Evaluation of the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) Method for Chinese Cities

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ABSTRACT

China has become the largest emitter of greenhouse gases (GHGs) in the world. Urban areas only cover a small area, but contribute a large amount of the GHG emission. Along with the rapid urbanization in China, research on the urban GHG inventory has received significant attention from scholars.

The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) Method was developed to explore appropriate methods to measure city GHG and assist cities in improving GHG accounting capabilities, and provide decision making support to urban low carbon development, based on the international common GHG inventory methods.

The previous studies show the Guidelines for National Greenhouse Gas Inventories by Intergovernmental Panel on Climate Change (IPCC method) and ICLEI Protocol do not apply to cities in China as well. At present, China lacks a unified standard, guidance or tool for city GHG accounting (GPC, 2014). This paper presents a detailed analysis of GHG inventory for Chinese cities, aims to review the applicability of GPC method for accounting the GHG emission inventory of Chinese Cities.

The selected case city, Beijing, was accounted for the urban GHG inventories in 2014 to evaluate the GPC method complete and applicable for Chinese Cities, through the activity data collection from the public source. Almost all the GHG emission of energy sector can be accounted based on the GPC method. However, the other sectors, including the industry, agriculture, waste, and forestry and land use change sectors also face the problem and difficulty, related to a lack of local activity data in Chinese cities. The GPC method provides a robust and clear framework that builds on existing methodologies

for calculating and reporting urban GHG inventory. This is also a useful tool to understand and profile GHG emissions for Chinese cities, and design tailored and targeted emission factor and few kind of the activity data for GHG inventory account.

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LIST OF ABBREVIATIONS AND ACRONYMS

AFOLU	Agriculture, Forestry, and other Land Use
CH_4	Methane
CO_2	Carbon Dioxide
CO_{2e}	Carbon Dioxide equivalent
C40	C40 Cities Climate Leadership Group
GHG	Greenhouse Gas
GPC	Global Protocol for Community-Scale Greenhouse Gas emissions Inventories
HFCs	Hydro Fluoro Carbons
ICLEI	Local Government for Sustainability
IEAP	International Local Government GHG Emissions Analysis Protocol
IPCC	International Panel on Climate Change
IPPU	Industrial Process and Production Use
N_2O	Nitrous Oxide
PFCs	Per Fluoro Carbons
SF_6	Sulphur Hexafluoride
UNFCCC	United Nations Framework Convention on Climate Change
WRI	World Resource Institute

CHAPTER 1: INTRODUCTION

1.1 Research Background

Climate change has become the most serious global environmental and development threat nowadays. It is a direct consequence of raised greenhouse gas (GHG) concentrations in the atmosphere. The international society recognizes the necessity to decrease the GHG to half by 2050 with the purpose of limit the increase in the atmospheric temperature up to two degrees Celsius. The main objective of Paris agreement is to keep a global temperature rise this century well below 2 degrees Celsius and to drive efforts to limit the temperature increase even further to 1.5 degrees Celsius above pre-industrial levels. (UNFCCC, 2015) This requires the joint efforts of the entire international community.

Cities represent concentrated areas of energy consumption, and it certainly becomes the hotspot of emissions (Cai, 2014). Urban areas only cover about 2.4% of the land area of the Earth, but contribute nearly 67% - 80% of the GHG emissions (Chen, et al., 2010). With growing evidence that human-induced (or anthropogenic) GHG emissions resulting from cities account for 40%-70% (UN Habitat, 2011) and among all discharge, and more than 80% of carbon emissions are originated from city. (G. Churkina, 2008). Therefore, the urban GHG emission area becomes an important component of GHG emission in the world.

Meanwhile, ever since the reform and opening-up, in the context of rapid social and economic development, China has undergone a rapid urbanization process, and China's urbanization rate had already reached 54.77% in 2014 (United Nations, 2015). As one of the largest GHG emitters in the world (IEA,

2009), Chinese government declared an emission reduction target in United Nations Climate Change Conference in Copenhagen that the CO_2 intensity in 2020 will be reduced by 40% to 45% compared to 2005. (Xiao, 2016)

The urban GHG emission inventory not only provides this type of information for public, but also is a key for policy-maker to build a sustainable and low-carbon cites. It is most important to create a sustainable and low-carbon cites, while encouraging important GHG emission mitigation.

However, the amount of urban GHG emission inventory were not published to the public in China. Few studies have offered GHG emissions through covering all GHG gases by using Intergovernmental Panel on Climate Change (IPCC)'s method for Chinese cities. Moreover, Local Government for Sustainability (ICLEI)'s method is inapplicable in Beijing's emission accounting (Yuan and Gu, 2011), which cannot compare with other cities of world. At present, China lacks a unified standard, guidance or tool for city GHG accounting (GPC, 2014).

This study focused on urban GHG emission inventory for Chinese cities by using Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) Method. A typical Chinese city will be selected as the case study to review the applicability of GPC method for Chinese Cities by using the official statistical data. Moreover, the innovative approaches towards the application of the GPC method could be explored in this study.

1.2 Research Purpose and Questions

This study aims to review the applicability of GPC method for accounting the GHG emission inventory of Chinese Cities. The conducted research will focus on answering the following question:

- Is the GPC method complete and applicable for Chinese Cities?

- What kind of innovative approaches towards the application of the GHG inventory method could be explored?

1.3 Significance of the Study

In response to the climate change problem, the Chinese government has formulated a decline in carbon intensity target and the gradual decomposition. In 2009, China announced the target that the 2020 national carbon dioxide emissions per unit of GDP fall by 40% to 45% lower than those of the year 2005, and as the binding targets into national economic and social development and long-term planning. In 2011, the China's State Council issued the "twelve five" work program to control greenhouse gas emissions, and proposed the national GHG emissions in 2015 per unit of GDP should decrease 17% compared to the GHG emissions in 2010. After that, some provinces have radially-level city issued the goal. According to the "Sino-US Joint Statement on Climate Change" in 2014, China committed that the GHG emissions would peak in 2030, and the non-fossil fuels in primary energy consumption would reach around 20% by 2030. This means that the Chinese city of the future is likely to face more stringent GHG emission constraints, and objective setting and assessment needs comprehensive data supporting the role of the list will be more prominent.

This study aims to analyze urban GHG emission inventory method for Chinese cities. Some studies show that the IPCC method does not apply to cities in China as well, which is already international consensus. The research of GHG emission inventory faced two major difficulties: firstly, the different definition

between western cities and Chinese cities; secondly, the approach system of Chinese cities is imperfect.

This research would be valuable to advance the research GHG emission inventory for Chinese cities by concerning in the utilization of the latest data from Chinese administration. The results of analysis obtained from this study can be used as reference for other researcher's work and that of policy-maker s who seek to know the GHG emission inventory and consider as the foundation for development of low carbon society in Chinese cities.

