Carbon footprint as a policy tool in Indian cities

Process, Inventory, Application

THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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DECLARATION

This work has not been submitted in substance for any other degree or award at this or any other university or place of learning, nor is being submitted concurrently in candidature for any degree or other award.

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Abstract

Carbon footprints are increasingly being used as strategic policy tools for climate change mitigation at all levels national, regional, local or product. Cities being the centre stage of consumption and concentrations of populations are key in Climate change mitigation both in terms of reduction policies and adaptation. Many studies have been conducted to create and refine the methodology of conducting Greenhouse Gases (GHG) inventories at the city scale as well as to compare global or regional cities. Whilst the practice of GHG inventorying is rapidly finding place in cities in the developed nations, cities in developing countries haven't been as proactive. This thesis, takes a case study approach to identifying the opportunities and barriers to using a GHG inventory as a policy tool in a mid size Tier III city(<1 million population) in India.

The results show that whilst possible to conduct a GHG inventory within the existing data and governance structure, the success of such a policy and monitoring tool is highly dependent on a conducive governance environ with clear accountability. The five-year study showed rapidly increasing emissions rising from 1.07 Metric Tons per capita in 2007 to 1.43 Metric Tons per capita in 2011. Transport and residential sectors were identified as the key drivers. Yet compared to global benchmarks the emissions are very low, hence, suggesting that the policy target must be set at containing the emissions at low levels rather than reducing. A key finding was a declining annual growth rate for emissions within the city pointing to a positive trend that emissions are not rising at an exponentially growing rate that is sometimes assumed in relation to cities in developing countries. While emissions per capita have increased, emissions per unit GDP have gone down. The recommendations suggest leveraging existing government policies to reform the process and increase awareness.

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List of acronyms

ADB – *Asian Development Bank*
AFOLU – *Agriculture, Forestry and Other Land Use*
ARAI – *Automotive Research Association of India*
BEE – *Bureau of Energy Efficiency*
BPL – *Below Poverty Line*
BRE – *Building Research Establishment*
CAIT – *Climate Analysis Indicators Tool*
CDP – *Carbon Disclosure Project*
CDP – *City Development Plan*
CDP – *City Development Plan*
CNG – *Compressed Natural Gas*
CO2 Eq. – *Carbon Di Oxide Equivalent*
DNN – *Dehradun Nagar Nigam (Local Authority)*
DSO – *District Supply Office*
EF- *Emissions Factor*
EPA – *Environment Protection Agency*
EKC – *Environmental Kuznets Curve*
GHG – *GreenHouse Gases*
GOI – *Government of India*
GRIHA – *Green Rating for Integrated Habitat Assessment*
ICLEI – *International Council for Local Environmental Initiatives*
IEA – *International Energy Agency*
IPCC – *Intergovernmental Panel on Climate Change*
IPPU - *Industrial Processes and Product Use*
IUCN – *International Union for Conservation of Nature*
JNNURM – *Jawaharlal Nehru National Urban Renewal Mission*
LA – *Local Authority*
LCA – *Life Cycle Analysis*
LEED – *Leadership in Energy and Environmental Design*
LULUCF – *Land Use, Land Use Change and Forestry*
MDDA – *Mussourie and Dehradun Development Authority*
MT - *Metric Tons*
PWD – *Public Works Department*
RTO – *Regional Transport Office*
SAP – *Standard Assessment Procedure*
SUDA – *State Urban Development Agency*
TCPO – *Town and Country Planning Organisation*
TERI – *The Energy and Resources Institute*
UEPPCB – *Uttarakhand Environment Protection and Pollution Control Board*
UJS – *Uttarakhand Jal Sansthan*
ULB – *Urban Local Bodies*
UNDP – *United Nations Development Programme*
UNEP – *United Nation Environment Programme*
UPCL – *Uttarakhand Power Corporation Limited*
UPJN – *Uttarakhand Pey Jal Nigam*
WBCSD – *World Business Council for Sustainable Development*
WCED – *World Commission on Environment and Development*
WCS – *World Conservation Strategy*
WRI – *World Resources Institute*

Chapter 1 Introduction

"More than half the world's population already live in cities and the number will swell to almost 5 billion by 2030." (Shyan, 2012)

In recent times, such statements have consistently appeared in reports and media, an indication of the unprecedented looming urban growth crisis. There have been numerous studies and world forums to discuss the future of urban living especially concerning energy use and pollution. The rising concern for Climate Change that has been attributed to anthropogenic emissions adds to the crisis. Cities being one of the biggest consumers of energy and resources are now at the receiving end for criticism owing to the emissions/pollution caused by our fossil fuel based economies. The idea of sustainability has caught the imagination of urban planners, policy makers, and even the common man. This chapter describes how the research question was arrived at and why it is important in the academic and practical context.

1.1 The origin of the idea

The background to this research was an exploration into what is called sustainability today amid this global outcry for sustainable development. Sustainable development is defined as '*development that meets the needs of the present without compromising the ability of future generations to meet their own needs'*. Since this most popular definition of sustainable development from the Brundtland report (WCED, 1987) is inherently ambiguous, it warranted an investigation of the history and evolution of the terms sustainability, sustainable development and sustainable urbanism. It is explained broadly in the literature review that follows. It would suffice here to say that sustainability is a complex web and even when limited to an urban context, sustainable development has numerous interpretations. However, three key elements are common to most of these adaptations – the social, economic and environmental concerns.

1.2 Finding the Research Gap

The idea of sustainability in the urban world can be discussed at various scales. At the global scale, the looming threat of climate change has prompted governments to take note and popularized the term 'sustainable development' as the way forward. Numerous International conferences (See United Nations conference on the Human Environment (1972), The biosphere conference (1968), Vancouver declaration on human settlements (1976), World Conservation Strategy (1980), Caring for the Earth (1991)) have led to global treaties, targets, and guidelines that are meant to help nations achieve sustainable development and mitigate Climate Change. Some of the key goals of these are related to energy use and emission mitigation, as well as improved quality of life, economic development and social uplift.

At the micro-urban or the building scale, tools have been developed to explore the idea of sustainable living with a focus on energy efficiency (See Standard assessment Procedure (SAP), UK (BRE, 2006); Green Rating for Integrated Habitat Assessment (GRIHA), India (TERI and MNRE); Energy Star Buildings Program, US[1]) and/or alternative energy options reference (See BedZed, UK (Bioregional, 2004); SamSoe, Denmark[2]). Many governments and other agencies have created and implemented policies and regulations and assessment methods to aid energy efficient design (See Leadership in Energy and Environmental Design (LEED), The BRE Environmental Assessment Method (BREEAM) (Rivera, 2009)) and sustainability standards/checklists/tools (See Sustainable Seattle (Various, 1998), Lisbon[3], Curitiba (ICLEI, 2002)) to help designers attain sustainability standards. Work has also been done on master planning new cities (See Masdar, UAE[4]; PlanIt valley, Portugal[5]; Hammarby Sjostad, Sweden[6]) based on sustainability principles with targets of going zero carbon/ reducing energy and water consumption etc.

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[1] www.energystar.gov
[2] SamSoe – A role model in Self Sufficiency, www.dac.uk
[3] Lisboa – Strategic Planning towards urban sustainability www.globalmayorsforum.org
[4] www.masdar.ae
[5] www.living-planit.com/planit_valley
[6] www.hammarbysjostad.se

The local municipal scale too has garnered interest in the recent past, wherein municipal and city governments are now stepping up to explore the idea of sustainability at the local urban scale. The local municipal scale is of much interest because this is where the global and micro-urban scales come together. This is where the socio-economic and environmental interactions occur and where the global policies will find implementation. This scale is comparatively challenging in that there are numerous stakeholders, policies directly affecting a large number of people, and usually there is a change-resisting governance structure.

1.2.1 The Past and the Future

Throughout the history of urban planning, issues that plague urban territories have driven planning and governance (**Figure** 1-1). In the 1950’s, garden cities and new towns evolved as a response to the poor living conditions after the industrial revolution. With advancements in the automobile technology came Le Corbusier and Frank Lloyd Wright’s visions of transport led designs for urban planning (Pinder, 2005).

The 1960’s were based on urban renewal, which though considered a failure, intended to revitalize neighbourhoods. 1970’s were the time for rapid economic development and the beginning of the environmental debate post the energy crisis. 1980’s urban policies focused on environmental impacts and slum up-gradation whilst the 1990’s saw the rise of globalization and consequently adapting cities to be global centres. In the past decades, issues of global warming and climate change and the need for sustainable development have taken the driving seat for urban developmental planning and governance.

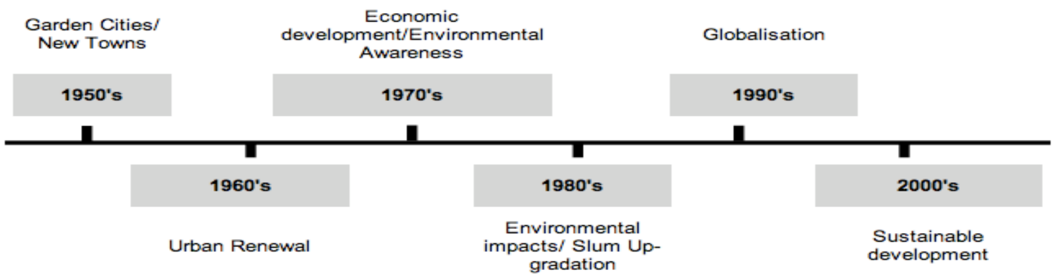

Figure 1-1: Timeline for issues driving urban planning

Although sustainability entails the three pillars of social, economic and environmental facets, the challenge therein is to reconcile socioeconomic development within environmental constraints to mitigate climate change. The underlying forces for climate change need to be addressed in order to facilitate development without endangering the planet. The future of urban planning and management is in addressing the issues of climate change by embracing sustainable development. Controlling climate change means reducing anthropogenic GHG emissions to ensure the temperature rise does not cross the mean 2-4ºC window above the pre-industrial average, 4ºC now being projected as the likely rise by 2060.

The basic research question that can be identified here is ***'How to employ sustainability in cities?'***

In order to reduce anything, it is important to first quantify it. It has already been noted that a number of cities use sustainability indicators to assess their sustainability in terms of the economic, social, and environmental aspects.

1.2.2 Contextualizing the Research Problem

A study of the local issues in relation to sustainability assessment tools in Chapter 2 highlighted problems at the governance level. In the context of developing countries, the practicality of large indicator sets that are resource intensive is questionable.

As a nation India is lacking in a lot of basic infrastructural facilities – but the question is, whether it is addressed as a shortcoming or as an opportunity to learn from the mistakes of our western counterparts. There are two pathways to solve the problems of urban India – one is to blindly jump onto the western bandwagon in a bid to bridge this gap in facilities before tackling the issues of climate change and sustainable development or the other is to employ a more holistic and sustainable approach to achieving these goals. Approaches that are conducive to the environment are ones that ensure social sustainability and are economically viable. What is the potential to innovate and come up with such sustainable solutions to these issues?

1.2.2.1 Opportunities amid Chaos?

57% of the Indian population does not have access to electricity. So is there a need to create more fossil fuel based power plants that provide energy through a network of inefficient grid services or alternative renewable sources of energy are employed and the efficiency of our distribution system improved?

This is not to imply that this is a novel pathway and there are risks and uncertainties involved. There already are numerous examples around the world that use alternative forms of energy successfully and most importantly India has a great potential for renewable energy, whether it's through solar farms across the nation or wind energy from the upper reaches of the Himalayas or from offshore farms in the Indian ocean, whether its tidal energy or geothermal energy. If only efforts are made to try to tap into these bountiful sources, all the nations' energy woes will be gone. And these sources provide an opportunity for a localised system of generation, which reduces the need for cumbersome and inefficient distribution systems in hard to reach areas of the nation.

In the transport sector – India has 10 cars per 1000 people compared to 779/1000 in US. Now, this figure can be taken as an indicator of how underdeveloped the nation India is as compared to the USA. But on the brighter side, there is an enormous potential to improve public transport systems such that the need for private vehicles does not arise. There is potential to promote hybrid and clean energy vehicles which protect our depleting resources and our environment.

Policies that target expansions and improvements in various sustainable forms of public transport, like the CNG bus systems in some cities and the metro rail systems, need to be explored and promoted. Government policies may be focused toward promoting hybrid, clean energy vehicles. A few steps in this direction are ongoing as part of the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) transport planning projects in cities across the nation.

Considering energy consumption, India uses 0.5 tons oil equivalent per capita. Compared to the US 8 tons this figure is very small. But it is also an accepted fact that with rise in economic and lifestyle development, the energy consumption is bound to rise. Although it may not be possible to go lower than the current consumption, policies may be targeted to maintain or limit the growth in consumption.

