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Original Research Paper

Emission Inventory for Xiamen by Using Global Protocol for Community-Scale Greenhouse Gas Emissions

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ABSTRACT

Cities present a challenge together with an opportunity for climate change. The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC), which was announced in December 2014 in Lima, offers cities a robust, transparent and globally-accepted framework to consistently identify, calculate and report on city-level GHG emissions. This study focused on the emerging GPC approach and applied it to establish the GHG emission inventory for Xiamen, which is a rapid developing coastal city in China. Based on the GPC approach and the gathered data, the total GHG emissions in the inventory boundary has reached to 19.85 million tonnes CO_2e in the inventory year 2007. GHG emissions discharged from stationary sources are 14.37 million tonnes of CO_2e and account for 72.37% of the total GHG emission in Xiamen. And the per capita emissions come to 8.17 tonnes CO_2e, higher than the average 5.3 tonnes CO_2e for China in the same year reported by The World Bank in 2015. The GPC, in general, is clear and practical, and provides a more comprehensive scope when calculating the GHG emissions. However, the main challenge for applying the GPC is the data availability. It is recommended for the government statistical offices and the public agencies to increase the additional input that is specifically used for improving the data required for GHG emission inventories. Future studies should try to use more local activity data and emission factors, so that the evaluation could be more objective and accurate.

INTRODUCTION

How to make cities more sustainable for living is one of the most crucial challenges of the world in the 21st century, as the city has a significant influence on the natural environment from both social and economic aspects. The urban population in 2012 accounted for 53.6% of the total global population (CIA 2012) and continues to grow by approximately 1.84% per year between 2015 and 2020, 1.63% per year between 2020 and 2025, and 1.44% per year between 2025 and 2030 (WHO 2015). The urban population is estimated to reach 60% of the global population by 2030 (EIFER 2015), and increase to 70% of the world's population or 6.4 billion by 2050 (Dhakal 2009). The urban population growth is more concentrated in the developing regions around the world in absolute numbers. WHO (2015) estimated that by the year of 2017, a majority of people will be living in urban areas even in less developed countries.

The Intergovernmental Panel on Climate Change (IPCC) had pointed out the need to cover urban carbon mitigation more vigorously in the Fifth Assessment Report (FAR). At the same time, city authorities require more scientific inputs for them to develop a long-term scenario about urban emissions and identify the potential low-carbon development pathways (Dhakal 2010). Although, cities play crucial roles in the issues of GHG emissions and environment, emission levels of different cities are obviously different because of the various levels of industrialization and commercialization. Moreover, who should be blamed for the GHG emissions is still open to debate. It is not a straight forward work to determine the different responsibilities of different cities for GHG emissions (UN Habitat 2011). Dodman (2009) examined the emissions by the city and by sector and discovered that per capita emission in nine of the considered eleven cities were lower than the average of the country they were located. Thus, the extent to which city should be blamed for contributing to global warming is open to debate (Satterthwaite 2008, Mitra et al. 2006).

It is necessary for city leaders and decision-makers to have a highly qualified GHG emission data, as it is considered to be an effective way to address the environmental issues from the perception of community level. City leaders can use the measurement of community-scale emission inventories to assess their chances and risks and build strategies to decrease their emissions.

This research will apply the Global Protocol for Community-Scale GHG Emission Inventories (Fong et al. 2014), which is an emerging international standard for city-level

GHG emission inventory, to set up a GHG emission inventory for Xiamen, which is an important coastal city and also a pilot city in low-carbon development in China. The results of this study could be used as a reference for local government to set up new emission reduction target.