1.4 Structure

This paper consists of five parts. Followed by the introduction chapter, the lecture review will be presented in the following part, including the lecture review on categories of urban GHG inventory method and the relevant studies on Chinese cities. The methodology and the data collection and introduction is introduced in Chapter 3 and 4. Chapter 5 presents the results of this study, offers processes and outcomes of urban GHG inventory. Finally, discussion and conclusions will be indicated to the accuracy analysis, GHG inventory and conclusion for GPC in Chinese cities.

CHAPTER 2: LITERATURE REVIEW

2.1 Categories of Urban GHG Inventory Method

The common methods for urban GHG inventory is classified as two main categories: (1) The Guidelines for National Greenhouse Gas Inventories by Intergovernmental Panel on Climate Change (IPCC); (2) The Greenhouse Gas Protocol (GHG Protocol) by World Resources Institute (WRI) and the World

Business Council on Sustainable Development (WBCSD). Even some other methods developed for the emission trading scheme (ETS) or reporting purposes, they were also based the above two methods, which were widely considered as the best practice for GHG inventories. The IPCC method categorized the GHG emissions into four basic sectors: Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Use (AFOLU) and Waste (IPCC, 2006). IPCC method provides a standardized method of inventory and formats for greenhouse gas emissions from human activities leading to the quantification of sources and sinks. Preparation of national inventories is a combination of different sectors and at different levels, from top to bottom and from bottom to top method of synthesis process. The objective of IPCC is to provide the standardized inventory method for the Parties under the United Nations Framework Convention on Climate Change (UNFCCC) to submit the national inventories in according to the requirement of international treaty. Urban GHG inventories should follow the similar procedure of IPCC methodology for national inventories. However, The IPCC method excludes several indirect GHG emissions, it does not provide a comprehensive inventory of a city's GHG emissions (Hoornweg et al., 2011). Many cities still applied the IPCC method to calculate the urban greenhouse gas emissions, but the IPCC method does not apply to urban scale, which is already an international consensus (Cai, 2012).The scope concept in relation to corporate or organizational inventories, dividing all emissions into three broad scopes. (Hoornweg et al., 2011). The GHG Protocol Corporate Standard recommends to group emissions into three "scopes" (WBCSD and WRI, 2004). Scope 1 emissions are those from sources under the direct emission in the cities, such

as stationary combustion, mobile combustion, process and fugitive emissions; Scope 2 emissions are from electricity or heat consumed by the cities, although the GHG emissions are produced outside; and Scope 3 emissions, all other indirect GHG emissions such as methane emissions in landfill.

On the basis of GHG Protocol, the Local Governments for Sustainability (ICLEI) (ICLEI, 2009) was developed for an urban GHG inventory for the cities and municipal administration level.

2.2 GHG Inventory Studies on Chinese cities

The GHG emissions of energy sector dominated in the urban GHG emissions of Chinese cities. The previous studies concentrated on GHG emissions for the fossil fuel consumption in energy sector. A great sum of studies have been conducted to research energy consumption and CO_2 emissions in China, especially CO_2 emissions, from a national perspective (Wei et al., 2006; Wang et al., 2010; Ming et al., 2009). Based on the IPCC method, the GHG inventory was studied on the various sectors instead of only energy sector, such as the industries sector. (Xing, 2007) Through statistical analysis, the energy sector contributed more than 90% of the GHG emissions from 1970 to 2007 in Beijing (Zhu, 2009). The GHG emissions of Shanghai by applied the IPCC Guideline, The GHG emissions of coal consumption took nearly 54% of the total energy emissions in 2008 (Zhang and Yang 2010). Moreover, some scholars also studied the GHG inventories in many Chinese cities individually, including Xiamen (Cao, 2010), Guangzhou (Zhou, 2013), Nanjing (Xu, 2011) etc.

The terminal energy GHG emissions in Beijing according to the IPCC method, and made the inventories of different sectors, energy varieties and

industries.(Xing, 2007) The GHG emissions of Shanghai in 2008 by referring to the IPCC Guideline, and discovered that GHG emissions of coal took up nearly 54% of the total energy emissions. (Zhang and Yang, 2010). The above research mainly focused on the energy and industry sector by using the IPCC method for accounting the GHG emission inventories.

Although the GHG emissions produced by the energy activities took a dominant position in the urban GHG emissions in China, the GHG emissions from agricultural, land utilization changes and other sectors could not be neglected. Few studies focused on the urban GHG inventories in China, and those that did so (Li et al. 2010), only explored the mega-cities. The urban energy use in 35 Chinese cities produced a general snapshot and considered the electricity and heat supplied from outside by using the similar ICLEI method. (Dhakal, 2009). The overall CO_2 emissions were investigated for global cities and metropolitan regions, including few the Chinese cities. (Kennedy et al. 2011)

In China, however, the sectoral division of activities (by which carbon emissions can be traced) differs from the subdivisions proposed by ICLEI (residential, commercial, industrial, and transportation initiatives) (Li et al., 2012). The GHG inventories and data sources in Beijing with ICLEI Protocol, and concluded that the statistics in China are not sufficient for urban GHG inventories (Yuan and GU, 2011). This study tried to use the ICLEI Protocol to accounting the urban GHG emission inventory for Beijing, which could cover the main sectors as well. However, the study concluded the ICLEI Protocol is not applicable for Chinese cities.

The above studies show the IPCC method and ICLEI Protocol do not apply to

cities in China as well. At present, China lacks a unified standard, guidance or tool for city GHG accounting (GPC, 2014). By the end of 2015, the study on urban GHG emission inventories by using the GPC method is not available for Chinese cities.

CHAPTER 3: METHDOLOGY

3.1 GPC Method Introduction

The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) is the result of a collaborative effort between the GHG Protocol at WRI, C40, and ICLEI. In 1993, the ICLEI launched the Cities for Climate Protection Campaign (CCP), which aimed to reduce the urban Greenhouse gas emissions, improve air quality and enhance capacity for sustainable development of cities. In 2012, the partnership expanded to include WRI and the Joint Work Program of the Cities Alliance between the World Bank, UNEP, and UN-HABITAT. An early draft was released in 2012 for public comment, which tested in 35 cities worldwide. Based on the feedback of the test, the GPC was further revised and issued for final version in 2014. In 2015, The Greenhouse Gas Accounting Tool for Chinese Cities contains the guidance document and spreadsheet calculation tool was established by WRI, Institute of Urban and Environmental Studies of the Chinese Academy of Social Sciences (CASS), WWF China, and Institute for Sustainable Communities (ISC), which is based on the GPC method and designed specifically for application in China.