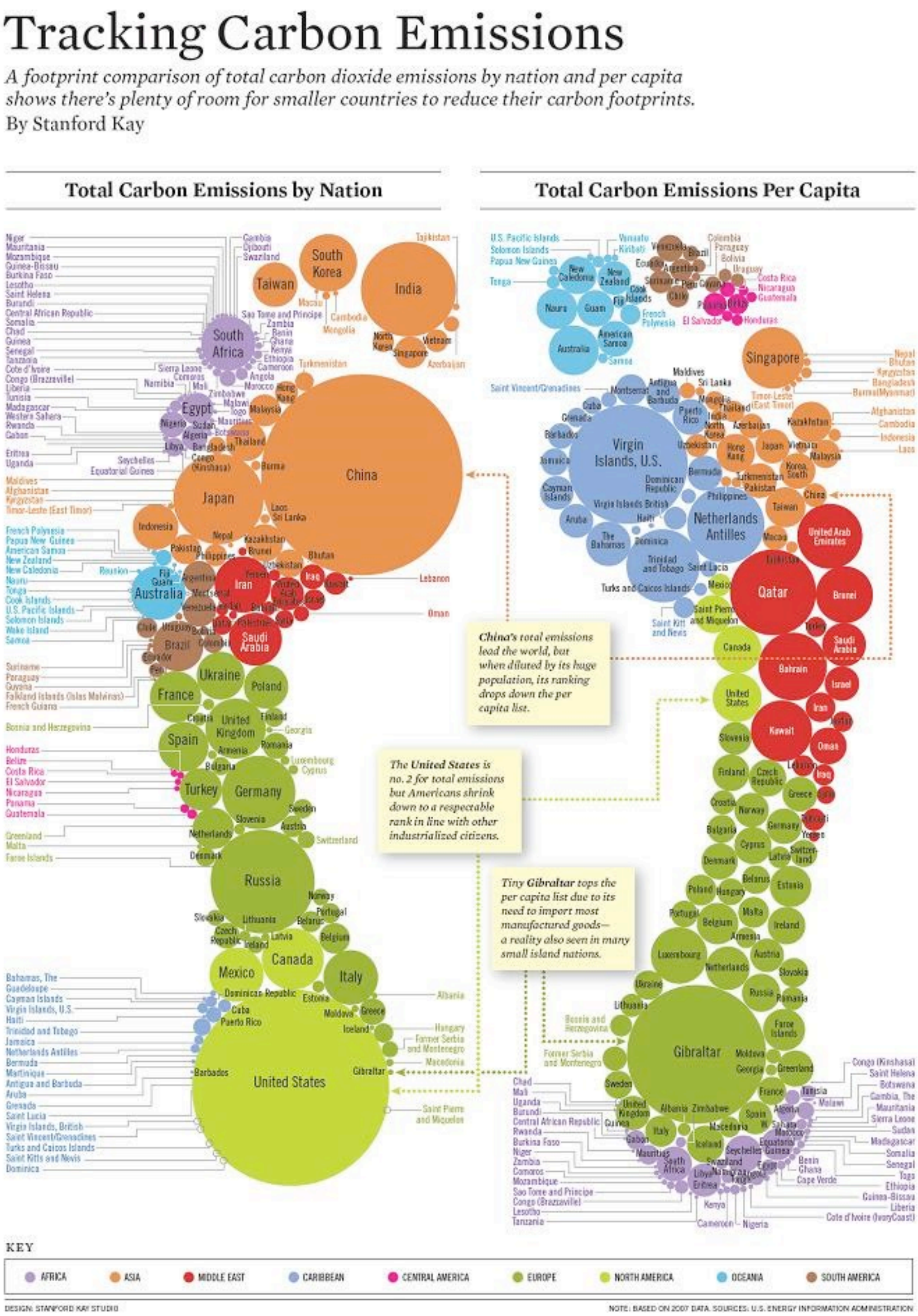

Figure 1-2: Total CO2 emissions by Nations and CO2 emissions per capita by Nations. (Source: Urbandesignplanning.blog)

Energy efficiency both in buildings and products should be promoted. The energy rating for products and the energy code for buildings should be strictly implemented. Certification of buildings should be incentivised to encourage adoption of Leadership in Energy & Environmental Design (LEED) or Green Rating for Integrated Habitat Assessment (GRIHA) energy reduction measure.

Overall India is the 5th largest GHG emitter and contributes 5.6% of world GHG emissions. The above-mentioned scenarios in the various sectors will contribute in reducing the carbon emissions from the country. Even though India is one of the largest emitters of GHG, its large population leads to one of the lowest per capita emissions in the world (**Figure** 1-2).

Only 33% of the Indian population has access to sanitation, 86% has access to safe water but not comparable to average international standards. One of the key requirements for a sustainable development is the provision of basic amenities. The use of service level benchmarking for assessing the level and quality of services in urban and rural areas must be promoted.

This list of opportunities among the chaos that is urban India highlights the potential of assimilating innovative sustainable pathways in urban India. However, the practicalities of such a phase change in development pathways cannot be ignored. For Local Governments that have poverty and infrastructure deficiency at the top of their priority, spending the minimal resources they have on an intensive sustainability assessment profiling may be too farfetched even though it may be beneficial.

The Research question can be thus framed as follows-

'How to incorporate Sustainability assessment as a policy tool at Local Authority level in Developing Countries?'

The impacts of climate change are indisputable and for cities in developing nations there is an immediate need to address the problems of energy use and resulting emissions in cities. If the issue of global warming and its impact are regarded as a priority for restricting the temperature rise to the 2ºC mark and the need to drive sustainability is considered central to the development of urban regions in developing nation, a case can be made for the use of GHG inventory as a driving indicator for sustainability assessment in cities.

India being currently plagued with problems of infrastructure and housing shortages is fixated with quantity. The targets are to fill the demand and supply gap with no consideration to the quality or the impact of the developments. There is thus, a need to look at ways to fulfil the demand sustainably with low CO2 impact. The use of GHG inventories is called for to measure the current emission scenario and make policies to mitigate it and monitor the implementation results.

An alternative argument for the need to quantify emissions especially for developing urban regions has to do with energy use and lifestyle. Research (Diamond, 2003, Korjenic and Bednar, 2011, Reusswig et al., 2004, Wei et al., 2007) has shown that people from the lower socio-economic strata use less energy, and as the socioeconomic status improves, lifestyles change, there is more consumption of energy and goods and thus more emission. The challenge for a developing nation is to improve the socio-economic status of the population but contain the carbon emissions associated with the lifestyle change. The need for case studies (Xi et al., 2011) at city level has also been identified in order to fill the gap between research at national/global level and that at equipment/product level (Weisz and Steinberger, 2010) and to identify a common method and policies specific to local reality considering the fact the local municipal level varies considerably around the world in terms of structure, requirements, size, governance and so on. The final research question can be framed as –

' How to use GHG inventory as a Policy tool in Indian Cities within existing data and governance scenario?'

1.3 The Aim and Objectives

The Aim of this thesis is to investigate the process of CO2 inventorying at the city/municipal scale and its applications to identify the opportunities and barriers of using it as a policy tool in mid size Tier III Indian (<1 million population) cities.

1. Through a literature survey, establish the need for introducing sustainability at the local urban scale in developing nations and
2. Through a literature study, identify viable tools to introduce and assess sustainability within the existing local context in Urban India
3. Use the literature survey and a study of the local Indian context to develop a model to inventory carbon emissions from Indian cities with existing data sources.
4. Through a Case study Research,
    a. To document the process of conducting a GHG inventory for a mid size city in the Indian context, to understand the governance structure and its implications on the data collection process and policy making for cities
    b. To identify data gaps and alternative calculation methods with available data and highlight issues with data quality
    c. To benchmark and analyse the results of the inventory and identify the driving factors for urban GHG emissions in Indian cities
    d. To explore policy options that use the GHG results to spearhead sustainability in the Indian cities

1.4 Research Process

The basic premise of the research method is to employ the scientific enquiry process as shown in **Figure** 1-3. The five steps are identifying the problem, reviewing the associated literature, designing the methodological framework and using it for analysing the data collected and finally offering concluding remarks to the study.

As the study progresses, this basic framework has evolved into the final research framework presented in **Figure** 1-4. An Empirical Case Study Research is identified as the main methodology for the study. The challenges highlighted from the review of GHG inventory tools in Chapter 2 helped form a framework for the method that follows a four-fold approach – Data Collection and Process, Inventory and Results, Analysis and Application.

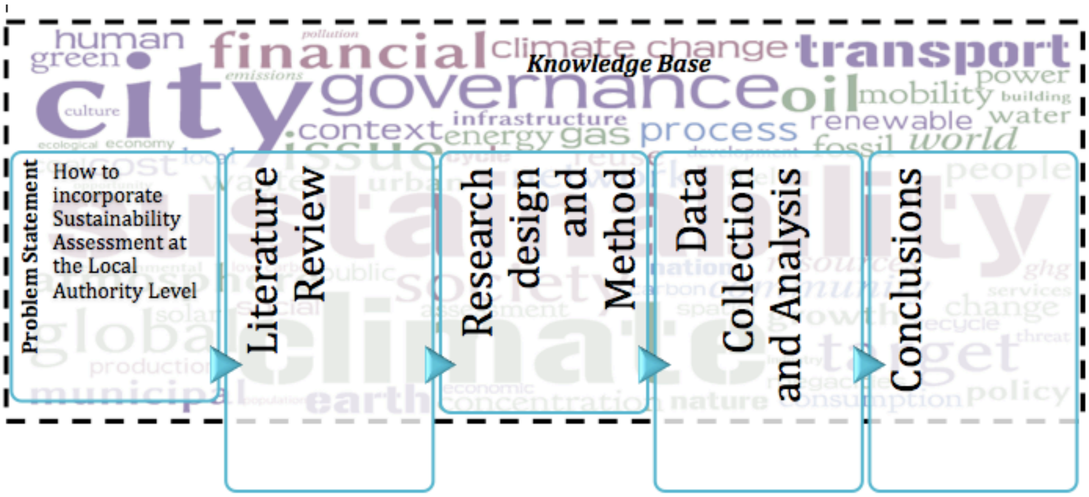

Figure 1-3: Research Process

The four stages form the main body of the study as the four core chapters. Since the methodology is based on the IPCC methodology for National inventories, a number of adaptations are required to fit it to the local context depending on the local issues and requirements out of an inventory and the data availability.

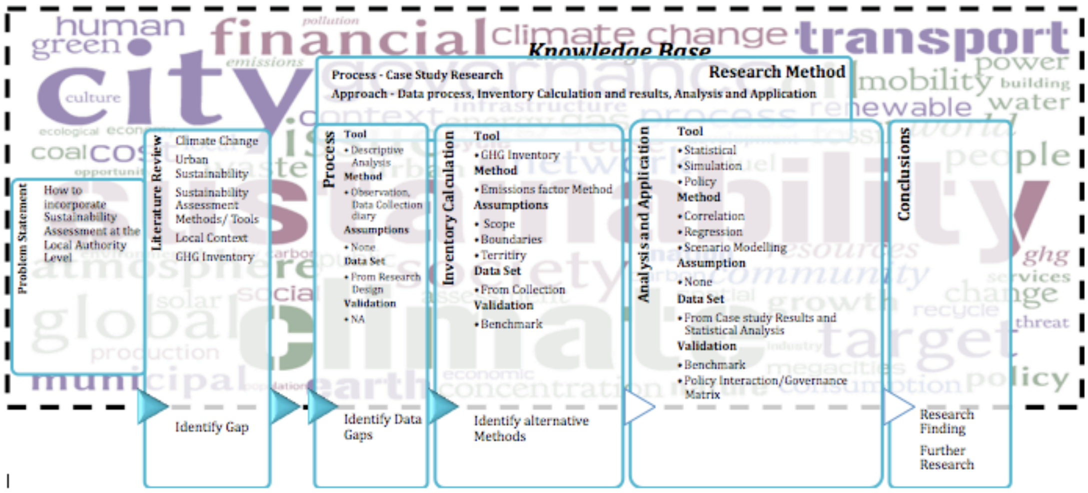

Figure 1-4: Final Research Framework

The case study helps identify the study gap and methodological issues, the process stage allowed for finding the data gaps in the local context, the inventory calculation stage was used to explore alternative methods of calculations based on the literature survey and Analysis and applications stage is used to reinterpret the results from an academic perspective and also propose policy pathways for the local government.

An iterative process of identifying data need from literature survey, checking its availability from data collection process, collecting the data, applying it to calculation or going back to the literature to find alternative data and method has been employed to contextualize the inventory to the local scenario and use currently available data for the study.

This is in consensus with the aim of the thesis to use available data to minimize the local authorities' resource needs for collection of specific data.

1.5 Thesis Structure

The thesis structure is as follows –

Chapter 1 – The main purpose of this chapter was to answer the question why? The Chapter aimed at setting the background for the research and identifying the research problem and following its evolution to the research question and the aims and objectives of the research.

Chapter 2 – Climate Change and Sustainable Development is about what? What is the scientific background, theoretical construct to the research? The Chapter introduces the global issues of Climate Change and its Impacts related to the study. The ideas of sustainability and its assessment methods have been explored in detail with a review of urban sustainability assessment tools. This Chapter helped frame the research problem and identify a research gap.

Chapter 3 – City Metabolism and GHG Inventory further explores the contextual and methodological basis of the study. An exploration to understand the role of cities in this global setting of issues and opportunities and a more comprehensive picture of the local governance structure in India is presented. Drawing the final research aim from this rigorous study, the methodological options of the study are examined. A comparative analysis of internationally used tools and methods for GHG inventories at the local urban scale provides a good methodological overview for the study highlighting the challenges.

Chapter 4– Methodology picks up from the previous chapter and answers how? The methodology clarifies what is meant by a case study research. Its main element is to describe how to execute a GHG Inventory? Starting from the process of data collection, the calculation of the inventory and benchmarking of the results and the analysis of the results and policy implication study are detailed as part of the research design of the thesis. All assumptions and methods to deal with any process issues are also identified.

Chapter 5 – Process goes back to the how? Using Dehradun city as a test case, it aims to highlight the process of carrying out a GHG inventory. The city is introduced, its location, climate, demographics, socioeconomic situation presented. The proposed framework is applied to the city, with a detailed account of the process to highlight the problems encountered in the data collection process and to bring forth the data unavailability issue. Where recommended data is unavailable, alternative methods are explored in the next chapter to help estimate the GHG emission.

In Chapter 6 – Inventory Calculation and Results, the question is what? What are the results of the inventory for the case study city? What is the method of calculation and what are the overall and sectoral results? How does the city's GHG profile compare to global and local benchmarks? Comparisons made with available data from other cities help to validate the model.

Chapter 7 – Analysis aims to answer why? It presents consolidated results for the city and a sectoral analysis of the results and attempts to find the drivers of GHG emissions in Indian cities.

Chapter 8 - Applications is about using the information from the inventory calculation and analysis to simulate policy scenarios. Policy pathways are identified and deliberated on their applicability to the context.

Chapter 9 concludes the thesis, highlighting the results and presenting notes for further research. Overall recommendation for streamlining the process of inventorying emissions is presented.

Chapter 2 Climate Change and Sustainable Development

To comprehend the background and identify and refine the aim of this research, four study areas were identified to form part of the literature study – The Scientific background, The Theoretical construct, The Contextual review and The Methodological basis. This first of the two literature review chapters deals with the global context of climate change and its associated impacts to give a scientific background to the study, strengthening its validity and the theoretical construct of sustainable development provides a deeper understanding of the challenges and helps define the research problem.

As part of the literature study, the role of cities in climate change and inversely its impact on the cities is studied with a focus on the Indian context. This is followed by an exploration into what sustainability means for the urban context and how it can be used to inform policy on city development and management with the use of indicators. A comparative review of several indicator systems in use in cities provides an understanding of how such systems can be used as policy tools and how they relate to each other. This chapter ends with a conclusion of the main findings of the reviews undertaken and the inferences drawn in the context of this research.

2.1 The Threats of climate change and energy shortage

Climate Change has been the focus of most national and international discourses in the recent past. In the context of this thesis, it is important to fully comprehend the idea of climate change. The role cities play in this and its impact on cities must be studied in order to recognise the threats and assist local governments devise measures for checking it or adapting to the changes.

