, Friedlingstein et al. (2014) argued that GHG emissions had already broken through 10 billion tons in 2013 in China, higher than any other country in the world. Meanwhile, they estimated that it would reach 12.7 billion tons in 2019, accounting for 29.4% of the world's total GHG emissions (43.2 billion tons).

As the contracting states of UNFCCC, China shall provide a national emissions inventory compiled according to IPCC Guidelines regularly. The first notification to the United Nations according to the convention was submitted in 2004, including the national GHG inventory of 1994. The second notification was released in 2013, covering the GHG inventories of Mainland China, Macau and Hong Kong in 2005, whose total GHG emissions in that year were 7.47 billion tons, 1.83 million tons and 41.56 million tons respectively (NDRC, 2014). At the provincial level, NDRC released Provincial-level Guidelines with seven provinces as the low-carbon pilot regions, including Liaoning, Yunnan, Zhejiang, etc. for guiding the estimation of provincial-level inventories. Until 2014, the GHG inventories of the above pilots had been basically completed, however, the results of these provincial-level GHG inventories have not been published. Compared

with well-documented national-level and provincial-level GHG guidelines, China has not released any urban-level inventory guidelines. Therefore, four direct-controlled municipalities, including Beijing, Tianjin, Shanghai and Chongqing, being the provincial-level administrations, can launch their inventory estimation directly under the guidance of Provincial-level Guidelines, but other cities lack official guidance in the compilation of their GHG inventories. Consequently, studies on urban GHG inventories in China mainly refer to IPCC Guidelines and Provincial-level Guidelines. However, the *Guidelines of Town GHG Inventories in China*, which is formulated by the Institute of Urban Environment, Chinese Academy of Social Sciences (2015), has already been completed preliminarily and submitted to NDRC for reference. The *Guidelines of Town GHG Inventories in China* classify the cities and towns in China into three types: prefecture-level city, central urban area and county-level city or town, then mainly focus on fields such as industry, construction and transport, and propose to combine the top-down and bottom-up methods. China is expecting standardized guidelines for the compilation of urban GHG inventories in the future.

3.2 Research of urban GHG inventory in China

Studies on urban GHG inventories in China started relatively late, but with the constant increase of GHG emissions and rising of the concept of low-carbon cities, studies on the GHG inventories in China have started to attract more and more attention. The GHG emissions produced by energy activities took a dominant position in the urban GHG emissions in China. Zhu (2009) discovered through statistical analysis that energy activities contributed more than 90% of the GHG emissions from 1970 to 2007 in Beijing. Therefore, early urban GHG emissions' studies in China mainly focused on the estimation of emissions in energy activities. Xing et al. (2007) estimated the terminal energy GHG emissions in Beijing according to the IPCC method and made the inventories of different sectors, energy varieties and industries. Zhang and Yang (2010) also estimated the GHG emissions of Shanghai in 2008 by referring to the IPCC Guidelines, and discovered that GHG emissions of coal took up nearly 54% of the total energy emissions. In addition, related scholars also estimated the GHG emissions in different cities, including Xiamen (Cao, et al., 2010), Guangzhou (Wang, et al., 2014) and Nanjing (Liu and Qiu, 2012). Liu et al. (2011) summarized three methods of estimating the GHG emissions and compared the results of different GHG inventories with Beijing as the specific research case.

Although the GHG emissions based on energy activities are the subject of urban emissions, the GHG emissions brought by the industrial process, agricultural and land utilization changes, as well as the waste, cannot be neglected. Therefore, Wang et al. (2011) supplemented the non-energy GHG emissions of the industrial process and solid waste based on the energy unit of GHG emissions and analyzed the GHG emissions in Wuxi. Zhao (2011) started from several sectors, such as that of energy activity, industrial production, etc., and estimated the GHG emissions of Shanghai comprehensively, finding that CO₂ was the main greenhouse gas accounting for more than 95% of the total emissions in Shanghai. Yuan and Gu (2011) sorted the GHG inventories and data sources in Beijing according to the ICLEI 2009 Protocol and concluded that the statistics in China are not sufficient for urban GHG inventories.