EARLIER STUDIES

The GPC: Because the GPC was expected to be a practical and comparable international standard from beginning, every draft version before the final official version was also available for general public to test. Brander et al. (2013) used 0.9 version of the GPC to create an inventory for Lochaber in the Scottish west highlands. The 0.9 version separated emissions into four parts: energy usage in stationary units, energy usage in mobile units, waste, and energy usage in industrial process and product. However, the main practical obstacle was still the availability of emission data. To some extent, some data are only partially available. For example, not all roads in the urban area have daily traffic volume data. Another important question that Brander et al. (2013) came up with, is to compare the cost involved in providing data and constructing city inventory with the potential benefit of allocating emission reduction targets at city level. Sowunmi et al. (2015) analysed the carbon emissions from livestock (sheep, goat, cattle and camel) manure in the United Arab Emirates under guidance of the GPC, and results showed that carbon emissions from sheep, goat, cattle and camel are respectively 22, 246, 56, and 11 kt CO_2e, of which Abu Dhabi Emirate contributes respectively 84%, 63%, 52%, and 91%. In total, Abu Dhabi Emirate was responsible for 64% of the total carbon emissions from livestock manure in the country.

Production-based and consumption-based inventories: The distinction between production-based and consumption-based inventories help to find out the main characteristics of the GPC. Production-based inventories are designed to quantify the in-boundary GHG emissions while consumption-based inventories quantify all the GHG emissions resulting from the in-boundary goods and services consumption (Larsen & Hertwich 2009). In general, two main approaches are usually used to develop a production-based inventory. One is a top-down approach, which allocates national GHG emissions to several regions. The other one is a bottom-up approach, which gathers regional GHG emissions data to build up total production-based inventory.

A series of studies have found that the consumption-based approach would increase the cities' nominal GHG emissions. Hertwich& Peters (2008) examined the GHG emissions embodied in international trade among 87 countries in 2001. Davis & Caldeira (2010) found that 23% of the global emissions in 2004 were traded as exports from emerging markets, mainly China, to final consumer developed countries. Brinkley & Less (2010) found that, 33% of total consumption-based emissions in 2006, compared with 3% in 1990, were turned out to be net imports by the EU's six largest member states. Peters et al. (2011a) explained the international carbon leakage problem between developing countries and developed countries by another set of data. In the regional area, Erickson et al. (2011) adopted a consumption-based method to establish the emission inventory of Oregon, a state of the United States.

Input-output analysis: Input-output analysis (IOA) is a simple approach to allocating GHG emissions and is helpful to trace environmental impacts of consumption. IOA offers two methods to reassign emissions caused by international trade from producer to consumer. One is emissions embodied in bilateral trade (EEBT), which calculates local emissions by using local consumption. Another is multiregional input-output analysis (MRIO), which enables to assign the global emissions to the final consumers. Neither of them were wrong because EEBT and MRIO answered two different type of questions, and the choice between them would mostly depend on whether the research is focused on bilateral trade or consumption (Peters et al. 2011b). The input-output model has an extensive range of life-cycle applications once it was combined with relevant data, like international trade statistics and environmental input-output statistics (Munksgaard et al. 2005).

METHODS AND DATA

General: Constructing the GHG emission inventory in Xiamen by using the GPC is the essential step in this study. The inventory boundary in this study will include GHG emissions occurring within the geographic boundary of Xiamen City, China, as well as the emissions discharged beyond Xiamen City as a result of city activities. The GPC guides cities to report their GHG emission inventories through two different but complementary ways. One is based on the scope framework, and emissions will be classified into three ranges. The other one is based on the city-induced framework, which measures GHG emissions attributable to activities taking place within a city boundary. The city-induced framework consists of the BASIC level and the BASIC+ level.

$$E_{total} = E_{SE} + E_T + E_W + E_{IPPU} + E_{AFOLU} \quad ...(1)$$

Where,

E_{total} = Total GHG emissions in BASIC+ level

E_{SE} = GHG emissions from stationary energy account

E_T = GHG emissions from transportation account

E_W = GHG emissions from waste account
E_{IPPU} = GHG emissions from industrial processes and product use
E_{AFOLU} = GHG emissions from agriculture, forestry and other land use

$$GHG\ emissions = Activity\ data \times Emission\ factor \quad ...(2)$$

Stationary sources: Referring to the calculation method in IPCC guideline (IPCC 2006), CO_2 emissions from direct fuel combustion from stationary sources were calculated by Equation (3).