Climate on earth has always been in a state of flux. Over centuries, there have been warm periods with little or no ice and then periods of widespread ice with differences of about 10˚C in the mean earth temperature(Dash, 2007). These changes have been attributed to many causes including changes in the solar radiation and earth's orbit, volcanic eruptions, continental drift etc. So, to consider climate change a new phenomenon would be inaccurate. What is new is the current anthropogenic cause of climate change .

One of the key reasons for climate change is the variation in the concentration of carbon dioxide in the atmosphere. And over the last few decades, the cause of this variation has been mainly anthropogenic. The use of fossil fuels has seen an exponential growth rate, and CO_2 being a by-product of burning these, has soared in levels over the last decades. In the 18th century, CO_2 concentration was 280 ppm; by 2000, it had reached 368 ppm mainly as a result of burning fossil fuels and deforestation (Dash, 2007).

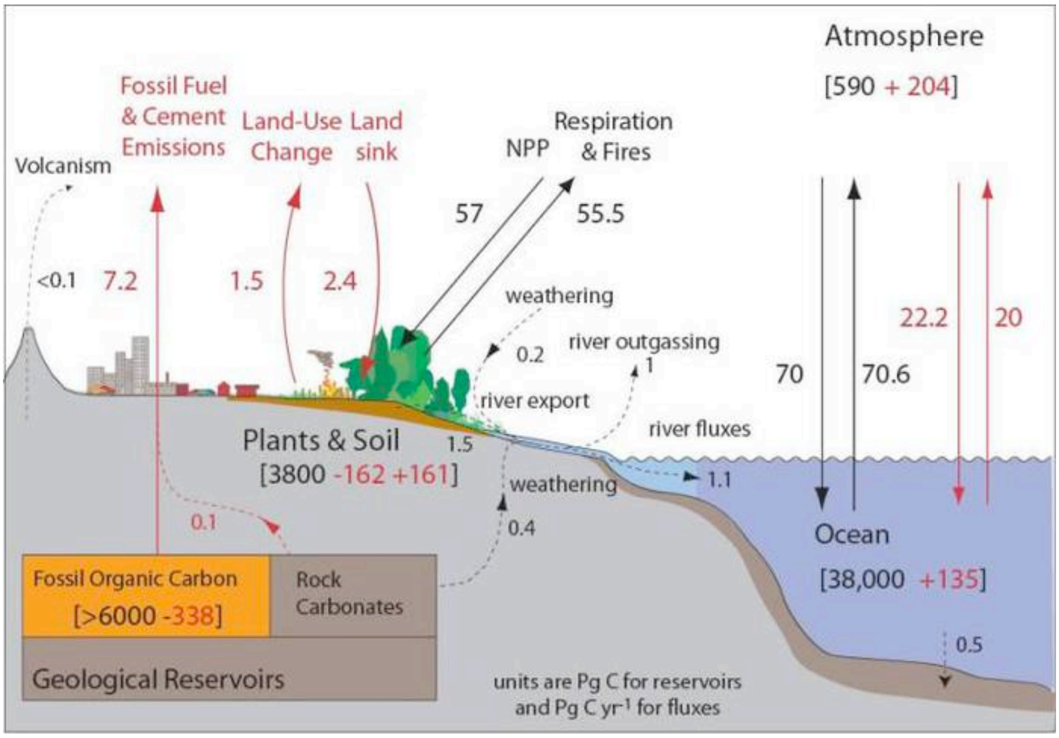

Figure 2-1: The Carbon Cycle Source - pmel.noaa.gov

An exploration of the carbon cycle helps understand the way changes in CO_2 concentration contribute to changes in climate. Carbon is the 15th most abundant element in the Earth's crust, and the fourth most abundant element in the universe by mass. Carbon is the constituent element of all life form on earth; it is also the reason life evolved on earth because its compounds made the planet warm enough. The carbon cycle is the circulation of carbon through the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of the Earth by biogeochemical process. This natural cycle of carbon has been skewed in the past decades by the extraction and burning of fossil fuels at an ever-increasing rate.

In **Figure** 2-1 the black arrows indicate natural CO_2 exchanges. The red arrows and numbers indicate additional exchanges and storage of carbon resulting from human activity. The exchanges are in petagrams of carbon per year (PgC yr-1) for the time period between 2000 and 2005(shown with numbers in brackets). Globally, the biological part of the cycle is the shortest. The atmosphere, surface layers of oceans and plants each contains between 500-700 billion tons of carbon, animal life contains a comparatively small amount of 1-2 billion tons. The geochemical part of the cycle comprising deep ocean water (36000 billion tons) and rocks (75 million billion tons) and soil (1500 billion tons) stores the carbon for millions of years and is only exchanged through volcanic eruptions, rock weathering or now extraction of fossil fuels.

Human intervention in the carbon cycle by means of fossil fuel burning and deforestation has radically increased the rate of release of CO_2 to the atmosphere tipping the carbon balance. This 'perturbed' carbon cycle as defined by the IPCC report is a result of human intervention. As per the Bern carbon cycle model, it will take 30 years to remove 50% of the increased CO_2 in the atmosphere, a few centuries for another 30%, while 20% of the increased amount may remain in the atmosphere for many thousands of years (Denman et al., 2007)

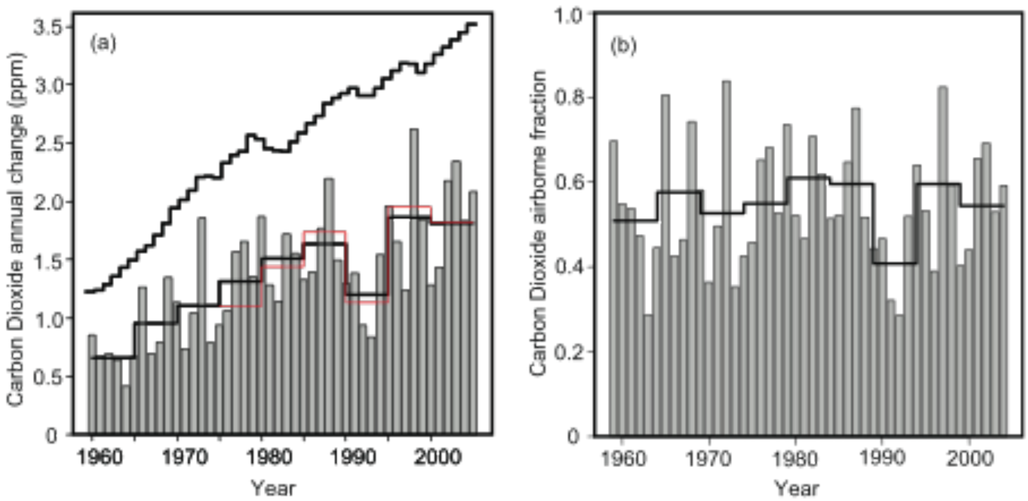

Figure 2-2: CO2 Concentration historical timeline Source - Denman et al., 2007

Figure 2-2 (a) shows the changes in global atmospheric CO2 concentration annually and as five year mean (black and red line) from two sources. The upper black line shows the concentration if all the fossil fuel emissions were to stay in the atmosphere. **Figure** 2-2 (b) gives the fraction of fossil fuel emissions remaining in the atmosphere as annual and five-year mean (Denman et al., 2007)

The increased concentration of CO_2 in the atmosphere influences the earth's climate through the greenhouse effect. The greenhouse effect is the atmospheric process that helps maintain the earth's temperature so that it is suitable for life.

2.1.1 Global Energy Balance and the greenhouse effect

Solar radiation comprises the whole electromagnetic spectrum with cosmic particles, x-rays, ultra violet radiation, visible light, infrared radiation, microwaves, radio waves and acoustic waves.

The amount of energy reaching the top of Earth's atmosphere each second on a surface area of one square meter facing the Sun during daytime is about 1,370 Watts, and the amount of energy per square meter per second averaged over the entire planet is one-quarter of this. Of the total 342 Wm-2 of incoming solar radiation [Figure 2-3], the earth absorbs 50% after the shortwave radiation passes through the atmosphere; the rest is absorbed, reflected (36%) or reradiated by the atmosphere. The radiation absorbed by earth is reradiated as long wave radiation back to the atmosphere. The constituent gases of the atmosphere that let visible light radiation pass absorb the long wave radiation from the earth's surface, thus warming the atmosphere. Each gas absorbs a certain band of wavelength.

Nitrogen and oxygen, which constitute almost 98% of the atmosphere by volume, have absorption bands only in the ultraviolet band. Most of the shortwave ultraviolet radiation is absorbed by the ozone layer and atomic and molecular oxygen and nitrogen in the upper reaches of the atmosphere. The long wave infrared radiation is absorbed by CO_2 and water vapour along with other trace gases in the atmosphere; this is termed as the greenhouse effect.

Despite its low concentration water vapour absorbs six times the solar energy compared to all other gases combined as well as almost all of the terrestrial radiation in the band of 1-6.5μm and at 18μm and longer. CO_2 absorbs radiation in the wavelengths 2.7-4.2μm and 14μm and higher. CO_2, water vapor and other GHG trace gases thus trap most of the long wave radiation increasing the atmospheric temperature.

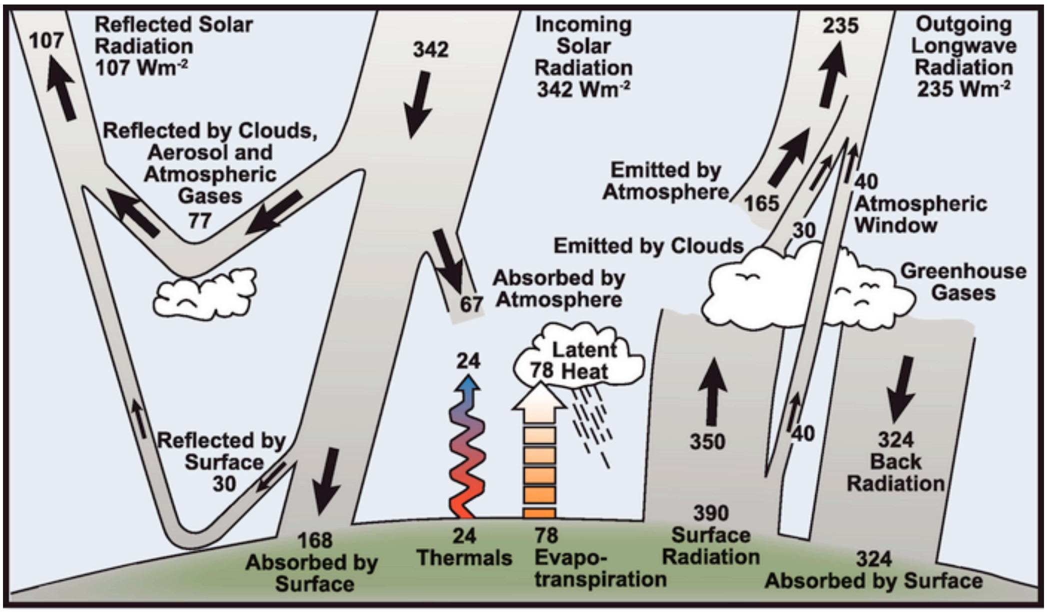

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Figure 2-3: Global Energy Balance; Source: ipcc.ch; Kiehl and Trenberth (1997)

There is scientific consensus that there has been a significant increase in the concentration of these gases in the atmosphere as a result of anthropogenic activity in the past few decades. It is also conclusive that the skewed carbon cycle is impacting our atmosphere by enhancing the greenhouse effect and effectively raising the mean atmospheric temperature, which will have far reaching effects. In the past century itself the global mean temperature has risen by 0.8º C with a projection of up to 6º C rise in the next century (EPA, 2012).

The relationship between the increasing concentration of CO2 in the atmosphere and the global mean temperature increase from 1800 to 2005 can be seen in **Figure** 2-4. Even accounting for the uncertainty, the relationship between the CO2 concentration in the atmosphere and the global temperature rise is self-evident. The rapid increase from the 1850-1900 baseline can be correlated to the continual increase in fossil fuel use around the world after the industrial revolution of 1750-1850.

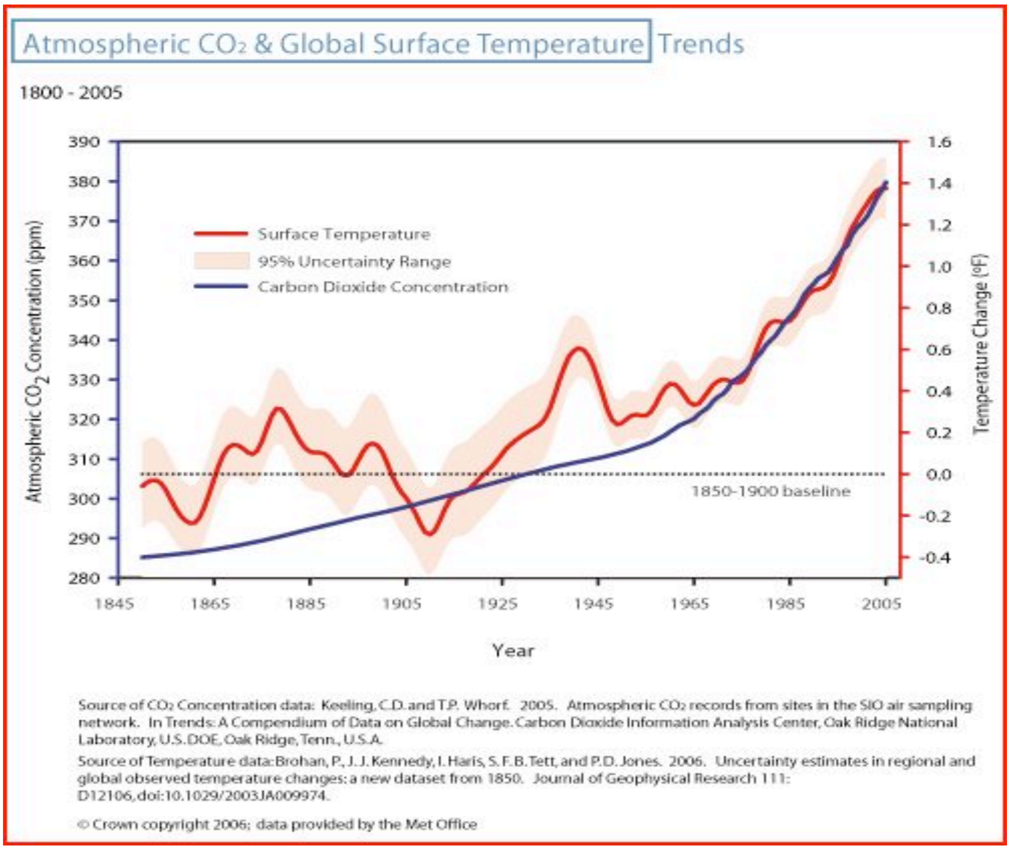


Figure 2-4: CO2 Concentration and Global Temperature historic timeline; Source: tusconcitizen.com

Overall, the effects of this global warming would translate as extreme weather events, reduction in polar and glacial ice and consequent rise in sea level, changes in precipitation pattern, species extinction and changes in crop productivity(Dash, 2007, Sunita Narain et al., 2009, Parikh and Parikh, 2002). All these events pose a threat to human species in one way or the other. While the rising sea level threatens many coastal and island settlements, a change in agriculture productivity threatens food security, extreme weather like droughts or cyclones also threaten lives. The extent and effects of this climate change will vary from region to region.