To compress accounting of urban GHG inventory, The GPC method covers five sectors including Energy, Industrial processes, Agriculture, Land-use change

and forestry, and Waste. Within the above five sectors, the six sort of GHG (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6) specified in the IPCC were measured in the GPC method. CO_2e is a universal unit of measurement that accounts for the global warming potential (GWP) when measuring and comparing GHG emissions from different gases.(GPC, 2014) Individual GHGs should be converted into CO_{2e} by multiplying by the 100-year GWP coefficients in the fifth assessment report of IPCC as below table 3-1:

Table 3-1 Global Warming Potential (GWP) of major GHG gases

Name	Formula	GWP values in IPCC Fifth Assessment Report (CO_2)
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
Sulfur hexafluoride	SF_6	23,500
Carbon tetrafluoride(PFCs)	CF4	6,630
HFC-23(HFCs)	CHF_3	12,400

Combining the top-down and the bottom-up data collection methods. Top-down approach refers to access to existing public statistics and departmental data from relevant governmental agencies, such as statistical department, local government and sector's associations. The bottom-up approach implies access to data through research and sample surveys. Because there is not enough statistics and department data, top-down and bottom-up methods often need to be combined in the data collection to be compatible with international and domestic standards. GPC method uses a set of data, according to the two international standards and domestic policy requirements, to generate multiple sets of output. The GPC method can generate all kinds of report formats, including GPC format, province inventory format, key areas (industrial,

construction, transportation and waste) format, industrial format, emission intensity of the format, and information on the project. The GPC method provides a way to meet these two Chinese national and international standards, to facilitate the user to carry out greenhouse gas accounting and reporting of international comparisons of greenhouse gas accounting. GPC method provides the ease of use of embedded computing formula and default emission factors.

The scopes framework used in the Greenhouse Gas Protocol (GHG Protocol) by World Resources Institute (WRI) and the World Business Council on Sustainable Development (WBCSD) was applied in the GPC method: The Categories of GHG emissions by scope shown in below table 3-2:

Table 3-2 Scope definitions in GPC

Scope	Definition
Scope 1	GHG emissions from sources located within the city boundary.
Scope 2	GHG emissions occurring as a consequence of the use of grid-supplied electricity, heat, steam and/or cooling within the city boundary.
Scope 3	All other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary.

Source: GPC 2014 guideline.

According to the GPC method, urban GHG emissions were categorized into five main sectors: stationary energy, transportation, waste, industrial processes and product use (IPPU) and agriculture, forestry, and other land use (AFOLU). The Greenhouse Gas Accounting Tool for Chinese Cities combined the stationary energy sector and transportation sector to energy sector and

separated the agriculture, forestry, and other land use (AFOLU) to agriculture and the forestry and other land use to provide the convenience and facility for Chinese cities.

The sources and scopes covered by the GPC method was shown in table 3-3 below:

Table 3-3 the sources and scopes covered by the GPC method

Sector	GHG	Scope
Energy	CO_2, CH_4 and N_2O	Scope1, Scope2 and Scope3
IPPU	CO_2, N_2O, HFCs, PFCs and SF_6	Scope1
Waste	CO_2, CH_4 and N_2O,	Scope1
AFOLU	CH_4 and N_2O	Scope and Scope3

Source: GPC 2014 guideline.

3.2 Accounting Processes

Based on the procedure and requirement in GPC method, the selected case city, Beijing, is accounted for the urban GHG inventories in 2014 as the follows process, as shown in figure 3.1 below.

Figure 3-1 Accounting Processes

Step 1
• **Urban boundary** of this study is determined in the Section 3.3 case studied city;

Step 2
• **DATA Collection** is introduced in Chapter 4;

Step 3
• **DATA review** is introduced in Chapter 5;

Step 4
• **Calculation Result** is introduced in Chapter 5;

The urban boundary should be determined first, then, the latest data should be collected for this study. In China, the latest data would be published by the government after 1-2 years. The most recent data available at the time of this study is the activity data in 2014. Next is reviewing the quality of the collected data to evaluate the certainty of this study. The GHG emission equals the activity data multiplied by the emission factor as the following equation 3.1 (GPC, 2014):

Equation 3.1 Basic emission calculation method

$$GHG\ emissions = Activity\ data \times Emission\ factor$$

3.3 Case Studied City

In 1994, China and Canada carried out the study of GHG inventories and had comprehensive accounting of the GHG emissions of Beijing in 1991. After that, few studies were conducted to investigate the compressive Beijing's GHG inventories (Cai, 2012).

Beijing, the country's capital and host of the Beijing Olympic Games, located in the northern China with the Warm Temperate Half Moist Climate. Beijing is one of the largest mega-metropolises in the world. Rapid urbanization since 1980 has put incredible pressure on the environment and ecosystem, and made lots of environmental problems, such as heavy GHG emission.

With the population of 21.51 million people (2014), Beijing is the third largest Chinese city by urban population after Chongqing and Shanghai. However, the definition and conception of the Chinese cities is most differences than the cities in developed countries. Chinese cities have not only the urban area, but also many rural area in the municipal area. A typical Chinese city is the municipal administration conception. For example, the urban area in Beijing is 1,368.32 km^2 in 2014, however the municipal area is 16,410.54 km^2, which is 10 times more than the urban area in Beijing. Some studies introduced the "built-up" conception instead of the municipal area to discuss the urban GHG inventory in China. (Cai, 2011; Cai, 2012). Many scholars considered the city's municipal area as a narrow conception of the Chinese city, but the standard of county (rural) or district(urban) level are mainly based on the political and economic and geographic aspect in China, which also include large agricultural area in the city area. For example, Beijing has 15 districts and 1 county as of 2014, and Yanqing County, the last county in Beijing, became the Yanqing district by State Council approval in 2015, which includes a number of rural areas and the urban area. In fact, the "built-up" area of the city is the best characterization for urban GHG inventories, but the "built-up" area in the typical municipal administrative cannot be divided very clearly in China, which is resulting in complex and difficulty of unified data. It is difficult to complete the

data collection and accumulation. The geopolitical and municipal boundary defined by Beijing's government is applied in this study.

CHAPTER 4: DATA COLLECTION

Since there is currently no mandated standard for urban greenhouse gas accounting, inventories vary depending on the data availability and the organization responsible for calculations.(Hoornweg et al., 2011) Data availability not only affects the result of GHG inventories to a certain level, but also is the evaluation method to the selected methods applicable for Chinese Cities. The data problems are facts which are unlikely to be unique to China; other transition and developing countries experience similar difficulties (Holz, 2005), so the results still represent a vision of the reality in current Chinese cities(YU, 2012).

