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Comparative analysis of greenhouse gas emissions from major cities of India

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Abstract: Concentration of greenhouse gases in the atmosphere has increased rapidly due to anthropogenic activities resulting in significant increase in the temperature of the earth causing global warming. This is quantified using an indicator like global warming potential (GWP) and expressed as tonnes carbon dioxide equivalent. Assessing the greenhouse gas emissions is an important step towards making quantifiable emission reductions. This study focuses on estimating the greenhouse gas emission from major cities in India namely Delhi, Greater Mumbai, Chennai and Bangalore across various sectors and expresses the total emission in terms of Carbon dioxide equivalent (CO_2 eq). Emissions from key sectors like electricity, transportation, industries, agriculture, waste and others have been computed. Country specific emission factors have also been used to reduce estimation uncertainties. The total Carbon dioxide equivalent emissions are compared with their economic activity, measured in terms of GDP.The result shows Chennai emits highest CO_2 eq emissions per GDP followed by Delhi.

Keywords*: Green house gases (GHG), Carbon footprint, Carbon dioxide equivalent, Emissions, Gross domestic product (GDP)*

Introduction:

The increasing interest in quantification of greenhouse gas emissions comes as a result of growing public awareness of global warming. Many global metropolitan cities and organizations are estimating their greenhouse gas emissions and developing strategies to reduce their emissions. As per Intergovernmental Panel on Climate Change (IPCC), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbons (HFCs), per fluorocarbons (PFCs) and sulfur hexafluoride (SF_6) are the major greenhouse gases. Among the GHG's, carbon dioxide is the most dominant gas causing global warming which accounts for nearly 77% of global total CO_2 equivalent greenhouse gas (GHG) emissions (IPCC 2007c).

Climate change is a serious threat for all the countries. Concentration of (GHG's) in the atmosphere has increased rapidly due to anthropogenic activities resulting in significant increase in the temperature of the earth. Increase in the concentration of these greenhouse gases results in global warming. Observations over India show that in the last 100 years the mean annual surface air temperature has increased by 0.4°C (Hingane et al., 1985). So there exists a need for a global parameter to assess the global greenhouse gas emissions.

'Carbon footprint' can thus be defined as a measure of the impact of human activities on the environment in terms of the amount of greenhouse gases produced. The total greenhouse gas emissions from various anthropogenic activities are expressed in terms of carbon dioxide equivalent, which indicate the carbon footprint of a region. Carbon dioxide equivalent (CO_2e) is a unit for comparing the radiative forcing of a GHG to that of carbon dioxide. It is the amount of carbon dioxide by weight that is emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another radiatively active gas. Carbon dioxide equivalents are calculated by multiplying the weight of the gas being measured by its estimated global warming potential.

In the year 1996, Intergovernmental Panel on Climate Change (IPCC) published Guidelines for National Greenhouse Gas Inventories to estimate national greenhouse gas emissions from various sources (IPCC 1996 Guidelines). IPCC has also developed Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (GPG 2000) and the Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF). All these inventories taken together provide internationally agreed methodologies that countries currently use to estimate greenhouse gas inventories. Many researchers have estimated Indian emission inventories of different gases from various sources and for different years (Mitra 1991, ADB 1994, Parashar et al., 1994, 1997, ALGAS 1998, Gupta et al., 1999, Garg, Bhattacharya and Shukla., 2001a, Mitra A P et al., 2004). In the year 2004, effort was made to assess greenhouse gas emissions from anthropogenic origin from sectors like Energy, Agriculture, Industry, Land Use, Land Use Change and Forestry and Waste and efforts were also made to

assess the climate change impacts and vulnerability of key sectors of economy in India's Initial National Communication to the UNFCCC (NATCOM, 2004). The base year for the studies were taken as 1994 using 30% country specific and 70% default emission factor.