2.1.2 Global and Local contribution to Climate Change

The anthropogenic basis of climate change is widely accepted. To understand the anthropogenic contributions to GHG emissions from the world and from India is a key section in this study. **Figure** 2-5 shows the share of world GHG emissions by sectors and by gases. Energy is by far the biggest source of anthropogenic emissions accounting for 66.5% of all sectors. By the type of gas, it is evident that

CO2 has the largest contribution at 77% but the other gases have more global warming potential that must be considered.

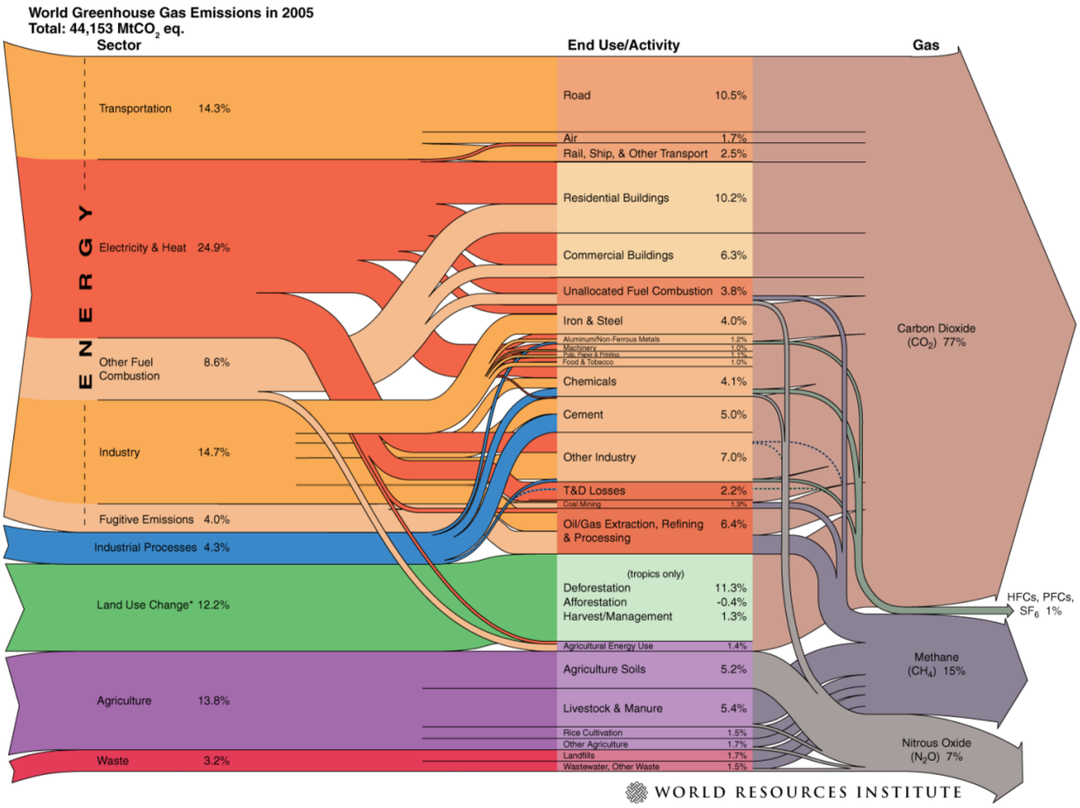


Figure 2-5: World GHG Emissions Flowchart; Source: World Resources Institute

The historic and projected share of different world regions as sources of CO2 emitters is shown in **Figure** 2-6. Where the developing nations historically accounted for lower emissions, their share of the total world emissions is on a rise with a rise in the total emissions. In 2008, the top carbon dioxide (CO_2) emitters were China, the United States, the European Union, India, the Russian Federation, Japan, and Canada (EPA, 2012).

Total global emissions grew 12.7% between 2000 and 2005; Mid-range projections from WRI suggest that, in the absence of policy actions, GHG emissions will increase by another 57 percent by 2025 compared to 2004 levels, with emissions in developing countries growing the fastest (Baumert et al., 2005).

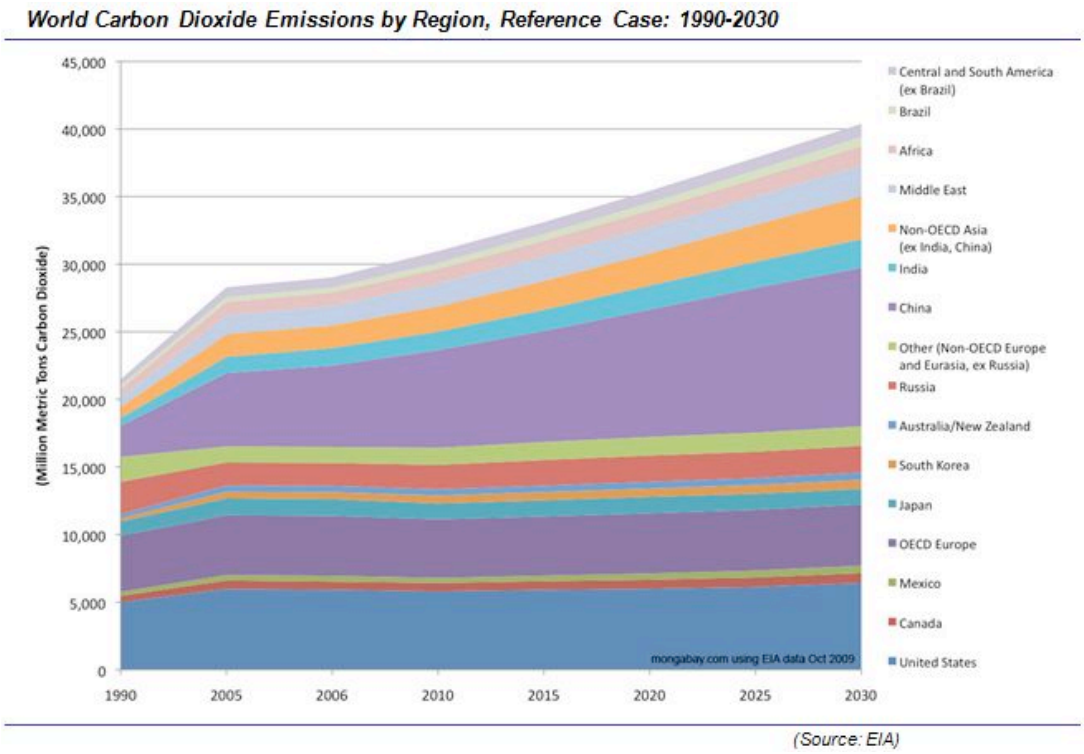


Figure 2-6: Share of world CO2 emissions by Region; Source: mongabay.com, EIA data

India's contribution to this rise in GHG concentration has been on a rise since 1950's, as shown in **Figure** 2-7. The rate of increase in carbon emissions from the country is very high; from the 1990's to 2009 emissions have almost tripled(IEA, 2011).

According to 2008 (Boden et al., 2011)estimates, India ranks third highest in the top GHG emitting nations accounting for 5.78% of the total emission. In 2010 (Olivier et al., 2011), the per capita emissions from India were estimated at 1.5 tonnes CO_2. It can be argued that compared to the 16.9 tonnes CO_2 per capita emissions from the US, India's per capita emissions are relatively low. Yet, this should not induce a false sense of security, as India will be one of the worst affected nations by a rise in global temperature. Thus, any proactive contributions by India to reduce the GHG emissions are highly relevant.

Although India's stand in world forums has always been to stress on the developed nations being held responsible for the increased levels of GHG, and giving developing countries flexibility to maintain the economic growth that being fuelled by fossil energy is the main source of rising GHG. Yet, considering India rapid population and economic growth and its rising position on the top

GHG contributing nations of the world, its accountability towards reducing emissions cannot be overlooked.

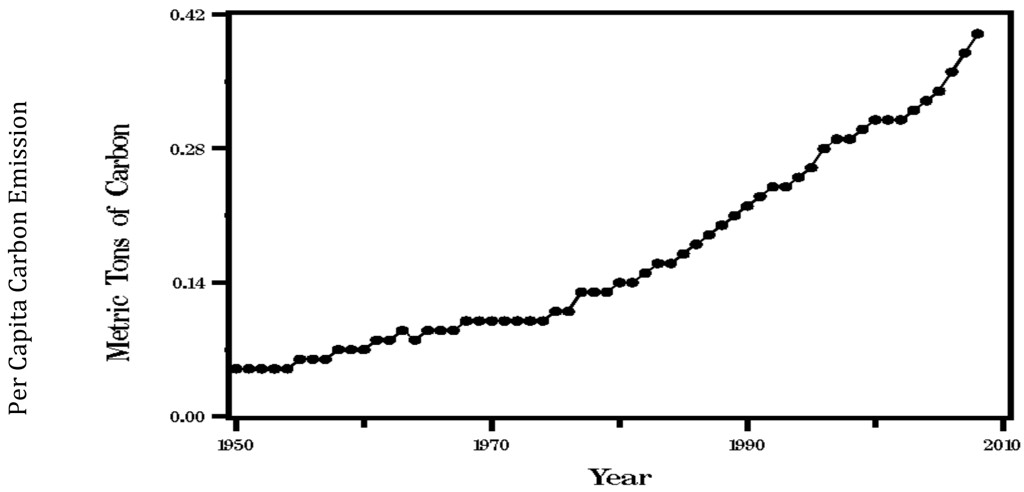


Figure 2-7: Per Capita Carbon emission from India 1950-2010; Source: CDIAC

The good news for emissions scenarios in India is, according to WRI(CAIT, 2011), the projected growth in the CO2 emissions from different countries has a lot of uncertainty [**Figure** 2-8]. And this uncertainty in emissions scenario between the high estimate and low estimate is the highest in India implying that there is a real opportunity to constrain the GHG emissions from the country to a really low level.

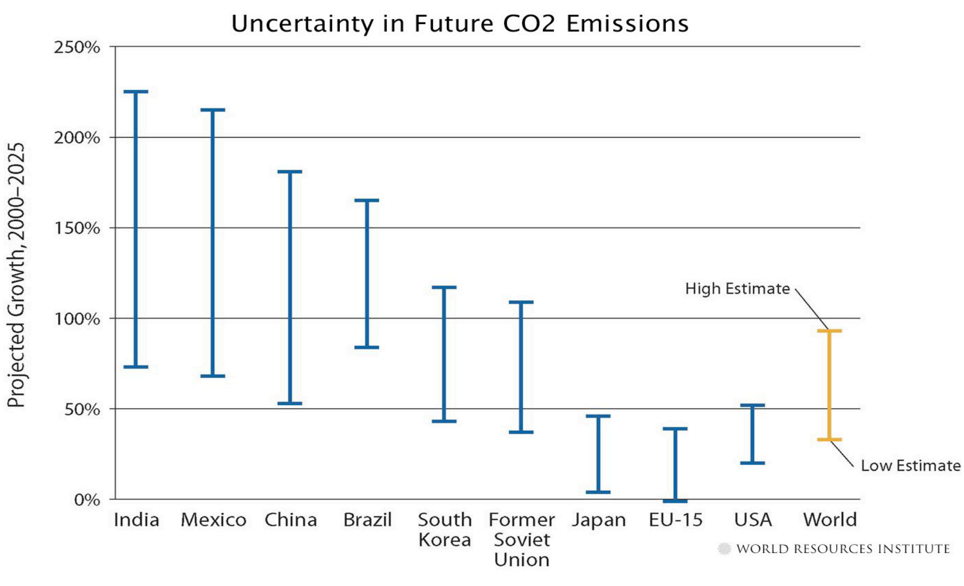


Figure 2-8: Uncertainty in emissions projection; Source: WRI

The 152% point difference in the emissions scenario for India is the highest among all countries.

2.1.3 Cities and Climate Change

What is the role of cities in climate change? Cities are the platform for all human interactions. It is in cities that most of the world's produce is consumed, in cities that most of the economic growth is concentrated, in cities that most of the world population now resides. So, it is also in cities that most energy use occurs. Although, cities do account for the most energy use in the world, from a production perspective they may not be the emitters since the energy is produced elsewhere. But from a consumption perspective, where for equity, the emissions are allocated to the consumer; cities become the major drivers of emissions. Emission from cities comes in the form of direct and indirect sources. Direct sources include fuel use especially in transport and industries or for heating and cooling buildings, whereas, indirect sources mainly account for the electricity use in buildings (of which just residential and commercial account for 16.5 % of the world's total energy use) and the energy used for goods consumed in the city.

As well as being the drivers of emissions in the world, cities will also have to face the effects of climate change. They will need to mitigate and adapt to the global impacts of climate change and protect their ever-growing population.

2.1.3.1 Energy Use and Emissions from Cities

50% of the world's population now lives in cities but they account for 71% of its GHG emissions. By 2050, the world's urban population has been predicted to reach 6 billion and will predictively account for 76% of GHG emissions (Ranade et al., 2010). To sustain their population and provide it with the basic infrastructure and services, cities expend a lot of energy, thus, accounting for major GHG/CO2 emissions. Urbanization has been positively correlated with the rise in emissions. Whereas, in the past the highest urbanization occurred in European and American regions, the trend has now shifted to Asia. Where in developed countries the per capita energy use in cities is close to the national average (IEA, 2008); in developing countries cities are much more energy intensive than the national average. This can be attributed to energy poverty in the rural region in these countries.

India is one of the fastest developing economies in the world. This rapidly growing economy is fuelled by increase in energy consumption in various sectors as the industry and infrastructure in the country develops. This development is characterized by high rates of urbanization as the rural population migrates to cities and towns for better opportunities and a better lifestyle. Often better lifestyle can be translated to mean more energy use as larger parts of the population have access to electricity, clean water and good sanitation facilities.