$$E_{CO2-fuel} = \sum_i \sum_j AC_{i,j} \times NCV_j \times CC_j \times O_{i,j} \times \frac{44}{12} \quad ...(3)$$

Where,
$E_{CO2\text{-fuel}}$ = Total CO_2 Emissions from fuel combustion (1,000 t)
i = Category of sector
j = Category of fuel
AC = Amount of fossil fuel combusted (10,000 t or 10^8 m^3)
NCV = Average low calorific value (kJ/kg or kJ/10^8 m^3)
CC = Carbon Content (t Carbon / TJ)
O = Carbon Oxidation Rate
44/12 = Converting factor from Carbon to Carbon Dioxide

Equation 4 calculated the CH_4 and N_2O emissions from direct fuel combustion from stationary sources.

$$E_{CH4(N2O)-fuel} = \sum_i \sum_j AC_{i,j} \times NCV_j \times EF_{CH4(N2O)} \quad ...(4)$$

Where,
$E_{CH4\text{-fuel}}$ = Total CH_4 Emissions from fuel combustion (1,000 t)
$E_{N2O\text{-fuel}}$ = Total N_2O Emissions from fuel combustion (1,000 t)
NCV = Average low calorific value (kJ/kg or kJ/10^8 m^3)
EF_{CH4} = CH_4 Emission factor (kg/TJ)
EF_{N2O} = N_2O Emission factor (kg/TJ)

Fuel consumption data were taken from Xiamen GHG Emissions Inventory (2005-2009) (XMDRC 2012). Average low calorific value and carbon oxidation rate were national values and taken from 2013 China Energy Statistical Yearbook (NBS 2013).

***Scope 2 emissions*:** Grid-supplied energy was mainly electricity and heat. Therefore, Equation 5 and Equation 6 could compute the indirect emissions from electricity and heat consumption.

$$GHG_{Electricity} = \sum_i C_{electricity,i} \times EF_{electricity} \quad ...(5)$$

Where,
$GHG_{electricity}$ = CO_2e Emissions from grid-supplied electricity consumption (1,000 t CO_2e)
$C_{electricity}$ = Grid-supplied electricity consumption (10,000 kWh)
$EF_{electricity}$ = CO_2e Emission factor (t CO_2e / 10,000 kWh)

$$GHG_{heat} = \sum_i C_{heat} \times EF_{heat} \quad ...(6)$$

Where,
GHG_{heat} = CO_2e Emissions from grid-supplied heat consumption (1,000 t CO_2e)
C_{heat} = Grid-supplied heat consumption (GJ)
$EF_{electricity}$ = CO_2e Emission factor (t CO_2e/GJ)

The detailed in-sector grid-supplied electricity consumption data were also presented at the same source. However, the complete in-sector heat consumption data could not be found at the general public available database or government reports.

***Scope 3 Emissions*:** Equation 7 could calculate the GHG emissions from transmission and distribution losses of electricity, and regional loss factor for electricity was taken from Lin et al. (2012).

$$GHG_{elec-loss} = \sum_i C_{electricity} \times L \times EF_{electricity} \quad ...(7)$$

Where,
$GHG_{elec\text{-loss}}$ = CO_2e Emissions from transmission and distribution loss for grid-supplied electricity consumption (1,000 t CO_2e)
$C_{electricity}$ = Grid-supplied electricity consumption (10,000 kWh)
L = Transmission and distribution loss factor
$EF_{electricity}$ = CO_2e Emission factor (t CO_2e/10,000 kWh)

Transportation sources: Transportation source accounts for GHG emissions resulting from direct fossil fuel consumption and grid-supplied electricity consumption from transportation activities (Xie et al. 2014). Combined with the GPC (Fong et al. 2014) and IPCC-2006 in the classification of means of transportation, sources of emissions in the transportation account could be divided into five sub-sectors: on-road transportation, railway, water-borne transportation, aviation, and off-road transportation.