In recent years, there are more studies on urban GHG inventories in China than ever before. Yang et al. (2012) synthesized the greenhouse gas produced in five processes, including fuel burning and fugitive emission, industrial processes, husbandry processes, waste disposal and wetland processes, and found out that GHG emissions presented an increasing trend from 1997 to 2008 in Chongqing. During this period, the primary energy GHG emissions increased most substantially, but the GHG emissions per unit of GDP kept declining. Wang (2013) selected Nantong as a representative for the inventory construction following IPCC Guidelines, and calculated that the GHG emissions of Nantong was 43.8451 million tons in 2009. In addition, its GHG emissions per capita was higher than the national average, but the GHG emissions per unit of GDP was a little lower. Meanwhile, energy activity was the main GHG emission source, and the GHG emissions of raw coal was far higher than that of other fossil fuels. Qin et al. (2012) developed a GHG inventory of Shenzhen by referring to the IPCC Guidelines, settled the activity data, emission factor, GHG emissions of all sectors in detail, and found that the energy sector and industrial process sector contributed 97.3% of the total emissions. Moreover, its reliance on coal was lower than that in Beijing, Tianjin and Shanghai, and the GHG emissions per capita and GHG emissions per unit of GDP were relatively lower than those cities. Zhou and Deng (2013) made the GHG inventory of Guangzhou in 2010 based on the Provincial-level Guidelines, and found out that CO₂ took a dominant position, while the energy activity was the largest emission source. As a result, they compared the GHG emissions per capita in Guangzhou with that of other cities. Zhao et al. (2015) analyzed the GHG emissions in Xi'an by combining IPCC Guidelines and Provincial-level Guidelines and found out that GHG emissions presented an evidently increasing trend from 1995 to 2011, and sectors with the highest increase were the cement production, waste and energy consumption sectors. Moreover, they also found that the GHG emissions per unit of GDP in Xi'an kept declining, while the GHG emissions per capita and GHG emissions per area grew rapidly. Zhang (2014) made the GHG inventory of Qingdao from 2001 to 2011 based on such sectors as the energy activity, industrial production, environment, urban population, agricultural and forestry carbon storage sectors, finding that changes in the ratio of industry composition was the main influencing factor of the gradual annual growth of GHG emissions. In addition, he also discovered that GHG emissions per capita were far higher than the national average. In addition, Wang et al. (2013) calculated the GHG emissions of Shanghai from 2000 to 2008, and found that it increased by nearly 48% during the research period. Moreover, only the GHG emissions of the agricultural sector decreased, and the GHG emissions per capita in Shanghai was higher than the national and world averages, but the GHG emissions per unit of GDP was higher than the world average, though lower than the national average. Lin et al. (2013) estimated the direct and indirect GHG emissions of Xiamen in 2009 with a mixed method, and found out that the GHG emissions of Scope 3 that was overlooked by many researchers may reach 33.84%. It was concluded through a comparison that GHG emissions per capita was only 1/3 of that in Denver, America.

The GHG inventory studies above mainly conducted the business accounting according to related statistical data of urban administrative divisions following a top-down method. However, due to the particularity of the urban geographical boundary in China, the top-down accounting method may not be able to support a direct comparison of cities. Cai tried the

bottom-up method early in China and realized the construction of GHG inventories using the point data of industrial enterprises. He and Wang constructed a 1km of GHG emissions' grid in Tianjin in 2007 by settling the GHG emissions data of all industrial enterprises of the city, separating them into the grid of the city, and sharing the GHG emissions of primary and tertiary industries according to the corresponding population ratio. Meanwhile, they also conducted a comparative analysis of the GHG emissions in four urban geospatial boundaries of Tianjin ([Cai and Wang, 2013](#)). Cai also conducted studies on Chongqing ([Cai, 2014a](#)), Shanghai ([Cai and Zhao, 2014](#)) and cities in the Yangtze River Delta ([Cai and Wang, 2015](#)), following the same methodology, and further refined the grid method of GHG emissions accounting. The main method is to equalize urban residential emissions, rural residential emissions and agricultural activity emissions to the urban construction land, rural residential area and cropland, respectively, obtained through remote sensing imaging and population data, in order to improve the spatial precision of GHG emissions.

By integrating the GHG emissions studies above, we selected significant research papers that cover not only the energy sectors, but also the non-energy sectors, and listed the accounting results in [Table 1](#). It shall be noticed that different scholars differ greatly in their accounting method, gas type, emission scope, geographical boundary and inventory content and therefore, the accounting results are of no direct comparability. However, the inventory accounting result of different studies may reflect the following features: seen from the horizontal comparison, the total GHG emissions is basically related to the urban-level, and the GHG emissions per capita of eastern cities, such as Shanghai, Shenzhen and Xiamen, are relatively higher than that in mid-west cities, such as Xi'an and Chongqing. But, the GHG emissions per unit of GDP of the mid-west cities are relatively high, with relevance in the differences of urban industrial structure. In addition, the GHG emissions per capita and per unit of GDP are generally higher than the world average level. Seen from the longitudinal comparison, research results covering more than one year are selected, and it basically reflects the constant increase of total GHG emissions and GHG emissions per capita. However, the GHG emissions per unit of GDP presents a decreasing trend, showing that with the technical promotion, GHG emissions per unit of GDP keep decreasing. However, due to the rapid increase of economic mass, the GHG emissions still grows rapidly and a reduction of emissions is an urgent need. It is worth noting that the total urban GHG emissions currently increases more rapidly. For instance, the research conducted by Zhao et al. ([2015](#)) indicated that ever since 2000, the growth speed of GHG emissions of Xi'an increased substantially when compared with the previous stage, while the research conducted by Yang et al. ([2012](#)) also found that the growth speed of GHG emissions of Chongqing after 2002 kept accelerating rapidly.