Moreover, with increase in income people are able to afford more cars, and other amenities like air conditioners that contribute to yet more energy use. In this cycle of development [**Figure** 2-9], energy consumption and the resulting carbon emissions are always on a rise. As defined in 'Managing Asian Cities', these rapidly developing cities have become a victim to their own success (ADB, 2008). There are myriad problems to deal with for managing such cities that includes pollution, infrastructure deficiency, poverty and living conditions etc.

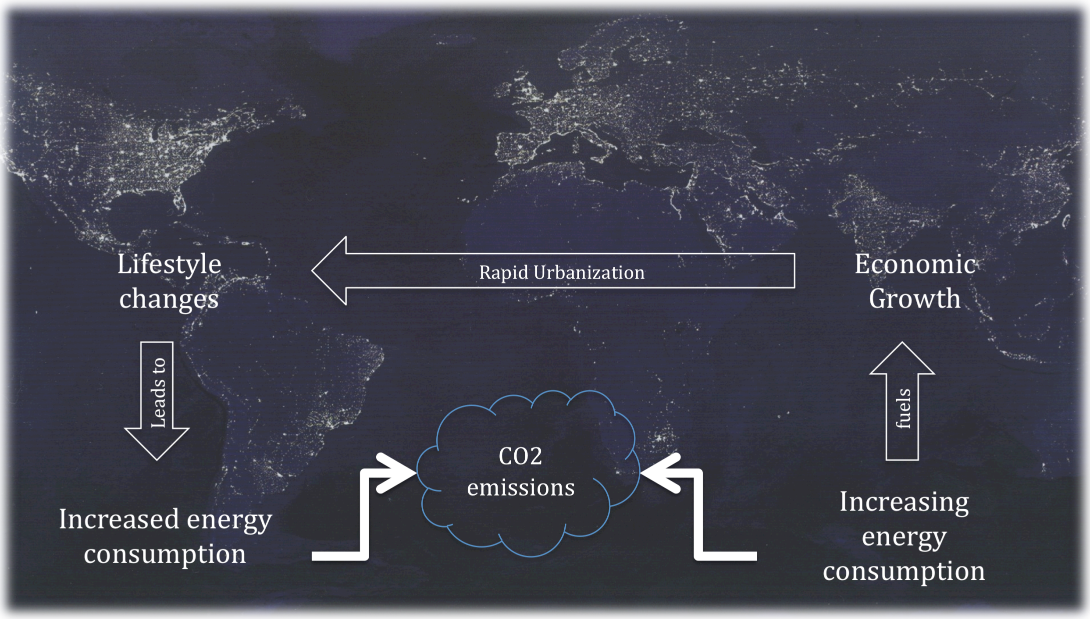


Figure 2-9: Relationship between economic growth, urban development and energy consumption; Source: Author

There are growing concerns on the quality of urban life, energy sustainability, slum growth, infrastructure deficiency etc. In the words of urban experts(Westcott, 2006) we will witness an 'urban nightmare in the next 50 yrs', the 'migration-without-absorption' leading to a 'planet of slums' and growing problems of 'energy sustainability'.

The relationship between improved lifestyle and per capita energy use can be gleaned from **Figure** 2-10 comparing the Human Development Index (HDI) and per capita energy consumption. There is a direct positive correlation between the two, meaning that an improvement in lifestyle will also translate as higher energy use per capita. 'No country in history has improved its level of human development without corresponding increase in per capita use of energy '(Sunita Narain et al., 2009). But it can also be inferred from **Figure** 2-10 that a high degree of HDI can be achieved with comparatively low increments in the per capita energy use. By 2015, 358 cities in the world will have a population of over 1 million of which 153 will be in Asia (Dhakal, 2004) and by 2030 India alone will have 68 cities with more than a million population, 13 cities with more than 4 million and 6 megacities with more than 10 million (Sankhe et al., 2010).

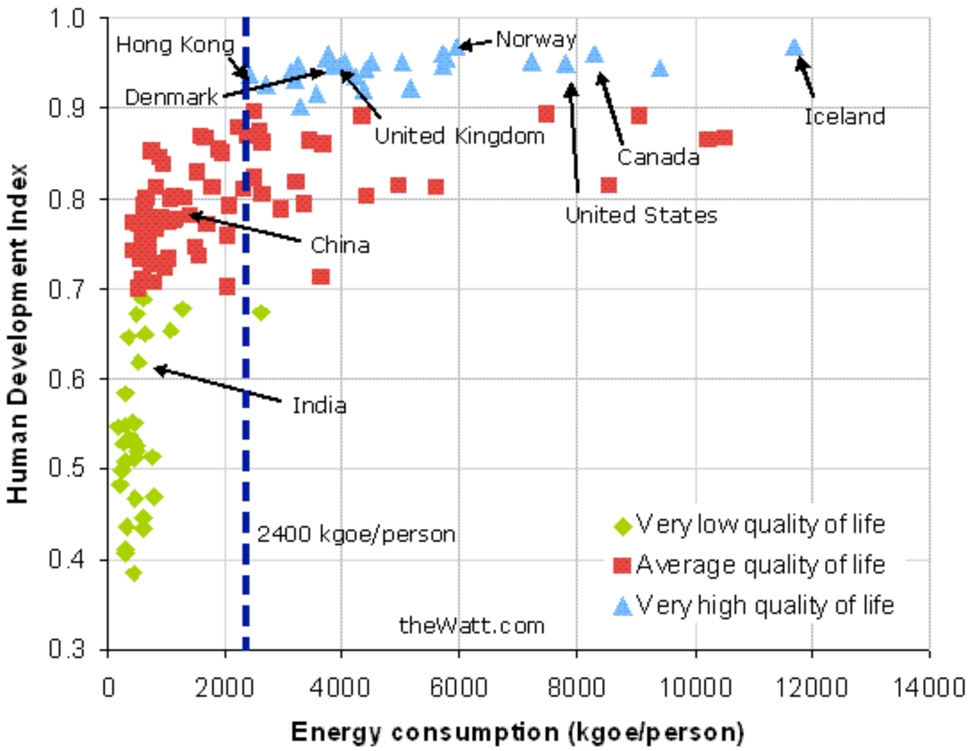


Figure 2-10: HDI Vs. Per Capita Energy Use; Source: UNDP Data

The challenge of sustaining the rapid growth of these cities and ensuring a high quality of life with infrastructure availability and poverty alleviation is the challenge that is faced by these growing cities in Asia. As per the World Bank, nine out of 10 of the world's most polluted cities are located in Asia.

Considering, the past experience of the local governments in providing infrastructure and managing poverty in Asian megacities, the future looks dismal. The only hope is for the local governments to change the way they manage the cities and introduce innovative sustainable methods.

In terms of energy consumption, one of the main targets for these cities will be to provide energy security, reduce or limit per capita energy demand as well as reduce related emissions; while maintaining economic growth and quality of life. To do that, there is a need to understand the major drivers of energy use in cities.

Shobhakar Dhakal (Dhakal, 2008a) summarizes some of the major drivers of energy use and emissions in cities, which have been further discussed in the Analysis Chapter.

1. Urban demography
2. Economic development
3. Infrastructure and Technology
4. Urban Form and Function
5. Behavioural and Societal factors
6. Globalization
7. Institutional and political factors
8. Natural Factors

An understanding of how these factors relate to energy use is imperative to decouple the energy dependence of development. Similarly, it is important to understand the threats from Climate Change. Just as cities with their energy use impact Climate Change, in the future, they will be victims of the threats posed by Climate Change.

2.1.3.2 Impact of Climate Change in Urban India

In India the effects of climate change will be far-reaching. India's long coastline will be affected by the rise in sea level. The melting of Himalayan glaciers might lead to devastating effects by volumetric changes in the river flows. The increased volatility of the climate has already been felt in the Indian subcontinent in the last decade.

IPCC(Cruz et al., 2007) figures projected the mean annual increase in temperature by the end of the century in South Asia as 3.3 °C with the min-max range of 2.7 and 4.7°C. Ongoing sea level rises have already submerged several low-lying islands in the Sundarbans, displacing thousands of people. As per the Indira Gandhi Institute of Development Research, the changes could mean a decline in India's GDP by as much as 9%.

India being a primarily agriculture economy, the climate change effects on agriculture can be disastrous for the livelihood of the poor. Research has predicted that there will be a lowering of agricultural production. Quoting (Parikh and Parikh, 2002) – 'Considering a range of equilibrium climate change scenarios which project a temperature rise of 2.5^{o}C to 4.9^{o}C for India, Kumar and Parikh (2001a) estimated that: (a) without considering the carbon dioxide fertilization effects, yield losses for rice and wheat vary between 32 and 40%, and 41 and 52%, respectively; (b) GDP would drop by between 1.8 to 3.4%. Their study also showed that even with carbon fertilization effects, losses would be in the same direction but somewhat smaller.' The IPCC also projects a possible decline of productivity by as much as 30% in South Asia(Cruz et al., 2007).

In this context of challenges facing the urban world, there is a need to employ a proactive approach to solving the problems that have been created, more so in the developing nations. According to the state of the world population report, most of this growth (93%) will be concentrated in developing regions in Asia and Africa. Thoraya Ahmed Obaid commented on the state of the world report 2007, calling attention to the need for far-sighted action to exploit urbanization (World-Bank, 2007).

Since the growth is inevitable, Obaid says, governments must develop timely policies that turn potential crises into opportunities.

"*If they wait, it will be too late*," she says. "*This wave of urbanization is without precedent. The changes are too large and too fast to allow planners and policymakers simply to react: In Africa and Asia, the number of people living in cities increases by approximately 1 million, on average, each week. Leaders need to be proactive and take far-sighted action to fully exploit the opportunities that urbanization offers*."

While the gravity of the problem and the need for action is unambiguous and reiterated in every discourse related to the urban world, there is no consensus yet on the approach to tackle the same. There are a lot of emerging theories that deal with the aforementioned urban crisis. Globally and locally, there is a consistent call for sustainable urban development.

2.2 Sustainable Development: The Theoretical Construct

What is Sustainable Development? This is probably the most iterated and the most perplexing question of modern times. There have been numerous attempts to explicate the universally accepted definition by the Brundtland commission – "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*" (WCED, 1987)

Being ambiguous in its explanation of 'needs', the definition is prone to many interpretations. This can be both good and bad for the case of sustainability. By being non-specific, the definition allows the flexibility for the concept of sustainable development to be adapted to many fields and issues. The said ambiguity of the concept is also one of its major strengths allowing it to be universally accepted as a positive and optimistic step in an increasingly pessimistic world (Holden et al., 2008). But with this flexibility, it also brings the danger of being manipulated to suit a purpose that in effect is not completely sustainable.

One of the major achievements of sustainable development is that it has brought two opposing worldviews on a common platform, the ecological worldview and the economic worldview. This synthesis is especially important when dealing with urban sustainability wherein both the ecological and economic aspects are in play. That is not to say that the two worldviews are no longer contested, they still lay stress on different aspects, but are looking in the same direction, towards sustainable development.

There have been a number of attempts to reconcile the different interpretations of sustainable development by way of setting a range for sustainable development and attributing a degree to the interpretations based on where they lie on the scale. The most common way is to define it in terms of soft to hard sustainability(Drummond and Marsden, 1999).

Whilst soft sustainability refers to development that is anthropocentric, focused more on the quality of life and economic development of the human race, hard sustainability refers to a rigid ecocentric view with emphasis on environmental protection above economic development.

Other debates in the theory of sustainable development are between those with faith in technology, scientific rationality and economic growth and those with a view that current economic structures, attitudes and lifestyles are incompatible to sustainable development; between those who focus on ecological crisis and those who emphasize social needs and equity; extent to which indigenous people should be used as models of sustainability; stable state notions versus chaos and complexity(Wheeler, 2004).

2.2.1 Urban Sustainability – the elusive goal

The concept of Sustainability as applied to the urban world is also prone to the said uncertainties. Over the years, many attempts have been made to interpret the meaning and role of sustainable development in relation to the urban world.

The **Table** 2-1 follows the growth of the concept through some of the different events and definitions from its inception. The table is in no way comprehensive and focuses only on the interpretations of Sustainable Development as applied to the urban environment.

Table 2-1: Events in understanding Sustainable Development

Year	Notable development relating to Urban Sustainability
1962	Silent Spring by Rachel Carson
1968	United Nations Biosphere Conference, Paris
1971	International Institute for Environment and Development (IIED) Established
1972	UN Conference on the Human Environment ENDA (Environment and Development Action in the third world) Established
1976	Habitat
1980	World Conservation Strategy released by IUCN
1983	Development Alternatives established in India
1984	Third World Development founded
1987	Tokyo Declaration WCED produces 'Our Common Future'
1988	IPCC established
1991	Caring for Earth publication
1992	Earth Summit Agenda 21 established
1995	World Summit for Social Development
1997	Kyoto Protocol
1998	Strategic Infrastructure reinvestment policy (SIRP) task force
2000	Earth Charter Millennium Declaration
2002	World Summit on Sustainable Development
2005	UN decade of education for sustainable development

It is widely believed that the concept of sustainable development originated as early as 1960's with the concern on pollution and environmental conservation raised by Rachel Carson's 'Silent Spring'. This was followed by the United Nations Biosphere Conference in Paris where experts argued over 'the scientific basis for the rational use and conservation of the resources of the biosphere.'

The biosphere conference promoted the idea of environmental and resource utilization and conservation going in unison and is deemed to be the first intergovernmental panel to discuss Sustainable Development(UNESCO, 1993). 1970's saw the growth of the environmental movement across the world, with the first Earth day in 1970 and the establishment of organizations like Greenpeace, International Institute for Environment and Development (IIED) and Environment and Development Action in the third world (ENDA). The UN conference on Human Environment in 1972 proclaimed that we have 'reached a point in history when we must shape our actions throughout the world with a more prudent care for their environmental consequences'(UNEP, 1972). Within its proclamation aimed at the protection and improvement of the human environment, the UNEP defined Sustainable development(UNEP, 1972), as we know it now -

'*To defend and improve the human environment for present and future generations has become an imperative goal for mankind-a goal to be pursued together with, and in harmony with, the established and fundamental goals of peace and of worldwide economic and social development.*'

Within its 26 principles, the UNEP postulated the foundations of Sustainable Development focusing on environmental protection in conjunction with social and economic development. The principles promote social development and the entitlement of world population to the rights of freedom, equality and quality of life, the economic development of developing countries while quoting our 'responsibility to protect and improve the environment for present and future generations' by safeguarding and managing natural resources and wildlife and preventing pollution. In the context of this thesis, it is noteworthy to quote the 15th principle that promotes rational planning.