4.1 Emission Factors

Emission factor is one of the two main factors to calculate greenhouse gas emissions, as well as the level of activity data. Depending on the source of emission factors, the emission factor is divided into the specific emission factor and the default emission factor.

Specific emission factor is measured for the specific sector based on the local actual situation. The GPC method also provide the default emission factors including regional emission factors (provincial or inter provincial, national emission factors and the IPCC emission factor). To reflect the accuracy of local emission characteristics from high to low is divided, emission factor priorities in turn as the measured emission factor, regional emission factors (provincial or inter provincial, national emission factors and the IPCC emission factor. The

emission factor is a numerical value, but may be jointly determined by a number of parameters.

The emission factors were selected by the principle of maximally presenting the characteristics of the activities of the study areas. The case-specific emission factors is priority considered as the first choice and used country-specific emission factors when no available in GPC method. In some cases, the definition of the activity data is not very clearly, the principle of maximum GHG emission or minimum GHG removal is applied in this study. In this study, the default emission factors are used to account the Beijing's GHG inventories.

4.2 Activity Data

This is a good preparation to start activity data collection with the initial screening of existing public data sources. This would be an iterative procedure to enhance the quality of the activity data applied in this study, and should be driven in the two main aspects of the consideration:

• Data should be from reliable and robust sources;

• Data should be time- and geographically-specific to the inventory boundary, and technology-specific to the activity being measured;

4.2.1 Activity Data Collection Processes

Activity data collection is an integral part of developing and updating GHG inventory. (GPC, 2014). The first step is to find out the activity existing or not in the data collection process and then the activity data existing or not. After the data collection, the accuracy of the activity data is marked for evaluation. The activity data collection process is shown in the following figure:

Figure 4-1 Activity Data Collection Processes

> Step 1
> • Whether the activity existing or not in the certain year;

> Step 2
> • Whether the activity data existing or not in the certain year;

> Step 3
> • The accuracy of the activity data;

> Step 4
> • Result

4.2.2 Notation Keys of Activity Data

The Activity Data usually come from a variety of sources, which have different quality, format and definition. The different quality, format and definition also result in the data availability problem. In order to adapt to the differences in data availability and the difference in the urban emission source, the GPC method recommends the use of notation keys, as provided in IPCC Guidelines. This is a good practice to start data collection activities with the initial screening of existing data sources. (GPC, 2014). The below table 4-1 provided the definition of notation keys in this study:

Table 4-1 the definition of notation keys

Notation key	Definition	Explanation
NA	Not Applicable	Activities that occur but do not result in specific GHG emissions
NO	Not Occurring	Not Occurring by judging from the references

NE	Not Estimated	Emissions occur but have not been estimated or reported
NENO	Not Estimated and NO way to know	Not Estimated because NO way to know if the activity exists in the city or not

In this study, the notation keys were used to provide the additional explanation for the source category of greenhouse gas emissions.

4.2.3 Categories of the Activity Data

Activity data can be obtained from a variety of sources, including statistical yearbooks by government departments, the information from the governmental administration, the national GHG inventory report, universities and research institutes, academic articles in journals and reports, as well as expertise from experts and stakeholders. Under normal circumstances, it is best to use a reputable source from publicly available, peer reviewed, and often available through government publications in international data and national data and local data. The following aspects are also considered in this study: The definition and description of the activity data in the source, the time series, units, assumptions, uncertainties and the frequency and timescales for the information collection and publication. If the required activity data does not exist or cannot be estimated from existing sources it may be necessary to generate new data. This may relate to the physical measurement, sampling activity, or investigation, the survey may be the best choice for most emission sources. However, this study just focus on the activity data from the public information source, which can be verified or cross-checked by other scholars.

In order to facilitate the understanding of the source of the activity data, the

activity data are classified to various categories based on the accuracy in this study as following table 4-2:

Table 4-2 accuracy categories of the activity data

Categories	Explanation
A	Yearly statistics/report published by the government;
B	Official/governmental statistics/report;
C	Projected from A and B only;
D	Proceeded from A and B with uncertainly;
E	Activity data from Literature review;
F	Processed from A, B, C, D and E;

CHAPTER 5: RESULT

5.1 Result of the Activity Data Collection

This study aims to account Beijing's GHG inventories in 2014, through the GPC method based on the latest available data. The activity data used in this study are from the following sources:

Table 5-1 Categories of the Activity Data Source

Source	Categories
Beijing Statistical Yearbook 2015 China Energy Statistical Yearbook 2015 China Industrial Statistical Yearbook 2015 China Agricultural Statistical Yearbook 2015 Beijing Electricity Statistical Yearbook 2015 China Forestry Statistical Yearbook 2015	A
The public information from central and local government	B
Projected from A and B only	C

Proceeded from A and B with uncertainly	D
Activity data from Literature review	E
Processed from A, B, C, D and E	F

5.1.1 Energy

According to the requirements in the GPC method, the activity data of the energy activity is divided into the activity data of the fossil fuel combustion, activity data of the biomass fuel combustion and the activity data of fugitive emissions from fuel.

The activity data of the fossil fuel combustion are collected from *China Energy Statistical Yearbook 2015*, the GPC method provides the same format with the *Energy Balance sheet of Beijing (Physical Quantity)* in *China Energy Statistical Yearbook 2015*.

The activity data of the biomass fuel combustion is required to collect the combustion amount of straw, firewood, charcoal and animal manure which consume for the energy purposes. The activity data of straw combustion amount cannot found in any official statistics directly, thus the following equation 5.1 is applied in this study:

Activity data = Amount of crops × ratio of grain to straw × ratio of combustion

Amount of crops is collected from *Beijing Statistical Yearbook 2015*, the ratio of grain to straw and ratio of combustion are cited from the literature (ZHANG, et al., 2010). The activity data of firewood combustion amount is collected from the *Beijing's forestry production information* which is public information on the official website. The activity data of firewood charcoal and animal manure

cannot be found in any source.

Regarding the activity data of fugitive emissions from fuel, the amount of mining, processing, storage, and transportation of petroleum, coal and nature gas are required to collect in GPC method. According to the *Beijing Statistical Yearbook 2015,* there is no petroleum and natural gas manufacturing activity in Beijing's municipal area. The amount of the coal production is collected from *Beijing Statistical Yearbook 2015.* Based on the manufacturing license of coalmine by Beijing's government, all the coal mines in the Beijing area are state-owned enterprises, which shall applied the emission factor accordingly. The activity data of energy sector applied in this study as following table 5-2:

Table 5-2 the activity data of energy sector

Sub-sector	Item	Activity data	Accuracy
Fossil fuel combustion	All the data referred to the *"Energy Balance sheet"*		A
Biomass fuel combustion	Straw	372,792.72 tons	F
	Firewood	280.72 tons	D
	Charcoal	NENO	-
	Animal manure	NENO	-
Fugitive emissions from fuel	Coal Production	4,755,000 tons	A
	Petroleum and Nature gas Production	NO	-

5.1.2 Industrial Processes and Product Use (IPPU)

GHG emissions are released from a wide variety of industrial processes and product use. The key GHG emissions are produced from industrial processes that chemically or physically transform materials (e.g., the blast furnace in the iron and steel industry, and ammonia and other chemical products

manufactured from fossil fuels used as chemical feedstock). (GPC, 2014) The following Table 5-3 illustrates the activity data from industrial processes by industrial type.