This paper focuses on calculation greenhouse gases (eq CO2) in the major cities of India (population above 10 million as per 2011 census) namely Delhi and Greater Mumbai Chennai and Bangalore from key sectors. The total Carbon dioxide equivalent emissions are compared with their economic activity, measured in terms of GDP. The emissions from methane and nitrous oxide are expressed in terms of carbon dioxide equivalents using their respective global warming potential values as shown in the Table 1.

Table 1. Major greenhouse gases and their Global Warming Potential

Species	Chemical formula	GWP_{100}
Carbon dioxide	CO_2	1
Methane	CH_4	25
Nitrous oxide	N_2O	298
HFCs	-	124-14800
Sulfur hexafluoride	SF_6	22800
PFCs	-	7390-12200

Source: Inter Government Panel on Climatic Change (IPCC), 2007

Methods and methodology:

The methodologies used for this study are obtained IPCC 1996 guidelines and IPCC 2006 guidelines. As per 2006 IPCC Guidelines for National Greenhouse Gas Inventories, emission of each GHG is estimated by multiplying fuel consumption by the corresponding emission factor. To calculate total emissions of a gas from all its source categories, the emissions are summed over all source categories.

$\text{Emissions}_{Gas} = \sum_{Category} A \times EF$

Where, Emissions_{Gas} is the emissions of given gas from its entire source categories; A is the amount of individual source category utilized which generates emissions of the gas under consideration and EF is the emission factor of a given gas type by type of source category.

Greenhouse gas emissions from various major sectors like electricity consumption, transportation, domestic sector, industries, agriculture, livestock management and waste are calculated. The activity data for various source categories used are for the years 2009 and 2010. These data have been obtained from the government reports of central and state governments, published documents from various data organizations. Where all year wise data is not available like in livestock data, the official census data for 2003 and 2007 is extrapolated for the base year taken. Country specific emission factors have been taken where all available for different source categories because the regional specific factors results in accurate estimation of emission values compared to default IPCC values. IPCC default emission factors (IPCC1996 and IPCC 2006 guidelines) are taken in categories where all regional emission factors do not exist.

Emissions from electricity consumption is calculated using the fuel consumed to produce energy which is given by,

Emissions (t) = Fuel consumption (kt) × NCV (TJ/kt) × Gas specific emission factors (t/TJ)

Emissions from road transportation is calculated using the VKT approach as it is more accurate and is calculated using,

Emissions (g) = Number of vehicles × VKT × Emission factor (g/km)

Industrial emissions are a major source of greenhouse emissions. The major industries includes, cement production, iron and steel, ferroalloys and aluminium production, production of chemicals like ammonia, ethylene, carbon black, carbide, glass and ceramics production, pulp and paper, food processing, textiles and leather and others. As these are polluting industries, normally they are not located within the city boundaries. Agricultural related emissions generally occur from paddy cultivation, managed soils and burning of crops as shown in Table 3. Emission factors for livestock sector for enteric fermentation and manure management is also considered.

Results and Discussion:

GHG emissions from energy sector

The major sectors for which greenhouse gases are assessed under electricity consumption are consumption in domestic sector, commercial sector, industrial sector and others (public lighting, advertisement boardings, railways, public water works and sewerage systems, irrigation and agriculture). Emissions resulting from electricity consumption in domestic sector and industrial sectors are attributed to domestic sector along with the emissions from fuel consumption in this sector and industrial sector along with emissions occurring from industrial processes.

GHG emissions from electricity consumption in commercial sector and other sectors are represented in isolation for the comparative analysis. among the cities. Emissions resulting from auxiliary power consumption in plants located within the city boundary and from the supply loss is also calculated in this study. Figure 1 illustrates the emissions resulting from electricity consumption in commercial and other sectors along with auxiliary consumption in

power plants and supply losses. In Delhi the emission from commercial sector due to power consumption is 5428.55Gg of CO_2 eq, others is 2099.11 Gg of CO_2 eq and form auxiliary consumption and supply loss is 857.69 Gg of CO_2 eq which is highest among all the cities.