'*Planning must be applied to human settlements and urbanization with a view to avoiding adverse effects on the environment and obtaining maximum social, economic and environmental benefits for all. In this respect projects which are designed for colonialist and racist domination must be abandoned.*'(UNEP, 1972)

The UNEP principles can thus be said to have laid the foundation of the three pillars of sustainability bringing economy, society and environment on the same stage and introducing the principle of inter-generational equity.

Following this the 1976 global meeting on Habitat was instrumental in bringing the environmental concern into the human built environment. The Vancouver declaration was based on worldwide concerns about the state of the human built environment attributed to inequitable economic growth; Social, economic, ecological and environmental deterioration; population growth; Uncontrolled urbanization; Rural backwardness, dispersion and migration(UN-HABITAT, 1976).

The 19 general principles and 24 guidelines are intended to 'guide the world community in solving the problems of human settlements'. Most general principles are reiterations of those already mentioned in the UNEP declaration though with a more social and humanistic perspective. Along with ideas of cultural, social and economic sovereignty, it advocates historical conservation and recommends that governments take responsibility of urbanization such that it facilitates socio-economic growth, cultural and environmental preservation along with industrialization and a focus on rural habitat improvement.

Although these stipulates defined what the global community wanted to achieve, there has been little guidance on how to reach these goals. The guidelines from the Vancouver declaration were also too generalized and more like objectives than action plans.

The World Conservation Strategy that followed in 1980 built on the previous world conferences and proposed three main objectives: to maintain essential ecological processes and life-support systems; to preserve genetic diversity; and to ensure the sustainable utilization of species and ecosystem(IUCN et al., 1980).

It can be inferred through the sustainability time line so far, that economic development is considered to be the chief goal of the human society and in the process of achieving this growth, as is now identified, natural ecosystem has been harmed. It is with intent to rectify or rather prevent further harm that all these world events have occurred.

The focus thus has been on preservation and conservation of natural resources whilst also aiming to continue economic development and uplift the living conditions of the human race. The once 'at-odds' ideals of economic development against environmental protection have been reconciled. To combat the various social, economic and environmental problems faced today, various world agencies have come up with a new goal termed Sustainable Development.

Now comes the year Sustainable development gained its popularity. The 1987 Brundtland report 'Our Common Future' popularizes the concept of sustainable development and gives the world its most widely used definition(WCED, 1987). As mentioned before, this is also the most ambiguous definition. There have been more than 40 different definitions of sustainable development that have been formulated on the basis of the ideals of intra and intergenerational equity and the management of needs and wants(Pearce et al., 1995). Critics have pointed out that the term has become a buzzword that has more attraction than meaning. Policy-makers and professionals alike are using it excessively often without understanding the real concept.

Caring for the earth report by the International Union for Conservation of Nature (IUCN), United Nations Environment Programme (UNEP) and World Wildlife Fund (WWF) was the successor of the World Conservation Strategy (WCS) and focused on sustainable living adding to the WCS principles, the principle of changing personal attitudes and practices and enabling communities to care for the environment. It attempts to clarify the confusion that follows the idea of sustainable development/growth/economy etc. According to the strategy,

"Sustainable development" is used in this Strategy to mean: improving the quality of human life while living within the carrying capacity of supporting ecosystems.

A "sustainable economy" is the product of sustainable development. It maintains its natural resource base. It can continue to develop by adapting, and through improvements in knowledge, organization, technical efficiency, and wisdom. (IUCN et al., 1991)

In addition to the general principles, caring for earth report also provides specific guidelines for municipal and national governments to deliver sustainability in various fields like energy, agriculture and human settlement planning etc. There are four listed actions for sustainable human settlement planning, under each of which are suggested strategies that can be employed by the municipal or national governments(IUCN et al., 1991).

1. *Adopt and implement an ecological approach to human settlement planning.*
2. *Develop more effective and representative local governments, committed to caring for their environments.*
3. *Develop an efficient and sustainable urban transport policy.*
4. *Make the city clean, green and efficient.*

The earth summit in Rio de Janeiro again focused on the social and environmental aspects of sustainability, while agenda 21 was established to give more detailed and concrete goals to achieve sustainable development.

The Agenda 21 programme (UNCED, 1992) areas relating to urban settlements included:

1. *Providing adequate shelter for all;*
2. *Improving human settlement management;*
3. *Promoting sustainable land-use planning and management;*
4. *Promoting the integrated provision of environmental infrastructure: water, sanitation, drainage and solid-waste management;*
5. *Promoting sustainable energy and transport systems in human settlements;*
6. *Promoting human settlement planning and management in disaster-prone areas;*
7. *Promoting sustainable construction industry activities;*
8. *Promoting human resource development and capacity building for human settlement development.*

Unlike the economic pursuit of the industrial revolution, or the social agendas in the post war urban reforms or even the environmental focus of the 1960's and 1970's; Sustainable development aims to tie all these concerns together. This trans-disciplinary goal gives a unique opportunity to delve into this interconnected web. Instead of trying to solve each problem separately without being well aware of its consequences on other aspects exploration of the connections and analysis of the impacts of changes in one aspect on others can help innovate policy and plan sustainably.

From within the ambiguity of sustainable development, a few basic principles can be found that are common to most of its interpretation. Foremost is the recognition of the 'three pillars of sustainability'(UN, 2002)– Environmental, Economic and Social. These three aspects of sustainability have been universally accepted and are often used to define it. What exactly do these three pillars encompass is dependent on the interpretations.

However, the ideas of environmental conservation, quality of life, satisfaction of basic needs, stimulating economic growth, maintaining natural resource base, promoting equity and community progress are intrinsic to the idea of sustainable development. See United Nations Millennium Declaration (Assembly, 2000), World Conservation Strategy (IUCN et al., 1980), Caring for the Earth (IUCN et al., 1991), Principles of Sustainable Livelihoods (NARCSL, 1995), The Earth Charter (Secretariat, 2000), Vancouver Declaration on Human Settlements (UN-HABITAT, 1976), Report of the World Summit on Sustainable Development (UN, 2002), Our Common Future (WCED, 1987), and Agenda 21(UNCED, 1992)

2.2.2 Assessing Sustainability

The focus on urban sustainability has led to the development of a number of indicator sets. Some have been developed at a global scale while others at national or even city scales. To understand the practical aspects of using sustainability assessment as a policy tool in city management, a review of several such tools used across the world has been conducted.

In the following review a comparative assessment of 10 urban sustainability indicator sets taken from across the world and corresponding to different scales of development and application in terms of what issues they address through their indicators has been presented. The aim of the review is to identify the differences and similarities between these tools, to identify the most common issues and indicators used and their significance in urban sustainability assessment.

The issues addressed have been collated from general sustainability requirements and the indicator sets. The indicator sets are assessed on the following criteria – total number of indicators; the areas covered – social, economic and environmental; Scale; Comparability – across urban region; the frequency of collection; Use – assessment, monitoring, both; Based on – Agenda 21, MDG etc.

Table 2-2: Summary of Comparative Analysis of Urban Sustainability Indicator sets

	Global Urban Indictaors	European Common Indicators	Sustainable Seattle	Ecosistema Urbano di Legambiente	VRIND	Monitor Urban Renewal	Sustainable Cities Index	Hammarby Sjostad	Curitiba	European Urban Audit(Malmo)
Total No. Of indicators	20 key, 13 extensive	10 key, 100 Sub	40	18 key, 42 parameters	700	6	13	-	23, 8 Goals	9 domains 250 indicators
Country of origin	UN	EU - Italy	US	Italy	Flemish	Netherland	UK	Sweden	Brazil	Sweden
Pillars Covered	Mostly Socio-Economic	Key indicators exclude economic	All three	Env.	Env., Economic	Socio Economic	All three, focus on env.	Env.	Social, Env	Eco, Social and Env
Types of Indicators	Quant and Qual	Quant and Qual	Qual	Quant	Quant		Quant	Quant	Quant	Quant
Scale	Global	Regional	City	National	National	National	National	City	City	Regional
Comparability	Yes	Yes	-	Yes			Yes	-	Intracity	Yes
Frequency	5 year	NA	2-3 years	Annual	Annual		Annual 2007-2010			3 years
Based on	Habitat Agenda	Local Agenda 21	Citizen Volunteer Consultation		Agenda 21		-	LCA	MDG	-
Use	Benchmark Database	Benchmark	Monitor progress	Monitor	Regional Database and Benchmark	Reference for subsidies	Monitor progress	Env. Monitoring	Monitor Progress	Ranking cities
Quant – Quantitative; Qual - Qualitative										

Table 2-2 provides a summary of the comparison of indicators sets based on the criteria mentioned earlier. It is evident from the review that there are a number of differences in the way indicator sets are designed and used. What they measure, which aspect of sustainability do they prioritize, how they measure it and how often do they measure it are all subject to the sets design basis which varies with scale and use profile.

To further help identify the differences and similarities in the indices used within these indicator sets, an analysis of the number of indicators under various sustainability pillars and sub heads is undertaken. **Table** 2-3 is split to represent the indicators in the categories of economic, social and environmental. The number in the boxes shows the number of indicators used for that issue of sustainable development. The following descriptive analysis also provides further details on the methodological and practical concerns for each indicator set.

Table 2-3: Summary of key Indicator numbers from Sustainability Indicator sets

	Global Urban Indictaors	European Common Indicators	Sustainable Seattle	Ecosistema Urbano di Legambiente	VRIND	Monitor Urban Renewal	Sustainable Cities Index	Hammarby Sjostad	Curitiba	European Urban Audit(Malmo)
Employment	2		2			1	1			2
Inward Investment	1		1			2	1			
Land and Property Market			1		2	1				2
Income	1		2						3	3
Health	1		3	1			1		8^	
Education	1		2				1		3	3
Safety And Security	1		1							1
Community		1	6			4	1		4	1
Access to Services	1		1	1					1*	
Air Quality		1	1	4			1	1		2
Pollution		1§	1			3#				
Water			1					1	1	
Energy			2	1	2	1		1		
CO2 Emissions		1		1	1		1	1		
Waste Management	2		1	3	2	1	2	2	1	2
Urban Greens		1	1	1		3	1			1
Transport	1	2	1	4			1			2
Biodiversity			1				1			
Land use	1	1	1		1	2				

The Global Urban Indicators (GUI) (UNHSP, 2004)is based on the Habitat agenda and comprise of a set of key indicators and a qualitative checklist. It comprises of

20 Key indicators that are both important for policy and relatively easy to collect. They are either numbers, percentages and ratios;

9 Checklists which give an assessment of areas which cannot easily be measured quantitatively. They are audit questions generally accompanied of checkboxes for yes or no answers;

13 Extensive indicators which are intended to complement the results of the key indicators and qualitative data in order to make a more in-depth assessment of the issue. (UNHSP, 2004)

Being a global indicator set, the availability of data is a major issue and thus the focus is on quality of life. Quality of life data is usually available in all countries from their economic and census data. The GUI has created the biggest dataset on urban sustainability indicators available today.

The European Common Indicators (Ambiente-Italia, 2003)is a regional indicator set based on the Local Agenda 21 and is a combination of user satisfaction survey and data based indicators. It has a social and environmental focus with no indicators to assess economic sustainability. It also uses an underlying ecological footprint tool that is based on nourishment, shelter, mobility and goods and services. The 10 common issues/indicators have been chosen after a deliberation over 18 themes and 100 sub indicators. The Indicators are driven by the citizen satisfaction survey and are based on 6 sustainability principles.

1. Equality and social inclusion (access for all to adequate and affordable basic services, e.g. education, employment, energy, health, housing, training, transport);

2. Local governance/empowerment/democracy (participation of all sectors of the local community in local planning and decision making processes);

3. Local/global relationship (meeting local needs locally, from production to consumption and disposal, meeting needs that cannot be met locally in a more sustainable way);

4. Local economy (matching local skills and needs with employment availability and other facilities, in a way that poses minimum threat to natural resources and the environment);

5. Environmental protection (adopting an eco-systems approach, minimising use of natural resources and land, generation of waste and emission of pollutants, enhancing bio-diversity);

6. Cultural heritage/quality of the built environment (protection, preservation and rehabilitation of historic, cultural and architectural values, including buildings, monuments, events, enhancing and safeguarding attractiveness and functionality of spaces and buildings). (Ambiente-Italia, 2003)

Sustainable Seattle (Various, 1998) is one of the most comprehensive indicator sets available and covers all three aspects of sustainable development. It is an award-winning indicator set that has been used as a precedent for other attempts across the world. It monitors the social, economic and environmental issues on sustainability trends declining, improving or neutral. It also sets out the criteria for indicators–

1. Relevant.
2. Reflect Community Values
3. Attractive to local media
4. Statistically measurable
5. Logically or scientifically defensible
6. Reliable
7. Leading
8. Policy-relevant

Its 40 indicators were created through a voluntary citizen consultation process.

Ecosistema Urbano di legambiente (Berrini et al., 1999)is defined as a ‘thermometer for sustainability’ and focuses on environmental quality in 103 Italian cities. It does not include social and economic sustainability.

Every year Urban Ecosystem collects data on 42 environmental parameters. On this basis 18 environmental sustainability indicators are selected, having a balanced P-S- R approach (Berrini et al., 1999).

Data availability is again one of the major concerns when designing indicators. As a final result Ecosistema Urbano di legambiente ranks the cities as excellent, good, fair, average and insufficient depending on the percentage of sustainability objectives achieved.

VRIND (CSTB and Technology, 1999) is a Flemish regional indicator set that annually monitors cities in Belgium. The focus is on energy use with some economic indicators based on housing.

Regarding Flemish Regional indicators, demographic and environmental indicators are published annually in VRIND. The Flemish Government created a database - Functional Regional Database, FRED - to cover all types of policy relevant indicators (UNDESA, 1998).

Monitor Urban Renewal monitors progress by local authorities in Netherlands, of investments in Urban Renewal. This has a strong inclination towards community vitality and economic development although it does monitor pollution, waste management and urban greens.

The monitor is being used as a reference to assess requests for subisidies from local authorities. There are six performance criteria that are being measured through a subset of indicators. (VTT, 2003)

Sustainable cities index(Ross and Underwood, 2010) is an indicator set developed by Forum for the Future that has monitored sustainability indicators in 20 of UK's biggest cities. It uses 13 indicators in three heads – Environmental Impact, Quality of Life and Future Proofing. The results were published annually from 2007 to 2010. The Indicator set was also the basis of an Australian version with 15 indicators.