Table 5-3 the activity data of IPPU

Category	Activity data	Accuracy	Year
Cement	5,214,000 tons	A	2014
Limestone	1,350,000 tons	F	2007
Iron/steel	NE	-	-
Calcium carbide	NO	-	-
Adipic acid	NO	-	-
Nitric acid	NE	-	-
HCFC22	NO	-	-
Aluminum	NO	-	-
Magnesium	NO	-	-
Electric device	NENO	-	-
Semiconductor	NENO	-	-
HFC	NO	-	-

In accordance with the *China Industrial Statistical Yearbook 2015*, the amount of the cement production can be found, the amount of the calcium carbide, aluminum and magnesium production are considered as "Not Occurring", and are marked as "blank" in the *China Industrial Statistical Yearbook 2015.*

The amount of limestone production is reviewed from the literature (Lancui, 2012), however it is the activity data in 2007. Based on the manufacturing license and public information by the central government, HFC, HCFC22 (MEP, 2013) and adipic acid (MOC, 2014) production did not exist the manufacturing activity in Beijing. However, the activity of electric device and semiconductor

production cannot be estimated because no way to know if the activity exists in Beijing or not.

5.1.3 Agriculture

Given the highly variable nature of agricultural emissions across geographical areas, GHG emissions from agriculture are amongst the most complicated categories for accounting GHG emissions. (GPC, 2014) In some other cities where there are no agricultural activities in the boundary, however, the rural area is approximately 90% of total municipal area in Beijing. The GHG emissions from the agricultural sector cannot be ignored in Beijing. The following figure shows the overview of agriculture emission sources:

Figure 5-1 overview of agriculture emission sources
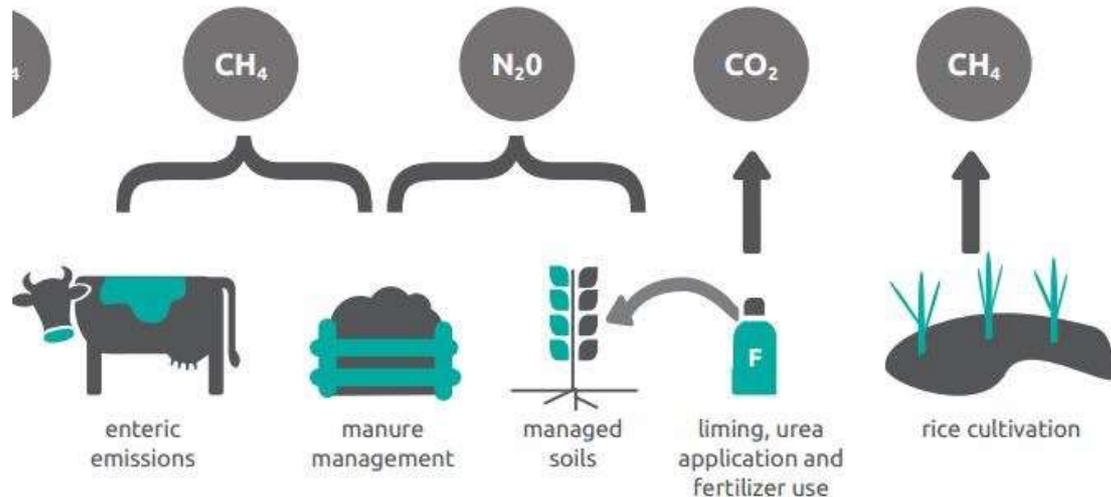
Source: GPC 2014 guideline.

The main GHG emission source is classified as three categories:

- The CH_4 emission from the rice cultivation and enteric emissions;

- The N_2O emission from the managed soils and manure management;

- The CO_2 emission from liming, urea application and fertilizer use;

For rice cultivation, the sown areas is collected from the *Beijing Statistical Yearbook 2015.* The emission from fertilizer use requires many activity data, such as the sown areas, yield, amount of nitrogen fertilizer utilization, rate of straw returning on soil and amount of organic fertilizer utilization. Regarding enteric management, the number of livestock are collected from the *Beijing Statistical Yearbook 2015* and *China Agricultural Statistical Yearbook 2015.* As mentioned above, the activity data for the agriculture sector is more complex than in other sectors, the following table 5-4 shown the simplified result of the activity data for agriculture:

Table 5-4 the activity data of agriculture

Sub-sector	Accuracy
Rice cultivation	A
Fertilization	F
Enteric management	A

5.1.4 Forestry and Land Use Change

GHG emissions and removal from the forestry and land use change sector are released or removed through a variety of pathways, including land use change (e.g., forested land being cleared for cropland or settlements), and GHG removal by sink(GPC, 2014). The main GHG emission source is classified as two categories:

- The GHG removal by forestry (sink);

- The GHG emission from the land use change;

Table 5-5 the activity data of forestry and land use change

Sub-sector	Item	Activity data	Accuracy
Forestry	Timber reserves of forestry	1669.9 m^3	C
	Reserves of grassland	439.2 m^3	C
	The amount of area change for bamboo	NE	-
	The amount of area change for economic forestry	131 hectare	D
	The amount of area change shrubbery	104 hectare	D
Land use change	Forestry	NENO	-
	Bamboo	NENO	-
	Economic forestry	NENO	-

Regarding the timber reserves of forestry and reserves of grassland, the activity data are collected from the *Beijing Statistical Yearbook 2015*, however, the name in the statistical yearbook is tiny different from the GPC method. Moreover, the Beijing government provides public information (BMBLF, 2015) on the amount of area change for economic forestry and the amount of area change shrubbery, however, that information must be projected to the GPC method with uncertainly. The amount of area change for bamboo was not described in the statistical yearbook, public information and literature, which exist but have not been estimated or reported in Beijing. The activity data of the land use change cannot be found in any source, which marked as "NENO".