$$E_{transport} = \sum_{i,j} AC_{i,j} \times NCV_{i,j} \times EF_{i,j} \quad ...(8)$$

Where,

$E_{transport}$ = Total CO_2e Emissions from transportation activity (1,000 t)
i = Means of transportation
j = Category of fuel
AC = Amount of fuel consumed (10,000 t)
NCV = Average low calorific value (kJ/kg)
EF = Emission factor (kg/TJ)

The combustion of gasoline and diesel in internal combustion engines mainly resulted in GHG emissions from the on-road transportation sector in Xiamen. Equation 9 and 10 could calculate the fuel consumption.

$$AC_{i,j} = TPK_{i,j} \times PEC_{i,j} \div NCV_{i,j} \quad ...(9)$$

$$AC_{i,j} = TFK_{i,j} \times FEC_{i,j} \div NCV_{i,j} \quad ...(10)$$

Where,
AC = Amount of fuel consumed (10,000 t)
i = Vehicle type
j = Category of fuel
TPK = Total passenger kilometres (10,000 passenger km)
TFK = Total freight kilometres (10,000 passenger km)
PEC = Passenger energy consumption rate (kJ/passenger km)
FEC = Freight energy consumption rate (kJ/t km)
NCV = Average low calorific value (kJ/kg)

Waste sources: The treatment or disposal of municipal solid waste, industrial waste, clinical waste, and hazardous waste would generate a large number of CH_4 emissions. In addition to CH_4, solid waste disposal sites also produce biogenic CO_2 and a less number of N_2O. This study chose the other evaluation method that is Methane Commitment (MC). MC calculated the CH_4 emission based on the waste disposal amount in the given study year, regardless the historical and future influence. However, in most cases, the MC method would consistently overestimate the GHG emissions.

$$DOC = (0.15 \times A) + (0.2 \times B) + (0.4 \times C) + (0.43 \times D) + (0.24 \times E) + (0.15 \times F) \quad ...(11)$$

Where,
DOC = Degradable organic carbon (t carbon/t waste)
A = The proportion of food waste in solid waste
B = The percentage of garden waste in solid waste
C = The percentage of paper waste in solid waste
D = The percentage of wood waste in solid waste
E = The percentage of textiles waste in solid waste
F = The percentage of industrial waste in solid waste

Incineration, currently touted as the holy grail for dealing with recyclable materials, was a controlled waste treatment process. By contrast, open burning was a sporadic and uncontrolled process, which frequently happened in the rural area. Equation 12 could calculate the CO_2e emissions from incineration.

$$E_{CO2} = \sum_i (m_i \times CF_i \times FCF_i \times OF_i) \times \frac{44}{12} \quad ...(12)$$

Where,
E_{CO2} = Total CO_2 emissions from incineration
m_i = Mass of I matter incinerated (kt)
CF_i = Fraction of carbon in i matter
FCF_i = Fraction of fossil carbon in carbon component of i matter
OF_i = Oxidation factor

Industrial processes and product uses (IPPU) sources: The GPC framework reported GHG emissions from industrial production processes from mineral industry, chemical industry, and metal industry. GHG involved in these industries included carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, and perfluorocarbons. Equation 13 could assess the amount of CO_2 emission.

$$E_{CO2} = M_g \times EF_g \times (1 - CR) \quad ...(13)$$

Where,
E_{CO2} = CO_2 emissions from glass production process
g = Melted glass type
M = Mass of melted glass
EF = Emission factor of glass production process
CR = Cullet ratio

Agriculture, forestry and other land use (AFOLU) sources: Agricultural GHG emissions inventory includes a total of three aspects, namely animal methane emissions from enteric fermentation, manure management methane emissions and manure management nitrous oxide emissions. Equation 14 could calculate methane emissions.