According to the analysis of accounting methods, gas types covered and emission scopes in all research literature, it was found that ([Table 2](#)): seen from the accounting method, nearly all researches are based on IPCC Guidelines, and some refer to the Provincial-level Guidelines, but few refer to other methods. Quite a few literatures would select the Provincial-level Guidelines or other corresponding studies as the source of the emission factors, since these factors are closer to the practical conditions in China. Seen from the gas types covered, most studies are limited to three basic

Table 1. Studies on urban GHG inventories in China

No.	Authors	Cities	Research Period	Total (10 ⁴ t CO ₂)	per capita (t CO ₂ / person)	per unit of GDP (t CO ₂ / 10 ⁴ dollars)
1	Zhao et al. (2011)	Shanghai	1996 - 2008	11713.5 - 18364.2	8.97 - 13.20	-
2	Wang et al. (2011)	Wuxi	2004 - 2008	6778.6 - 11536.2	15.16 - 24.98	24.93 - 17.32
3	Xu (2011)	Nanjing	2008	4229.15	-	-
4	Yang et al. (2012)	Chongqing	1997 - 2008	6636.4 - 15338.4	-	36.47 - 24.31
5	Sugar et al. (2012)	Shanghai, Beijing, Tianjin	2006	23252, 16964, 12806	12.8, 10.7, 11.9	-
6	Wang et al. (2012)	Shanghai	2000 - 2008	13554 - 20002	9.81 - 14.03	22.49 - 9.90
7	Wang (2013)	Nantong	2009	5196.37	4.69	8.47
8	Qin et al. (2013)	Shenzhen	2008	6569.4	7.49	5.83
9	Zhou et al. (2013)	Guangzhou	2010	16239.64	-	-
10	Cai et al. (2013)	Tianjin	2007	12599	11.3	-
11	Zhang et al. (2014)	Qingdao	2001 - 2011	2802.8 - 9059.8	4.45 - 12.35	24.66 - 8.91
12	Cai et al. (2014)	Chongqing	2007	13804.34	4.9	25.47
13	Gu (2014)	Nanning	2003 - 2012	1469 - 4396	-	-
14	Lin et al. (2013)	Xiamen	2009	2435.52	6.91	-
15	Zhao et al. (2015)	Xi'an	1995 - 2011	1207.16 - 3934.17	1.86 - 4.62	32.99 - 7.23

types of GHG, including CO₂, CH₄ and N₂O, except studies on Shenzhen conducted by Tan et al. and studies on Xiamen conducted by Lin et al. (2013), which cover six types of greenhouse gas. CO₂ takes up a dominant position in the GHG emissions of all cities. Seen from the emission scopes, studies involving Scope 1 and Scope 1 and 2 account for half of the studies, and only Lin (2013) et al. covered Scope 3 in studies on Xiamen. In addition, the geographical boundaries of the previously studied cities are analyzed, and all studies used the boundary of the administrative division, rather than the entity or the functional boundary of the city as the spatial boundary of

Table 2. Methods, gases and scopes of studies on urban GHG inventories in China

Literature No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Methods															
IPCC	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
Provincial-level									✓	✓		✓			✓
ICLEI		✓													
Hybrid-EIO-LCA														✓	
Accounting gases															
CO ₂	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
CH ₄	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓
N ₂ O	✓	✓	✓	✓	✓	✓		✓	✓					✓	✓
HFCs								✓						✓	
PFCs								✓						✓	
SF ₆								✓						✓	
Scopes															
Scope 1	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Scope 2		✓	✓	✓						✓		✓	✓	✓	✓
Scope 3														✓	

Notes: The Literature No. of this table corresponds to Table 1

the study. Among these, Cai's GHG inventory contains four types of urban boundary defined by the author, while the rest of the studies mainly take the municipal administrative area (including not only the municipal districts, but also counties and county-level cities that contain vast land of rural areas) as the geographic boundary of inventories.

As for the industrial process and product application, the Provincial-level Guidelines covers the GHG emissions in the production process of 12 industries, such as the cement, lime, steel, calcium carbide industries and so on, while the IPCC Guidelines cover at least 33 industrial products. However, due to the low accessibility of the data in industrial field, especially the data of intermediate input, there are few industrial categories included in the GHG emissions in the investigated literature. Most research on urban GHG emissions have included cement and steel into the inventory accounting. Major industrial products such as glass and synthetic ammonia are also regularly included.