5.1.5 Waste

Solid waste and wastewater may be generated and treated within the same city

boundary, or in different cities. (GPC, 2014) The following table 5-6 shows GHG emission and scopes in waste sector:

Table 5-6 the GHG emission and scopes in waste sector

Scope	Explanation
Scope 1	Emissions from waste treated inside the city This includes all GHG emissions from treatment and disposal of waste within the city boundary regardless whether the waste is generated within or outside the city boundary. Only GHG emissions from waste generated by the city shall be reported under
Scope 2	Not applicable
Scope 3	Emissions from waste generated by the city but treated outside the city This includes all GHG emissions from treatment of waste generated by the city but treated at a facility outside the city boundary.

Source: GPC 2014 guideline.

The GPC method requires accounting the CO_2, CH_4, and N_2O from the following waste management activities:

1. Solid waste disposal in landfills or dump sites;

2. Incineration and open burning of waste;

3. Wastewater treatment and discharge;

The following Table 5-7 illustrate the activity data of waste sector:

Table 5-7 the activity data of waste sector

Sub-sector	Item	Activity data	Accuracy
Solid waste disposal in landfills or dump sites	Amount of disposal in the city boundary	3,554,268 tons	D
	Amount of disposal outside the city boundary	30,000 tons	D
	Component of solid waste	organic :51.9%	E

Incineration and open burning of waste	Amount of disposal in the city boundary	NENO	D
	Amount of disposal outside the city boundary	NENO	D
	Component of solid waste	Municipal waste :96%	D
Wastewater treatment and discharge	COD removal in the city boundary	16,279 tons COD/year	A
	COD removal outside the city boundary	NE	-
	CH$_4$ removal	NENO	-

The activity data of solid waste is projected from municipal public information (BMEPB, 2015) with uncertainty. The activity data of COD removal in the city boundary is collected from the *Beijing Statistical Yearbook 2015*. The component of solid waste is reviewed from the literature (LIU, 2012). Other required activity data cannot be found in any source, which mark as "NE" and "NENO" accordingly.

5.2 Result of GHG Emission in Beijing

This study accounts Beijing's GHG emission in 2014 through the GPC method based on the latest available data. As shown in Table 5-8, the result shows that the total urban GHG emissions were 194,090,000 tCO$_2$e by applied the activity data, which are discussed in the above section of this paper. GHG emissions per capita was 9.5 tCO$_2$e and Carbon intensity known as per 10,000 RMB GDP emissions were 0.51 tCO$_2$e respectively. In general, the inventory covers all the sectors described in the GPC method, and also includes all kind of the GHG described in the GPC method.

Table 5-8 GHG Emission from different sectors

Sectors	Scope 1 (10^4 tCO$_2$e)	Scope 2 (10^4 tCO$_2$e)	Scope 3 (10^4 tCO$_2$e)	Total (10^4 tCO$_2$e)
Energy	10,111.66	8,989.64	499.72	19,601.02
IPPU	372.72			372.72
Agriculture	146.10			146.10
Forestry and Land Use Change	-1.20			-1.20
Waste	306.29		1.65	307.94
Total	10,936	8,989.64	501.37	20,426.58

5.2.1 GHG Emission from Different Sectors

As shown in Figure 5-1, Scope 1, 2 and 3 GHG emissions accounted for 53.54%, 44.01% and 2.45% in total GHG emissions in 2014. It shows that nearly half of Beijing's GHG emissions occurred as a consequence of the use of power produced outside the city boundary.

Figure 5-1 The Beijing's GHG Inventory in 2014
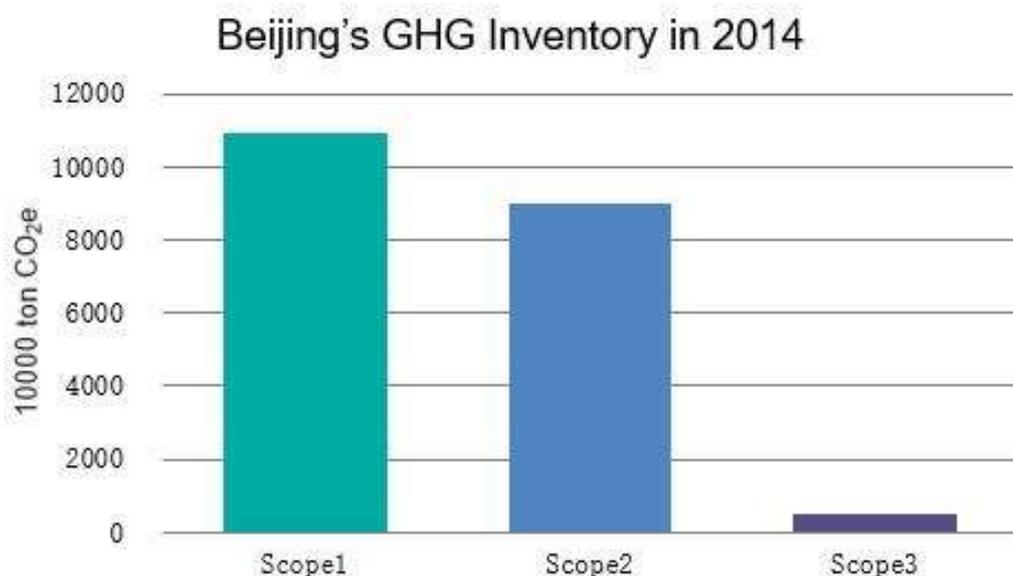
As shown in Figure 5-3, the GHG emissions of commercial buildings is more than other sectors, especially concerning the electricity consumption of commercial buildings. Considering the household and commercial building, the building energy consumption level of Beijing in this study is less than 15% of the total urban energy consumption. This finding indicates there will be considerable potential energy savings and increase in CO_2 reduction in the building sectors. The results of also show that the energy demand in action to mitigate the transport of energy demand is likely to increase, compared with the other sectors, in order to improve energy efficiency in the industrial sector is more significant.