$$E_{CH4} = \sum_i (N_l \times EF_l + N_s \times EF_s + N_f \times EF_f) \quad ...(14)$$

Where,
E_{CH4} = CH_4 emissions from enteric fermentation
i = Species
N_l = Number of livestock that have been large-scale fed
N_s = Number of livestock that have been scattering fed
N_f = Number of livestock that have been free range fed
EF = Emission factor

RESULTS AND DISCUSSION

Because of China's current information disclosure level and the relevant data availability, this study may not reflect 100% of the real GHG emissions in Xiamen, in the study year of 2007. However, in each individual account, this study tried to gather the most veritable figures and cover as many sectors as it could.

For activity data, some emission sources were covered with highly-qualified data, including fuel consumption data in stationary energy use, most waste treatment data, cross-boundary aviation activity data, and industrial process data, while some data sources only provided a single element of data, which was considered as not being enough for a complete inventory picture. For example, in-boundary grid-supplied energy consumption only embodied grid-supplied electricity consumption without grid-supplied heat consumption due to lack of relevant data; emissions related to open burning were not included in the total emissions from waste incineration for a deficiency of complete activity data. For emission factors, the majority of them were extracted to local or regional data source. But, some emission factors in the stationary energy account and transportation account were referred to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) default values.

The results show that, GHG emissions discharged from stationary sources are 14.37 million tonnes of CO_2e, and account for 72.37% of the total GHG emission in Xiamen. Transportation activities in Xiamen produce 3.63 million tonnes of CO2e, which account for 18.27% of the total emissions. The 1.69 million tonnes of GHG emissions, which are 8.52% of the total GHG emissions, are results of waste disposal and treatment activities. Industrial processes and product use accounts for 0.03% of the total GHG emissions. Agriculture, forestry and other land use activities produce 0.81% of the total GHG emissions.

At the end of 2007, Xiamen had a total population of 2.43 million people. Thus, the per capita emissions come to 8.17 tonnes CO_2e, higher than the average 5.3 tonnes CO_2e for China in the same year reported by The World Bank (2015) (Fig. 1).

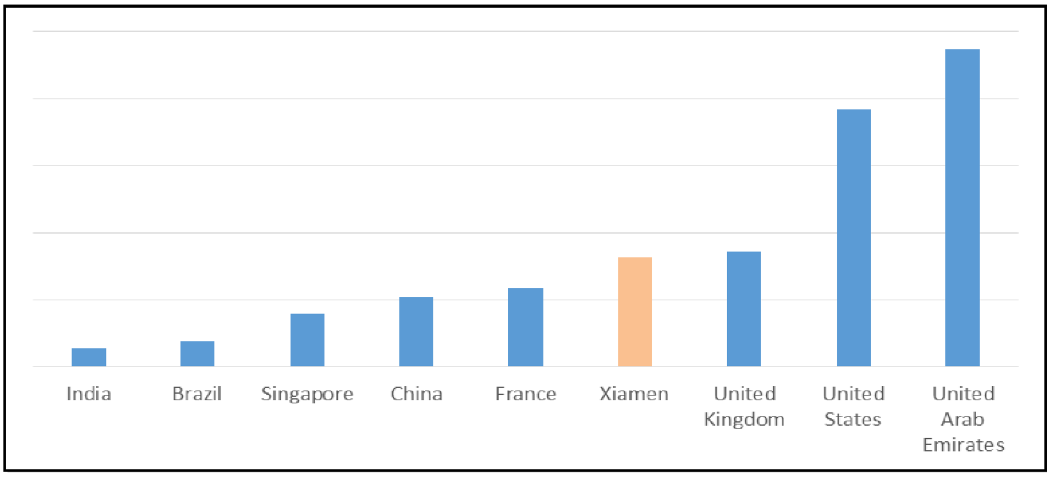
In the total GHG emissions, scope 1 emissions contribute the most part that is 80.38% from the total emissions. Scope 2 emissions come next and responsible for 11.09% of all emissions. Scope 3 emissions contribute the remaining 8.53% of the total emissions (Fig. 2). Unlike some other studies that showed the high potential of scope 3 emissions in community-level GHG emissions (Pattara et al. 2012, Schulz 2010), this may be due to the following factors: In the first place, the GPC is mainly concentrated on providing a production-based GHG emission inventory. Secondly, this study does not explicitly separate in-boundary activities and cross-boundary activities due to lack of detailed transportation data. Cross-boundary activities are usually recognised as an important source that produces scope 3 emissions.