Hammarby Sjostad (CSTB and Technology, 1999) at a city level uses very specific indicators for environmental monitoring. They are based on the urban project's goal to reduce environmental impact by 50% of an average building project in 1990.

The system of indicators has been used in the design phase to select the developers and shall be used to assess the management phase. The basis for the system is a structure of activities in three phases – production, use and demolition. In each phase impact indicators can be regarded for buildings, blocks and the area as a whole. In the use phase data can also be regarded for individuals and households. Environmental impacts are added from production to demolition over a 50-year period so that the total impact can be estimated in the design phase. (CSTB and Technology, 1999)

Curitiba uses the Millennium Development Goals to assess sustainability and thus has a strong social focus. It uses a set of 48 indicators organized under 8 sets that are defined as '8 ways to change the world' (ORBIS, 2004). These include –

1. *Eradicate extreme poverty and hunger*
2. *Achieve universal primary education*
3. *Promote gender equality and empower women*
4. *Reduce child mortality*
5. *Improve maternal health*
6. *Combat HIV AIDS, malaria and other diseases*
7. *Ensure environmental sustainability*
8. *Develop a global partnership for development*

The 8 main goals are to be met by 2015.

Malmo uses the European Urban Audit and covers some aspects of economic, social as well as environmental issues. The Urban Audit contains data for over 250 indicators across the following domains (Inforegio, 2003).

1. *Demography*

2. *Social Aspects*
3. *Economic Aspects*
4. *Civic Involvement*
5. *Training and Education*
6. *Environment*
7. *Travel and Transport*
8. *Information Society*
9. *Culture and Recreation*

This data collected every 3 years in 58 European cities is used to rank the cities in comparison to other cities.

2.2.2.1 Review discussion

Based on the above analysis, six key differences have been identified in relation to the scope and use of sustainability indicators across the world.

1. Difference in scales

For example the GUI indicator set is applied to cities across the world whereas Ecosistema urbano assesses 103 Italian cities and Hammarby Sjostad is a specific local Indicator set. The divergence in scale also leads to difference in the indicators being used depending on different priorities and the availability of data.

2. Difference in priorities

Where Hammarby Sjostad focuses only on environmental monitoring indicators, Monitor Urban Renewal Focuses on socio-economic indicators. The priorities based on the vision or goal of a city vary from place to place and thus the indicators used also vary. There is usually more emphasis on environmental and social indicators.

3. Difference in indicator type (qualitative/quantitative)

European Common indicators uses qualitative data by way of user survey but GUI uses only quantitative data for its key indicators. This is again dependent on data and resource availability. Quantitative indicators are generally preferred as they can be more easily understood and used to assess policy.

4. Difference in data used

For instance, Sustainable Seattle uses energy use /dollar income to assess the energy use whereas Ecosistema Urbano uses electric energy consumption in KWh/inhabitant/year for the same. The differences in data used can again be attributed to the availability and reliability of the data in various regions.

5. Frequency of collection

The frequency of collection for most tools is mostly annual but can also vary between 1-5 year intervals. This depends on the extensiveness of the indicator sets. If the indicator numbers are too large, annual collection may not be feasible and hence longer time periods are necessary. This may affect the monitoring process. Ideally, indicator sets should be designed to match the monitoring intervals for sustainability interventions.

6. Policy Implications

Whilst some indicator sets are designed to rank cities on a global or regional basis, most are intended for use as monitoring tools for the policy process. How successful they are in the endeavour is open to discussion as very little evidence is available on their impact in policy making and its subsequent realisation.

The most common issue addressed is that of waste management, included in 9 out the 10 sets. Waste management is usually a key role in any municipality and is linked to pollution and thus, its high priority. CO2 emissions calculation formed part of half of the sustainability indicator sets. Biodiversity on the other hand was addressed only in two indicator sets.

It can be summarized that the use of indicators, though useful, is a complex phenomenon. There is a plethora of issues involved and to achieve an optimum set of indicators which have good data availability and reliability and can inform policy is a hard task. Critics of the sustainability indicator system point out that they may be too extensive and hard to understand and interpret, ignore the interrelationships between indicators or try to over summarize the results and hence, tending to be less useful for policy. Bell and Morse and Mondini and Valle (Mondini and Valle, 2007) iterate as -

First, planning with respect to problems of the natural and built environment, the objective of sustainability analysis and the decisional process is particularly complex (bell and Morse, 1999). The supplied information is often insufficient as far as the real requirements are concerned; the impacts are uncertain and difficult to foresee in quantitative terms; the number of subjects that are involved (public, private, mixed etc.) is very high; each of these is characterized by specific objective that vary in time and priority; and the range of alternative scenarios is destined to change under the pressure of the interests at play. (Mondini and Valle, 2007)

2.3 Conclusion

Through the study of the scientific basis of Climate Change and the role of cities, an understanding of their interrelationship is arrived at, which provides a foundation to the research problem. Climate Change and Cities are closely correlated. Cities or city activities are one of the key drivers of Climate Change and cities and their inhabitants are also at risk from its impacts.

The review of literature on Climate Change and its impact on India shows that the importance of Climate Change mitigation and adaptation in developing countries like India is higher. The population that is most vulnerable to the effects of Climate Change is the poorer sections of the society and India still has 32.7% of its population below the poverty line. Due to constant migration from rural to urban areas, mid size cities are rapidly growing with an increase in the slum population. With a lack of basic amenities, this section of the population will suffer most from the affects of Climate Change making it important for the

Local Governments to take steps to mitigate and be prepared to tackle the adverse affects of Global Warming.

As a country, India's stand has been to compel the developed nations to take accountability of the anthropogenic reasons of climate change. It also does not take accountability for any emissions reductions, to help sustain its growing economy. But being one of the most vulnerable nations to the affects of Climate Change, and also one of the major contributors to world GHG emissions, it does have a responsibility towards intergenerational equity, to ensure that the future generations do not suffer at the cost of economic growth today. India often cites its low per capita emissions, but it must be noted that it also has the second highest population in the world, making the cumulative emissions the fifth highest in the world.

Although its stand not to be part of the Kyoto mandatory reductions to ensure that economic growth in the country does not suffer is understandable, it should still take a voluntary stand to explore sustainable pathways to economic development to ensure a better quality of life as well as mitigation and adaptation measures to reduce the impact of global warming on its large population.

To mitigate the effects of Global Warming, there is a need to identify what drives Climate Change and its association with cities and in order to adapt; the cities need to identify the threats posed by Climate Change and plan for future proofing. In the context of this study, this highlights the need for cities to find ways of quantifying their contributions to Climate Change and the threats it poses.

The idea of sustainable development, although ambiguous, has some key factors that recur in the debate on urban sustainability. The three pillars of Social, Environmental and Economic sustainability and the focus on shelter, infrastructure provision and poverty reduction in the urban context have found reference in all related literature.

Two key issues with sustainability in the urban context are whether to see it as a goal or as a pathway and whether sustainability can be measured.

The use of indicator systems attempts to direct urban areas towards a more sustainable future. There are goals but they are not finite, sustainability is more about the pathway that leads to these goals which themselves may change over time. From the review of sustainability tools, it can be summarized that Indicator sets have some advantages and disadvantages associated with them.

While indicator sets help provide a direction for policy as well as a monitoring tool and highlight issues; they need to be carefully designed. Indicator sets can cover a range of issues in the three constituents of sustainability – Social, Economic and Environmental but this can lead to a large unmanageable set of indicators. The review showed a range of 6 – 700 indices being used to assess sustainability in the Urban Context. Thus, the concern when designing indicator sets is how many indices are too many and also, which issues to focus on when limiting the indicator system to a more manageable size.

Often the indicator systems are too resource intensive making it difficult specially for developing nations to adapt them with their limited resource base. The usefulness of an indicator for policy should be a key criterion in the selection of indicators. For example, in the case of indicators for waste, an indicator that is more focused on the pollution by the landfill will be more useful to drive policy than the number of landfills indicator. The availability of data is always a major issue with indicator sets along with the issue of it being contemporaneous to allow comparisons. An important inference from the review that is relevant to this work is that the most used indicators are mostly environmental and quantitative.

Although, sustainable development or urban sustainability promote a multidimensional approach, this needs to be speculated so that the goals or targets do not become too idealistic to achieve or too many to handle. As such, there arises a need to contextualize the ideals of sustainability and prioritize the goals based on the local issues.

The underlying premise that emerges in this chapter is the need to operationalise sustainability with the help of tools in the urban context. There is much debate and theory surrounding the idea of sustainable urban development but still not enough evidence of its successful implementation.

In continuation with these conclusions, the next chapter aims to contextualize the research problem to the study area of Urban Indian cities and find a more focused research aim and thus refine the research questions before looking at the methodological basis of the study.

Chapter 3 City Metabolism and GHG Inventory

The contextual model of cities and associated process and the local urban Indian system help in narrowing the issues addressed through this study and assert the research aim identified through the previous chapters. Finally, the methodological outline helps in streamlining the focus of the research and identifying the appropriate method applicable to the research. This is the second and final part of the literature review, which led to the finalizing of the research aims and objectives and informed the method of research.

As part of this chapter, the idea of the city as a process is looked at exploring the metabolism of cities to understand the flow of energy and materials. The role of urban planning and management in regulating this process is studied. This is followed by a study of local Indian urban context, focusing on the governance structures and the priorities and needs of the local governments. Based on the conclusions from these three study areas, a case for the use of GHG inventories to inform policy in Indian cities is presented and followed up by a review of different methods and tools used to achieve this. The review results help identify the process and method of research undertaken in this study.

3.1 Cities and their process – The Contextual review

As important as it is to understand the idea of sustainable development in the urban context in order to explore its applicability to municipal governance, equally important is the need to comprehend the working of the city as an entity.

"*A city is an arena for economic development, political action, social life, cultural enrichment and environmental stress*." (Badcock, 2002)

The city is a complex entity that has evolved over centuries to contain and support human processes. From a modest beginning as an agglomeration of households, it has grown through agriculture, industrial and technological revolution, social reforms, economic innovations into a highly intricate web of systems and interactions. Whilst providing the human race with a stage to carry out the socio-economic interactions that form the basis the modern society, the city also has a profound impact on the environment and the ecological balance.

3.1.1 The city as a process

Since the beginning of civilization, there has been an incessant attempt to understand the city process and by doing so, to facilitate the creation of a utopian city, the acme of the civilized world, which exemplifies social harmony, constant economic development, high quality of life and a perfect balance with nature. This utopian vision has seen many manifestations, from early Greek interpretations of Plato (Pinder, 2005) to, 20th century pioneers like Ebenezer Howard's vision of the Garden City or Le Corbusier' modernist ideals of the city and more recently the emerging ideals of sustainable cities. This quest has focused on the imminent problems of the period, polity in the Greek era, socio-economic reforms in the 20th Century and is currently a response to the imminent energy crisis.

The urban world witnessed a tipping point in the middle ages when there was a spur to urban growth all over Europe as a result of a series of technological advances and then again in the 1800's owing to the exploitation of fossil fuels (Johnson, 2001). These phase transitions in urban history provide us with the much needed assurance that such change is possible and perhaps now, with the decline of fossil fuel energy, social problems and climate change, we are fast approaching another tipping point that will drive urban growth in a new direction. As mentioned earlier, the need to visualize the city processes holistically is very important for the planner or policy maker. One of the fundamental tools that can help do this is urban metabolic studies or material flow analysis.

Abel Wolman (Wolman, 1965) in "The Metabolism of Cities" first defined urban metabolism; it is a method to describe the flow of materials and energy in urban settlements. As cities become larger and as globalization progresses, the resource base for urban supplies has taken a global dimension. Now, to sustain a city process, materials and energy are not only sourced from the surrounding hinterland but from across the world. The idea of urban metabolism helps identify the resource consumption and waste generation in the city. With the globalised dimension this is a challenging task. From an urban sustainability perspective, urban material flow analysis is an excellent tool to view the system as a whole and understand the linkages.

Cities have a constant movement of food, goods, energy and services. The metabolism is characterized either in terms of cycles of major nutrients (Churkina, 2008) or active or passive inputs in the city. The active inputs are materials that are stored or transformed like construction material or water, food and fuel. Passive inputs come in the form of natural processes – water from rain, solar energy, gases and airborne particulates (Decker et al., 2000).

Understanding the flow of materials and systems through a city is critical for urban sustainability (Niza et al., 2009,(Barles, 2010 #64)). An analysis of the material and energy flow will give important insights into the pattern of consumption and hence, help the urban planner target policies effectively. Churkina (2008) identifies the increasing importance of urban systems in the global carbon cycle. Even though cities occupy less than 2.4% of landmass, they are responsible for $3/4^{th}$ of the anthropogenic carbon emission. As such their role in the carbon cycle can no longer be ignored. Kennedy et al. (2007) in "The changing metabolism of cities", have observed that the metabolism of cities is increasing with an increase in water and wastewater flows as well as increased material consumption. They also identify various factors that affect the metabolism of cities. These include the location and climate, cost of energy and the age of the city. It is important to note these factors in the context of the current study since the energy use and resultant carbon profile of a city would be affected by these factors.

Newman and Kenworthy (1999) argue in favour of applying the metabolism approach to achieve sustainability in cities. They contend that a city can be said to be approaching sustainability if it reduces its resource inputs and waste outputs.

The **Figure** 3-1 presents a schematic of the flow of materials and energy in cities. The linear model is considered unsustainable; Girardet (1999) recommends the circular model as the model for sustainable cities.

Carbon footprint can also be seen as an exercise in urban metabolic study that traces the flow of energy through the urban system.