Figure 5-2 GHG Emission related to the different fuels in different sectors
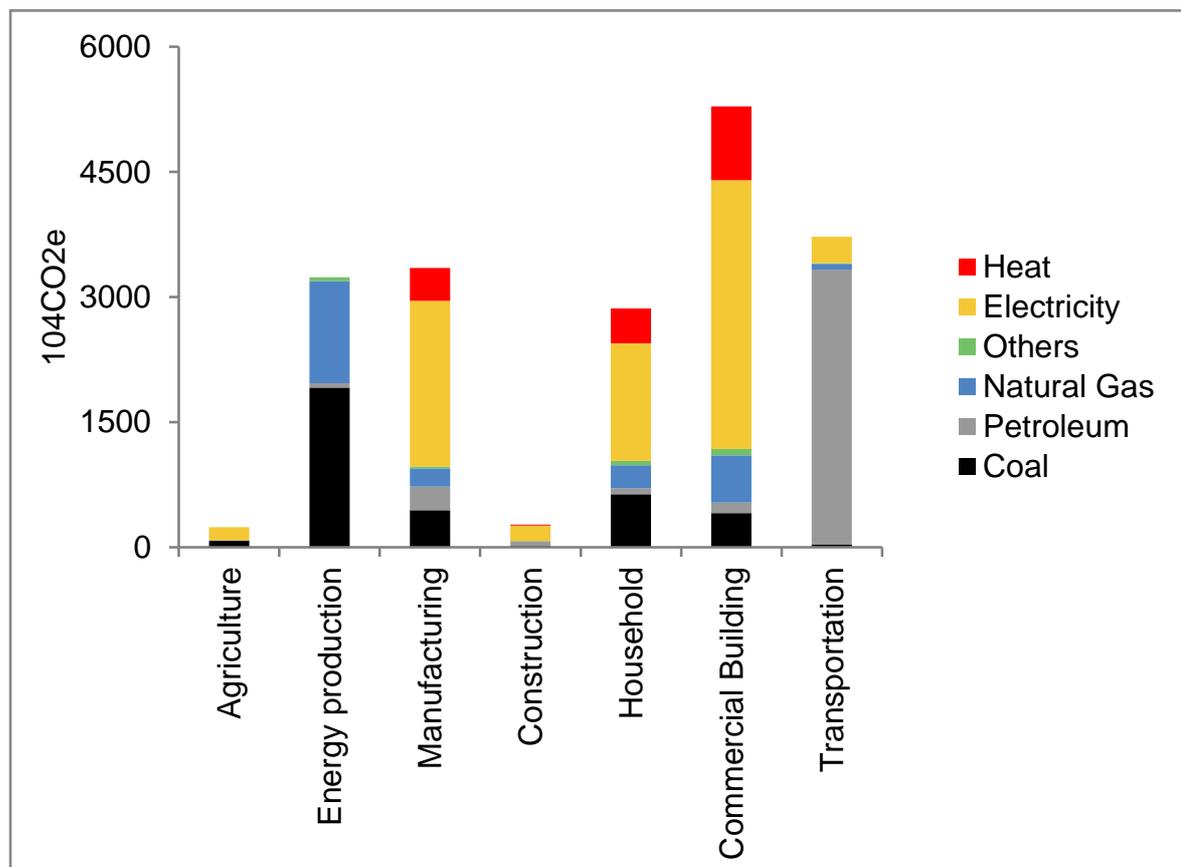
5.2.2 GHG emission of Energy Sector

The relationship between energy consumption and economic growth has been widely studied (Belke et al., 2011) and the results indicated a long-run relationship between energy consumption and economic growth. In China, urban areas already contribute 84% of total commercial energy consumption and 75% of total energy consumption (in 2006), and are responsible for 85% of energy related CO_2 emissions (Dhakal, 2009; World Energy Outlook, 2008).

As shown in Figure 5-3, the GHG emissions of the electricity production emitted 72,820,000 tCO_2e, the GHG emissions of the petroleum combustion released 38,930,000 tCO_2e, and the GHG emissions of petroleum combustion produced 35,200,000 tCO_2e. The GHG emissions of the energy sector is approximately 96% of total GHG emission in this study. Coal is one of the main energy sources for power generation in Beijing, and the promotion of low-carbon electricity will decrease the high level of dependence on fossil fuels and make the contribution to GHG emission reduction.

Figure 5-3 GHG Emission related to different fuels
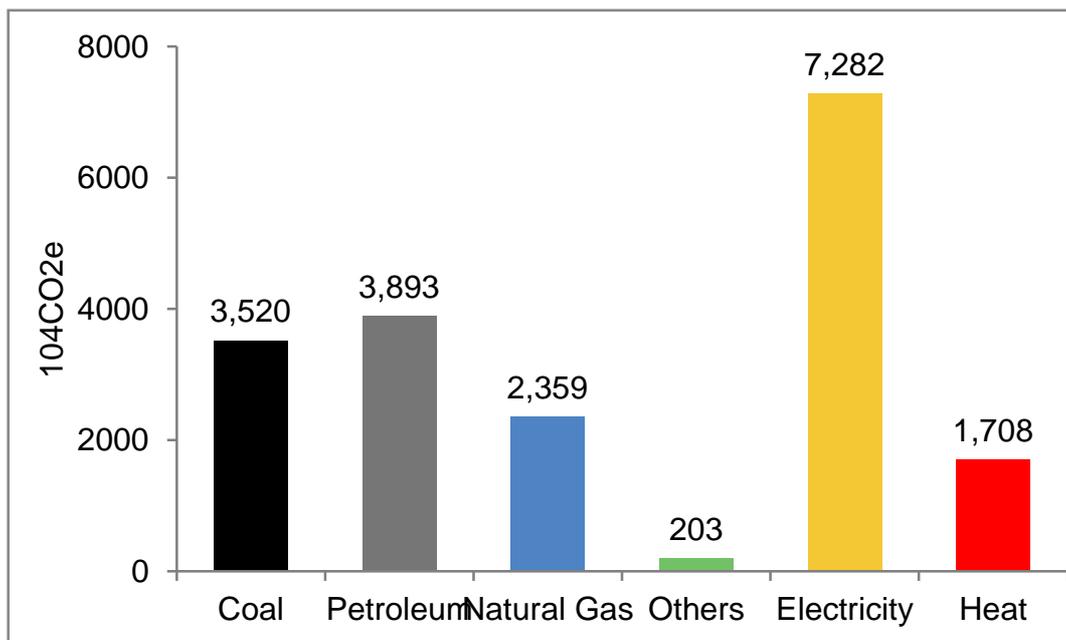
CHAPTER 6: DISCUSSION

6.1 Discussion on Data Availability

The availability of activity data and the emission factor lays a significant foundation for accounting the GHG inventory. The GPC method provides a robust and clear framework that builds on existing methodologies for calculating and reporting an urban GHG inventory. The Greenhouse Gas Accounting Tool for Chinese Cities contains a guidance document and spreadsheet calculation tool. The GHG emission of the energy sector is more integral and conveniently accounted with applied activity data from the energy balance sheet which is published in the China Energy Statistical Yearbook every year. However, Beijing is a provincial level city in China, and therefore the energy balance sheet is usually published on a provincial basis. Thus, other Chinese cities except Beijing, Shanghai, Tianjin and Chongqing cannot used the energy balance sheet to account the GHG emission of the energy sector, which is more complex work for other Chinese cities.