GHG emissions from domestic sector:

Domestic sector is a major sector which contributes to the considerable amount of emissions when city level studies are carried out. The major sources include electricity consumption for lighting and other household appliances and consumption of fuel for cooking. In the present study greenhouse gases emitting from electricity consumption in domestic sector and fuel consumption are accounted. The major fuels used in this study are LPG, Piped Natural Gas (PNG) and kerosene based on the availability of data. Total greenhouse gas emissions converted in terms of CO_2 equivalent from the domestic sector in major cities is shown in the Figure 2. In Delhi during the study base year 2009, 11690.43 Gg of CO_2 equivalents is emitted from the domestic sector which is the highest among all the cities. Electricity consumption accounted for 9237.73 Gg of emissions out of the total domestic emissions.

GHG emissions from transportation sector:

In the major cities transportation sector is one of the major anthropogenic contributors of greenhouse gases (Mitra and Sharma, 2002). Emissions resulting from total vehicles registered within the city boundary and also from CNG fuelled vehicles present in few of the major cities are calculated. Emissions resulting from road transportation including CNG vehicles and also in port cities of India are as depicted in Figure 3.

In Delhi during the year 2009-10, total number of registered vehicles was 6451883, out of which there were around 20 lakhs of cars and jeeps and 40.5 lakhs of motor cycles including scooters and mopeds. CNG fuelled vehicles emitted 1527.03 Gg of CO_2 equivalents whereas the remaining vehicles resulted in 10867.51 Gg of emissions which is the highest among all the major cities

GHG emissions from industrial sector:

As shown in the figure 4 emissions are estimated from the major industrial processes emitting considerable greenhouse gases which are located within the city boundary. Electricity consumption in industrial sector is taken into account using which the resulting emissions are calculated. Fuel consumption data is also used in few of the industries to estimate the emissions. Iron and steel industry, cement industry, fertilizer plants and chemical manufacturing are the few major industries which releases huge amount of greenhouse gases into the atmosphere during the process. Emissions are calculated from the major polluting industries in city boundaries as the data is not available for small and medium scale industries.

Though this study does not present the entire emissions across industrial sector in a city due to unavailability of data, the major greenhouse gas emitting industries are included in the study along with the electricity consumption which constitutes most of the emissions. Figure 4 shows that Chennai emits 4472.35 Gg of CO_2 eq and it is the greater emitter of GHG.

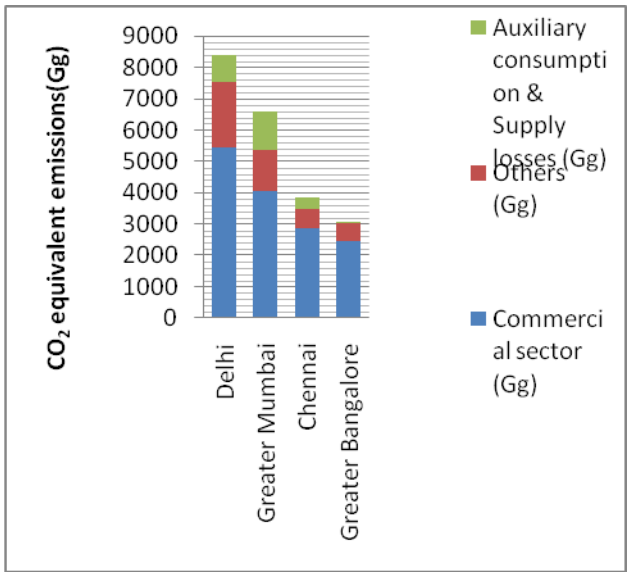

Fig. 1. Carbon dioxide equivalent emissions (CO_2 eq) from electricity consumption