In agricultural activities, many researches has calculated the methane emissions from rice, enteric fermentation and waste management methane

emissions. Since it is difficult to procure the data of waste and straw, nitrous oxide emission accounting is excluded in the inventory by most researchers. Quite a lot of literature fails to include any agricultural activities in the inventory content. As for the sector of the land use changes and forestry, fewer studies have estimated the emissions from land use change, carbon storage and carbon storage of forestry or plants. Compared with other emission sources, the inventory content of much research literature fails to cover these two sectors.

As for the waste, the guidelines have covered the disposal of solid waste, burning of solid waste and wastewater treatment. Since burning is not the main method of treating solid wastes in China, some literature neglects it and only calculates the GHG emissions in the disposal of solid waste and wastewater treatment. For the methane emission from the disposal of solid waste, the first-order attenuation equation recommended by IPCC Guidelines requires long-time time series data, but there is a general problem of lacking the statistical data in China. Consequently, most literature employs the hypothesis that the methane has been discharged completely within a year. This method may overrate the methane emission to a certain extent.

Table 3. Contents of studies on urban GHG inventory in China

Literature No.	1	2	3	4	5	6	7	8	9	11	13	14	15
Energy													
Industries	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Commercial / Institutional	✓	✓	✓		✓	✓		✓	✓	✓		✓	✓
Residential	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓
Biomass Energy									✓				
Transportation	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓	✓
Fugitive Emission				✓									
Industrial Processes													
Cement	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓
Lime													
Iron and Steel	✓	✓	✓		✓	✓	✓		✓	✓	✓		
Ferroalloys		✓											
Aluminium		✓											
Glass	✓					✓	✓	✓	✓	✓		✓	
Synthetic Ammonia		✓	✓				✓		✓	✓			
Calcium Carbide									✓				
Ceramic								✓					
Sodium Carbonate													
Electronics Industry								✓				✓	
Agriculture													
CH ₄ Emissions from Rice	✓			✓		✓	✓		✓			✓	✓
N ₂ O Emissions from Cropland	✓					✓		✓				✓	✓
Enteric Fermentation	✓			✓		✓	✓	✓	✓			✓	✓
Manure Management	✓					✓	✓	✓	✓			✓	✓
Land Use and Forestry													
Land Use	✓			✓				✓				✓	✓
Plant Carbon Storage	✓					✓			✓	✓		✓	✓

Soil Carbon Storage										√			
Waste													
Disposal of Solid Waste	√	√	√	√	√	√	√	√	√		√	√	√
Burning of Solid Waste	√				√	√		√	√			√	
Wastewater	√			√	√	√	√	√	√			√	√

Notes: The Literature No. of this table corresponds to Table 1

4. CONCLUSION

Urban areas are the hot spots of GHG emissions. With the rapid growth of urbanization progress around the world, especially in China, study on urban GHG emissions is of great significance. The calculation of urban GHG inventories will contribute to the learning of urban GHG emission and provide support to low-carbon urban planning and construction. However, urban GHG inventories are still in the exploratory stage in China. Based on the introduction of the main methods and key issues in the estimation of the GHG inventory, urban GHG inventory researches and results are reviewed. Currently, China's urban GHG inventory research mainly refers to the IPCC Guidelines and Provincial-level Guidelines. The inventory accounting method, contents and scopes are diversified, and there is a lack of unified guidance. Since the IPCC Guidelines aim at the national-level regions and Provincial-level Guidelines at the provincial-level administration divisions, their applications to the urban-level GHG inventories have inevitable limitations. Firstly, the adoption of inventory frameworks of a non-urban scale may not satisfy the urban GHG emissions' accounting demand, and there is insufficient attention to such fields as the industry, commerce, residence and traffic fields. Secondly, the statistical data is of low accessibility and precision, which may result in the inconsistency of inventory content. Meanwhile, this also brings about the uncertainty of GHG inventories. Thirdly, due to the disunity of method frameworks and inventory contents, as well as the particular urban geographical boundaries in China, it is difficult to compare inventory content between Chinese cities and cities in other countries. Although the inventory research result is of no direct comparability, the following characteristics can be found: both the GHG emissions per capita and GHG emissions per unit of GDP are higher than the world average level; although the GHG emissions per unit of GDP declines with technical promotion, the rapid development of urban economic mass brings the rapid growth of GHG emissions per capita, especially the constantly increasing GHG emissions over the past decade which reflects the severe situation of GHG emissions reduction in China; generally, China's government has made some efforts on the specification guidance on urban GHG inventory compilation; and, some cities have developed inventory compilation at the government level. However many related achievements have not been made public. With the *International Standard of the Urban GHG Accounting* and urban GHG accounting tool designed especially for Chinese cities, and *Guidelines for the Estimation of GHG Inventories for Cities and Towns in China* completed and ready for release, it is expected that standards for urban GHG inventory accounting and related studies will be provided, and the unification and perfection of the urban GHG inventory framework and method in China will be realized.

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