Because of the heavy air pollution problem, lots of the industrial manufacturing were required to move to other cities, especially the iron and steel production. Since Beijing's local government began promoting economic development in tertiary industries in 2008, more and more industrial manufacturing moved their manufacturing production line facilities to other cities and operate the their headquarters in Beijing. Though checking whether the industrial activity exists or not, many sub-sector can be excluded in the Beijing municipal area. Most of the industrial process in GPC method did not exist in Beijing municipal area. This top-down method to account the GHG emissions in urban areas should

face the problem and difficulty from data availability, of which local activity data is lacking in other Chinese cities.

Regarding the Agriculture, Forestry and Other Land Use (AFOLU) and Waste sector, even the capital of China, Beijing is also faced with challenges on the activity data collection. The urban population is approximately five times more than the rural population in Beijing municipal area.

Moreover, the major source of the emission factors are referred to the IPCC method, which are the universal emission factors for the whole world. The relevant study should be paid attention to find out the specific emission factors for Chinese cities, especially in the Industrial, Agriculture, Forestry and Other Land Use (AFOLU) and Waste sector.

6.2 Discussion on Activity Data Accuracy

The activity data of energy sector is collected from the energy balance sheet published in China Energy Statistical Yearbook ever year, which provided more integral and accuracy for accounting the urban GHG inventory of the energy sector.

Based on the GHG emission, the figure 6-1 shown the result by applied the different level of the activity data in industrial sector. The GHG emission from A level and F level accuracy accounted for 75% and 25% in total GHG emissions of industrial sector in 2014. There are still many uncertainty for accuracy of activity data in the Agriculture, Forestry and Other Land Use (AFOLU) and Waste sector.

6.3 Discussion on GHG Emission in Beijing

Chinese cities have not published the comprehensive urban GHG inventories as of the end of this study. Furthermore, few studies on GHG inventories were published since the latest ones in 2007, which only accounted CO_2 emissions. In spite of the above mentioned problem, research on urban GHG inventory should promote and enhance to identify the major GHG emission sectors and facilitate policy making for low-carbon development.

The results show that the GHG emission levels of Beijing are still at a high level due to rapid urbanization. Thus, the total CO_2 emission level of China will continue to rise. Currently, energy is the largest contributor of GHG emissions in Beijing, and the emission growth of building can no longer be ignored. Because of rapid economic growth, urban development requires more energy, which causes both the scope 1 and scope 2 GHG emission to take the dominant position.

Beijing, the country's capital and host of the Beijing Olympic Games, has suffered from heavy air pollution and thusly became a famous hazy city of the world. Because of the heavy air pollution problem, lots of the industrial manufacturing were required to move to other cities, especially the iron and steel production. Most of the industrial process in GPC method did not exist in Beijing municipal area. This top-down method to account the GHG emissions in urban area should face the problem and difficulty, which lack of local activity data in other Chinese cities. Moreover, the scope 2 GHG emission in GPC method only consider the power used in a city, which were produced in the other city boundary. As the one of the largest mega-metropolises in the world,

a huge number of high-carbon products and goods were transported to Beijing and totally consumed in Beijing. Even the GHG emission per capita cannot represent the real GHG emission for the urban consumption. The strict GHG reduction policies probably result in the GHG "leakage" in the city boundary.

6.4 Comparative Discussion on GHG Emission with other Studies

A great number of studies have been conducted to research energy consumption and CO_2 emissions in China, especially CO_2 emissions, from a national perspective (Wei et al., 2006; Wang et al., 2010; Ming et al., 2009). Few studies provided energy GHG emissions in Beijing according to the IPCC method, and made the inventories of different sectors, energy varieties and industries.(Xing, 2007) Through statistical analysis, it was found that the energy sector contributed more than 90% of the GHG emissions from 1970 to 2007 in Beijing (Zhu, 2009). The above research mainly focused on the energy and industry sectors by using the IPCC mothed for accounting the GHG emission inventories.The overall CO_2 emissions were investigated for global cities and metropolitan regions, including a few Chinese cities. (Kennedy et al. 2011). In Kennedy's study, the Beijing GHG emission per capita was 10.1 tCO2e in 2006, which applied the IPCC method and the ICLEI method. The following table 6-1 shown the main comparative discussion between this study and Kennedy's study:

Table 6-1 Comparative discussion between this study and Kennedy's study

	Year	Method	Sector	GHG/ million tons CO$_2$e	GHG per capita/ tons CO$_2$e	Population

This study	2014	GPC method	Energy IPPU AFOLU Waste	204.27	9.5	21,516,000
Kennedy study	2006	IPCC and ICLEI method	Energy Waste	159.00	10.1	15,810,000

In 2014, Beijing GHG emission per capita was 9.5 tCO2e, which was a bit lower than that in most of the other Chinese cities, including Shanghai and Tianjin (Kennedy et al., 2011), but higher than several Asian cities, including Seoul and Tokyo. Even with the difference of the base year and method between those two studies, the city's economic growth pattern, urban structure, existing infrastructure and technology determine the impact that the city will have on the climate (Yang and Li, 2013). Therefore, Beijing will have a higher emission level owing to its concentration of energy, as opposed to a city like Tokyo which is dominated by service sector industries.

CHAPTER 7: CONLUSION

Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) Method was developed to explore appropriate methods to measure city GHG and assist cities improve GHG accounting capabilities, and provide decision making support to cities' low carbon development. This study selected the GPC method from several common global methods to account the GHG inventories for Beijing in 2014.

Because of the geographic disparity of economic development in China, the goals and approaches for emission reduction used in Chinese cities should be differentiated. The cities in the highly urbanized eastern region can begin to conduct effective emission monitoring and reduction actions, while cities in other areas can observe and learn from these actions. (YU, 2012)

Chinese cities have not published the complete urban GHG inventory as of the end of this study. Furthermore, few studies on GHG inventory were published since the latest ones in 2007, which only accounted CO_2 emissions was accounted. In spite of the above mentioned problem, the research on urban GHG inventory should promote and enhance identification of the major GHG emission sectors and facilitate policy making for low-carbon development.

In conclusion, the GPC method provides a useful tool to understand and profile GHG emissions for Chinese cities, and design tailored and targeted emission factor and a few kinds of the activity data for GHG inventory account. Even the capital of China, Beijing is also faced with challenges on activity data collection. The determination of urban GHG emission in China suffers from the confusion generated by the various definitions of 'city' and the corresponding urban boundaries in the country. It is not names but physical and socio-economic

attributes that determine the boundary of a city. The different concepts and therefore different spatial boundaries for Chinese cities are responsible for the conflicting and confusing results associated with urban GHG inventory. It may be of interest to local governments to account their GHG inventory, to guide actions to adapt climate change and low carbon development. GPC method may also indicate the GHG management to Chinese cities, which are the most vulnerable areas to the impacts of climate change.

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