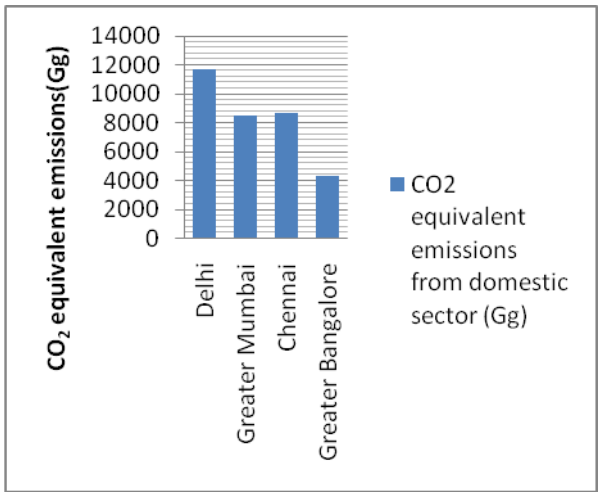

Fig. 2. Carbon dioxide equivalent emissions (CO_2 eq) from domestic sector

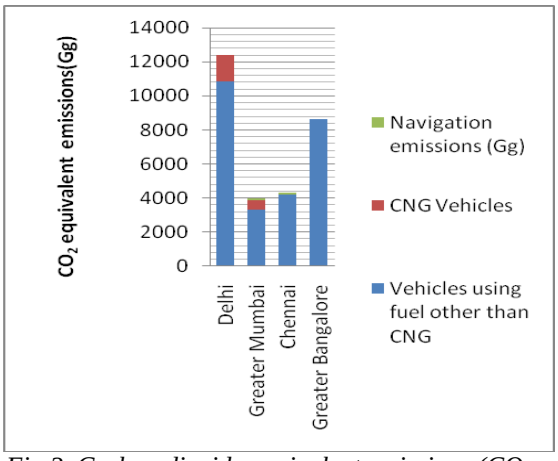

Fig 3. Carbon dioxide equivalent emissions (CO_2 eq) from transportation sector

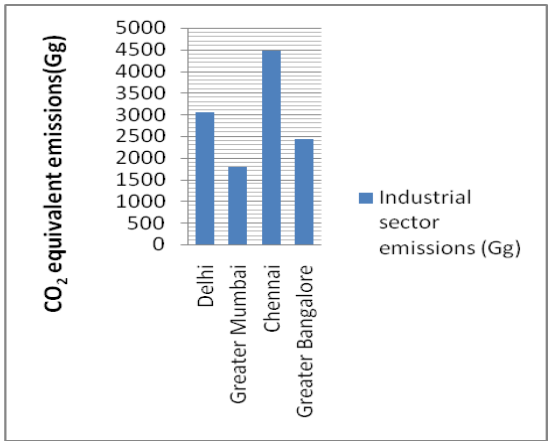

Fig 4: Carbon dioxide equivalent emissions (CO_2 eq) from industrial sector

GHG emissions from agricultural related activities:

Methane (CH_4) emissions from paddy cultivation, nitrous oxide (N_2O) emissions from soil management are the major sectors responsible for greenhouse gas emissions from this sector. Crop residue burning is practiced in few of the Northern parts of the India which also releases GHG emissions. In the current study emission inventory is carried out from these three sectors under agriculture related activities. The pattern of carbon dioxide equivalent emissions in the major cities from agricultural activities is as shown in the Figure 5.

Emissions from paddy cultivation are calculated for two major cities based on the area of paddy fields. Carbon dioxide equivalents were found to be 17.05 Gg in Delhi and 5.10 Gg in Greater Bangalore respectively. Emissions resulting from burning of crop residues at the end of growing year are estimated based on Delhi's emission of 2.68 Gg of CO_2 equivalents. N_2O emissions are converted into CO_2 equivalents. There are no agricultural activities in most of the cities which indicates decline in agricultural practices as a result of increasing urbanization.