CONCLUSION

This paper applies the Global Protocol for Community-Scale GHG Emission Inventories (GPC) to set up a GHG emission inventory map for Xiamen, China. The GPC is an emerging international standard to evaluate the city-level GHG emissions.

Based on the GPC method and the applicable data, the total GHG emissions in the inventory boundary has reached to 19.85 million tonnes CO2e in the inventory year 2007. Among them, GHG emissions discharged from stationary sources are 14.37 million tonnes of CO_2e, and account for 72.37% of the total GHG emission in Xiamen. Transportation activities in Xiamen produce 3.63 million tonnes of CO_2e, which account for 18.27% of the total emissions. The 1.69 million tonnes of GHG emissions, which are 8.52% of the total GHG emissions, are result of waste disposal and treatment activities. Industrial processes and product use accounts for 0.03% of the total GHG emissions. Agriculture, forestry and other land use activities produce 0.81% of the total GHG emissions. The per capita emissions come to 8.17 tonnes CO_2e, higher than the average 5.3 tonnes CO_2e for China in the same year reported by The World Bank (2015). From another perspective, more than 80% of the total GHG emissions are direct emissions. Moreover, grid-supplied energy consumption in energy industries is the largest indirect emission source that produces 1.26 million tonnes of CO_2e.

The GPC, in general, is clear and practical, and provides a more comprehensive scope when calculating the GHG emissions. However, the main challenge for applying the GPC is the data availability. The current information disclosure level in the study area is not enough for establishing a complete emission inventory. For example, the government's yearbook did not include the detailed electricity consumption for each industry; transportation data did not distinguish the in-boundary activities and cross-boundary activities; and open burning activity data were not available. Besides, the categories of the disclosed data sometimes are not detailed enough to cover every social activity. For example, the official statistic reports in China classify transportation, storage industry, and post industry as one industry and report the total statistical data together, which makes it hard to narrow down and extract the transportation data. Former studies in China's GHG emission inventory also have encountered these types of problems. Their solutions include interviews from the government, field research, and data projection (Peng et al. 2015, Dong et al. 2014, Lin et al. 2012). Another challenge is that local emission factors were not always available. In this situation, the IPCC default values might be used to accomplish the calculation. Further studies in this area are required to obtain more local emission factors.



Source: The World Bank (2015)

Fig. 1: Per capita GHG emissions in 2007 (metric tonnes CO_{2e} per capita.

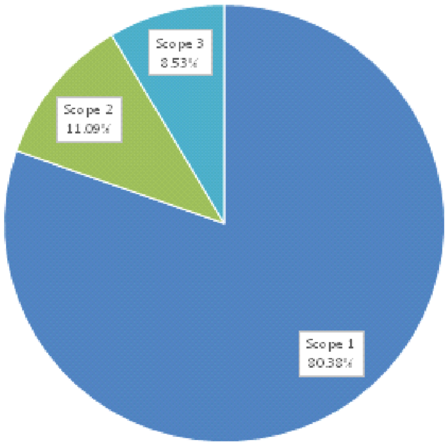


Fig. 2: GHG emissions in scope.

It is recommended for the government statistical offices and the public agencies to increase the additional input that specifically used for improving the data required for GHG emission inventories. For many reasons, the results from this study may not fully reflect the real GHG emissions of Xiamen in the inventory year. Future studies should try to use more local activity data and emission factors, so that the evaluation could be more objective and accurate.

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