GHG emissions from livestock management:

Enteric fermentation and manure management are the two major activities resulting in the emission of greenhouse gases from animal husbandry. In the present study emissions from livestock management is carried out to calculate the emissions resulting from enteric fermentation and manure management in the major cities. Livestock population for cities is obtained for cities using 2003 and 2007 livestock census, using which the number of livestock is extrapolated to the inventory year 2009 (MOA, 2000; MOA, 2005; MOA, 2007). The emission estimates for the major cities are as shown in figure 6. Delhi and Greater Bangalore are the major cities which emits higher amount of greenhouse gases due to animal husbandry.

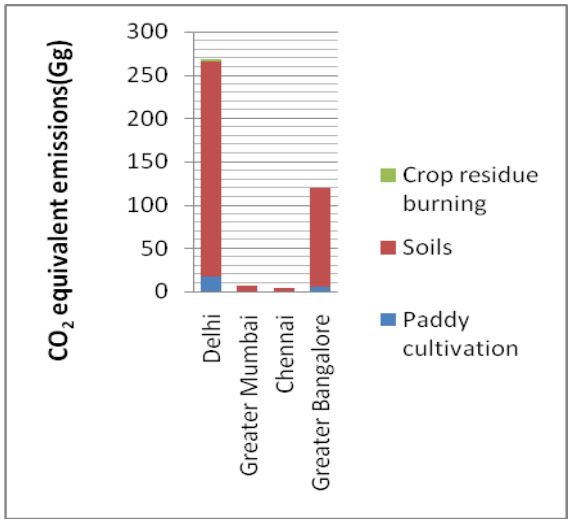

Fig. 5. Carbon dioxide equivalent emissions (CO_2 eq) from agricultural activities

GHG emissions from waste sector:

In the current study greenhouse gas emissions from two major waste sectors are calculated: municipal solid waste, domestic waste water. CH_4 emissions from municipal solid waste disposal data are obtained from the local city municipality. CH_4 and N_2O emissions are calculated from domestic sector. In this study the industrial waste water emissions is not calculated because of non availability of the data. The emission estimates from waste sector for the major cities are as shown in figure 7.

The emissions depend on the parameters like amount of waste disposed, methane correction factor, degradable organic carbon and oxidation factor (IPCC, 2006). Waste disposal at cities is a major source of anthropogenic CH_4 emissions these days. CH_4 and N_2O emissions from domestic water are calculated on the basis of population of the city. From the current inventories, major emitters from

domestic waste water sector are cities Delhi, Greater Mumbai and Greater Bangalore which emit 1378.75 Gg, 1058.09 Gg and 759.29 Gg of CO_2 equivalents respectively.

Comparative analysis of Carbon footprint:

Economic activity is a key factor that affects greenhouse gas emissions. Increase in economy results in rise in demand for supply of energy and energy-intensive goods which will also increase the emissions. On the other hand, growth in the economy of a country results in improvement in technologies and promotes the advancement of organizations which aims at environmental protection and mitigation of emissions. In this study, total carbon dioxide equivalent emissions emitted from different major cities are compared with their economic activity, measured in terms of GDP. The results shows that CO_2 equivalent emissions from Delhi, Greater Mumbai, Chennai, Greater Bangalore, are found to be 38633.2 Gg, 22783.08 Gg, 22090.55 Gg, 19796.5 Gg, respectively.

Figure 8 shows the relationship between carbon dioxide equivalent emissions per capita to GDP per capita. Chennai emits 4.79 tonnes of CO_2 equivalent emissions per capita which is the highest among all the cities, followed by Delhi which emits 2.40 tonnes of CO_2 equivalent emissions per capita.

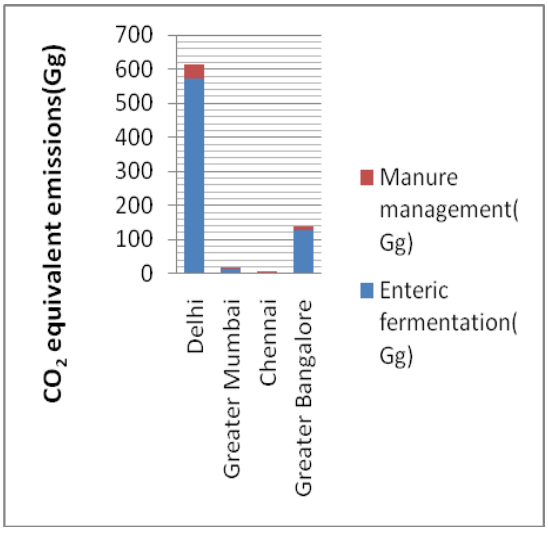

Fig. 6. Carbon dioxide equivalent emissions (CO_2 eq) from livestock management

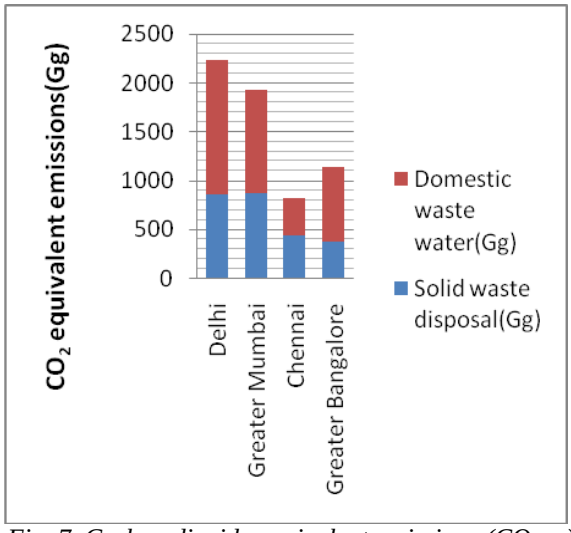

Fig. 7. Carbon dioxide equivalent emissions (CO_2eq) from waste sector

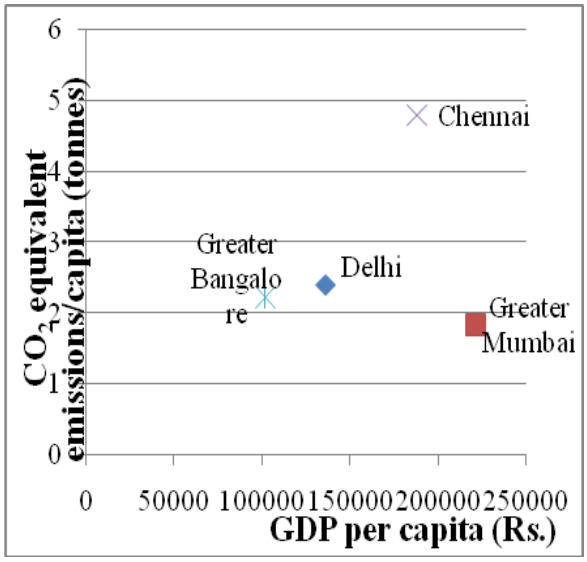

Fig. 8. CO_2 eq. emissions per capita versus GDP per capita for all the cities

Conclusion:

India is third biggest greenhouse gas emitter contributing about 5.3% of the total global emissions. Major cities in India are witnessing rapid urbanization. The quality of air in the major Indian cities which affects the climatic conditions as well as health of the community is a major environmental concern. Emissions levels depend on economic growth, which has increased the consumption of energy. The present study makes an attempt to estimate the Carbon footprint of major cities in India by calculating the greenhouse gas emissions from major sectors. This study shows that Delhi is the largest emitter of GHG followed by Greater Mumbai, Chennai and Grater Bangalore. The comparative study of CO_2 eq. emissions per capita versus GDP per capita shows that Chennai is highest and next is Delhi.

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