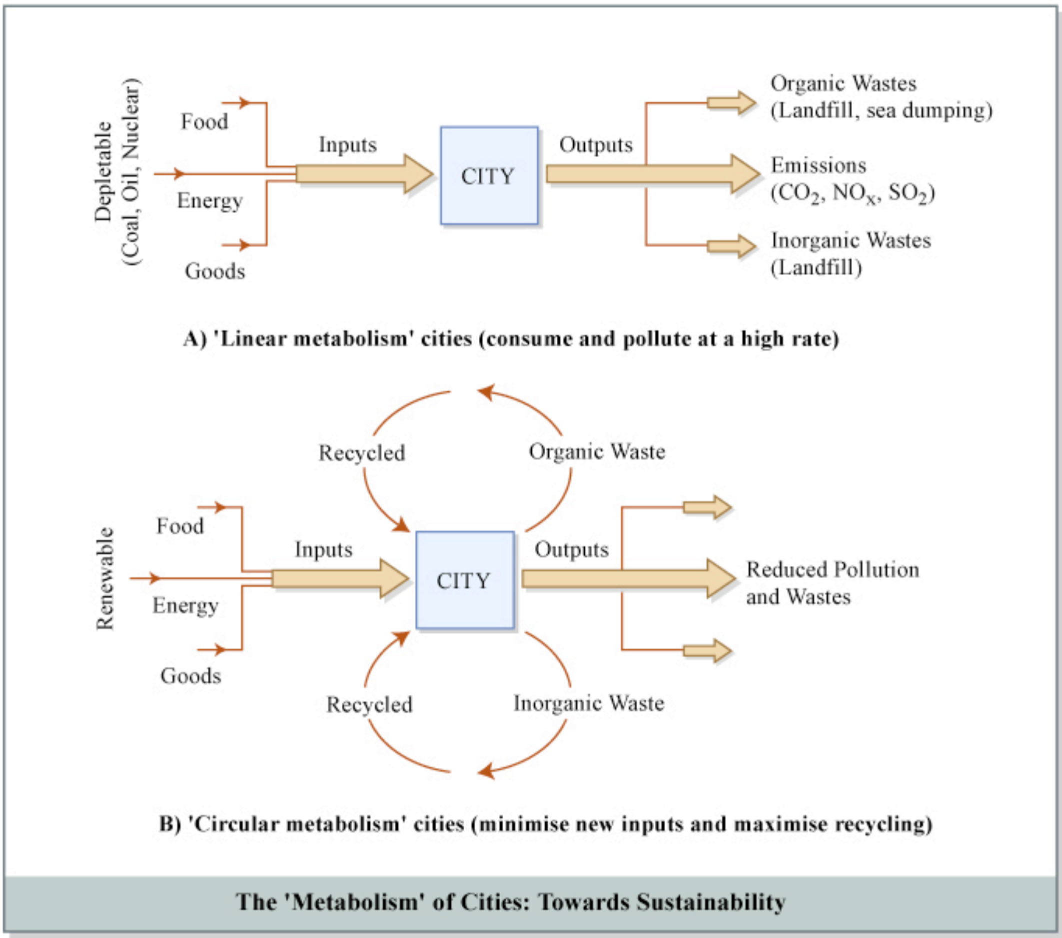


Figure 3-1: The City Metabolism; Source: Figure by MIT OpenCourseWare

3.1.2 Urban Planning and city management – managing chaos

Sustainable development started as a global issue and has been defined and refined by many global conferences and summits. While there is a lot of information on the goals that must be achieved in order to promote sustainable development in urban areas, there is often little guidance on how to do this. In the current world scenario, international treaties on sustainable development and climate change inform the national policies which are converted through regional plans into local action. Different governance structures allocate powers at different levels of the government such that in some places, the policy making and monitoring is done at a national or regional level and in other at the local level.

Many studies have brought out the inherent complexity of the cities and the interdependence of the various systems of social, physical, economic interactions that are difficult to predict or decipher. Yet, it is through these attempts that we are moving towards an in-depth perception of how cities work, evolve and grow.

The earliest settlements followed an evolutionary model; the location and growth pattern depended mostly on geographic constraints, soil fertility and safety. In this evolutionary model the city grows in a seemingly random pattern. But as discovered by Engels in his study of 1842 Manchester, the resulting urban form is not simple chaos; it has an order of its own(Adams, 1994). This self-organising property of the urban region was later ignored by the infusion of scientific thought in planning.

The deterministic ideals of the science led society, inspired planners to believe that through rational thinking and analysis they could achieve an absolute form for a city in equilibrium. The deterministic approach was characterized by predictability, ability to forecast and thus complete control of a given situation. There was no place for uncertainty; the city was a machine whose parts could be dealt with individually in isolation from the environment.

The many problems that this approach has led to are explicit in numerous critical works like those of Mumford and Jacobs. However, the shift in scientific thought from Newtonian determinism, a reversible conception of time and quest for equilibrium to notions of subjectivity, irreversible time and unpredictability from Einstein's theory of relativity, thermodynamics and quantum mechanics has begun to influence the way cities are planned and perceived.

The planner is no longer the master-designer and planning cannot fully control the city process, rather aims at influencing it (Adams, 1994). This observation is important for the planners and policymakers in India today since the ground reality is that the determinist ideals are still controlling the way planning in cities is approached. There are still separate departments that deal with separate urban processes with almost no interaction. Considering, comprehending and evaluating the city processes in a holistic manner is the key to urban sustainability.

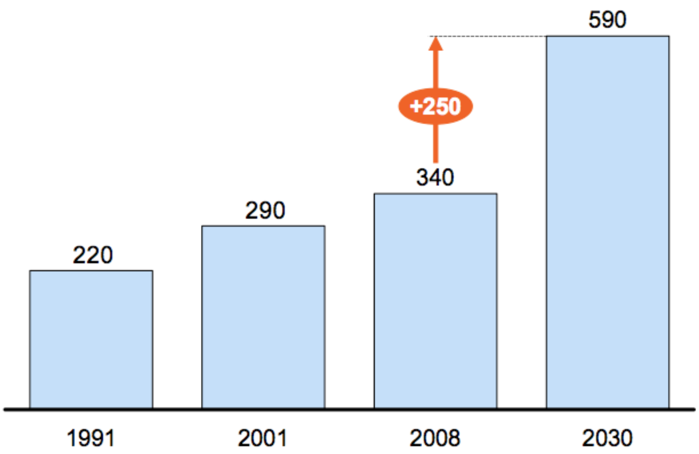
The need for urban sustainability is universally accepted with cities being considered as one of the major engines for the drive towards sustainability. Cities are the culminating points of economic activity, social interactions and environmental resource use and thus the ideal stage on which to tackle sustainable development.

3.1.3 Urban Indian Context

In an age of worldwide concerns over how human lifestyles, habitats and settlements influence the environment we live in; the state of Urban India rises as a major question. It is redundant to state the unprecedented rate of population and economic growth in India and the massive urbanisation that comes with it. Yet, to add a few numbers to better comprehend the state, of the 1028.6 million people in India in 2001, 286 million lived in urban areas, accounting for 28% of the total population.

The rate of Urbanisation in the 1991-2001 decade was recorded at 31.3%(GOI, 2007b). Still, India has one of the lowest degrees of urbanisation in the world and even the pace is slower than many nations. This can only be a cause of further concern as globalisation and economic growth propel urbanisation and related problems in India to greater heights. By 2030, 40% of India's population is projected to live in cities with an addition of 250 million from 2008 [**Figure** 3-2].

While local Indian municipal agencies are still struggling to find a foothold in this rapidly growing phenomenon, there is a rising global need and demand for a move towards sustainable development. The current threats of global warming and need for energy security make it pertinent to promote sustainable development.



	1991	2001	2008	2030
Total population Million	856	1,040	1,155	1,470
Urbanization rate[1] %	26	28	30	40

1 Defined as the ratio of urban to total population based on the census definition of urban areas; population >5,000; density >400 persons per square kilometer; 75 percent of male workers in nonagricultural sectors; and other statutory urban areas.

SOURCE: India Urbanization Econometric Model; McKinsey Global Institute analysis

Figure 3-2: Projections for India's Urban Population Growth 2030; Source: India's Urban Awakening

The National policy takes the global stand in account in the Report of the steering committee on urban development for the eleventh five year plan(GOI, 2007b) and the National Urban Housing and Habitat Policy (GOI, 2007a)clearly mentions it as its Ultimate Goal –

"*The ultimate goal of this policy is to ensure sustainable development of all urban human settlements, duly serviced by basic civic amenities for ensuring better quality of life for all urban citizens.*"

However, what the Government means by sustainable development and how it proposes to achieve it are still ambiguous. This presents us with a problem of colossal magnitude, to bring sustainability into the fast-track urban growth industry. As is the case around the world, the idea of sustainability is open to numerous interpretations and adaptations and is often seen moulded into concepts that do not really further the cause but are meant as a way to misguide people

The prime crisis, as identified by the global as well as local authorities, is that of providing the ever-increasing urban population with the basic infrastructure services. In the conventional view, sustainability takes a back seat as against the more emphasized problems of housing shortage and infrastructure inadequacy. As can be seen in the National Urban Housing and Habitat Policy (GOI, 2007a), 'the spotlight is focused on the mismatch between demand and supply of housing units', 'the core focus of this policy is provision of affordable housing for all'. Although, the policy does mention 'development of a sustainable habitat', it is defined as 'maintenance of the ecological balance in terms of a symbiotic perspective on rural and urban development while developing urban extensions of existing towns as well as new integrated townships'

This reflects the misguided ideology that sees sustainable development as a separate entity, a component, and not as the way forward that is the methodology. The potential of sustainable planning to resolve the existing problems of Indian cities is completely ignored. Instead, they are seen as two distinct problems, the problem of housing and infrastructure need in the city and the problem of sustainable development, when sustainable planning can be the key to solving the problem of housing and infrastructure.

3.1.3.1 City Governance in India

Compared to their international counterpart Indian Local Governments have a limited role. They are only responsible for the basic infrastructure facilities excluding health and education (Weist and Various, 2004).

India usually follows a three-tier system of urban governance where the city municipal corporation headed by the mayor forms the lowest tier. The state government headed by the chief-minister is the intermediate tier and the national government forms the highest tier. The devolution of power at the state and municipal level varies in different states within the country. In some metropolitan cities, like Delhi, there exists a separate authority that is given extra powers to plan the development in the city to counter the rapidly growing problems.

Figure 3-3, Figure 3-4, and Figure 3-5 show the governance structure from three cities in India, each with a slightly different regime (Urban-Age, 2007). It can be seen that while in Delhi, the major power lies in the hands of the Delhi development authority and the municipal corporation and the state government has minimal intervention in city matters; in Mumbai the state holds the executive power. The municipal commissioner is a bureaucrat appointed by the state government and heads the municipal corporation. Kolkata presents yet another governance structure, this time adding another tier to the governance structure.

"The city is therefore run on a two-tier management structure: at a mayoral and borough level with responsibilities for street lighting, road repairs, drainage and sewerage, education and disaster management, while the state government of West Bengal, through its Chief Minister, provides higher-level services and complements city functions."(Urban-Age, 2007)

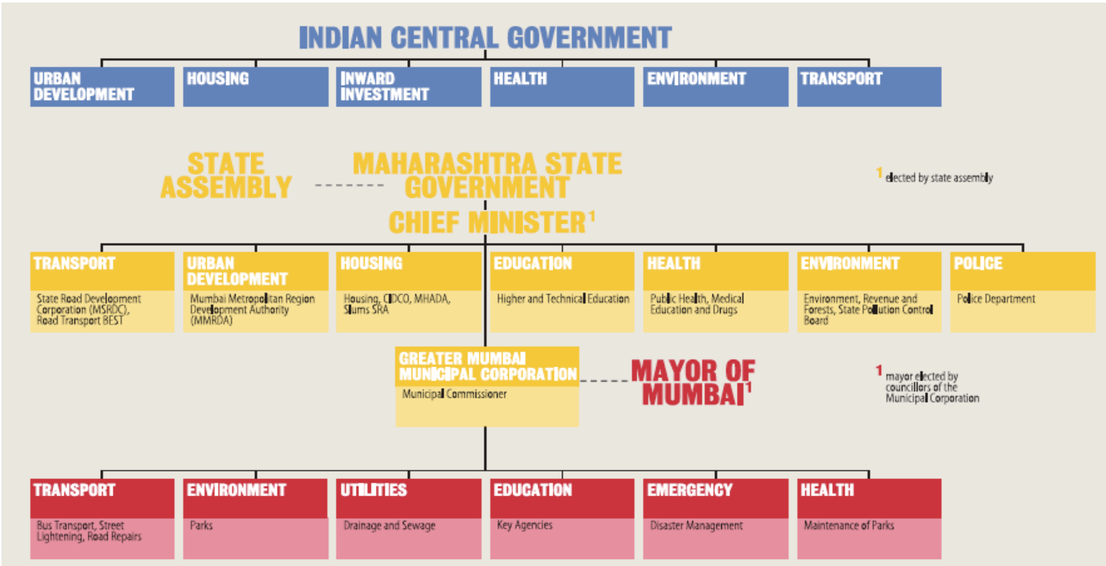


Figure 3-3: City Governance Structure - Mumbai

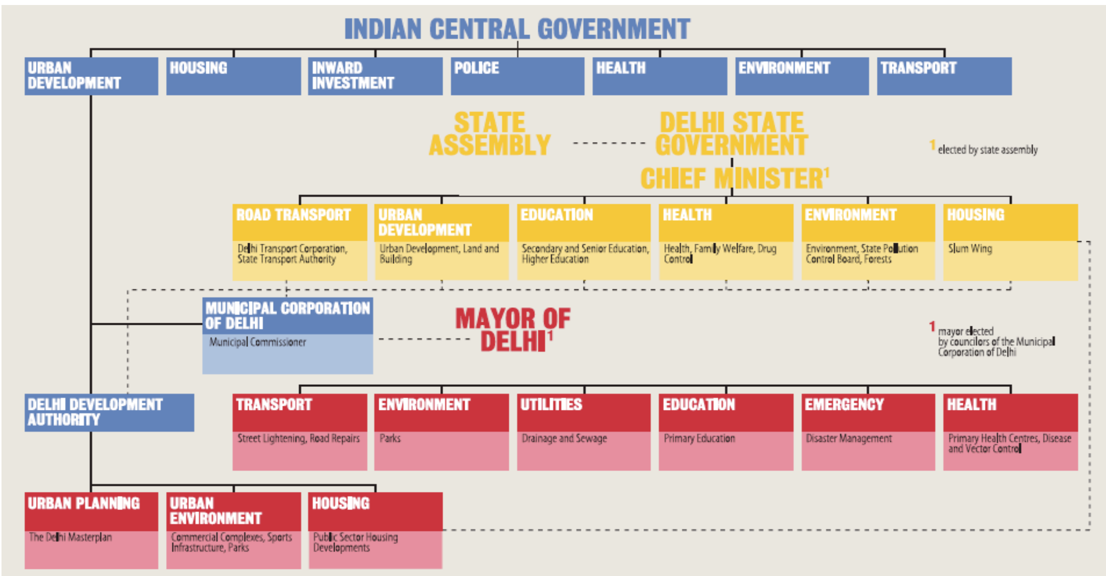


Figure 3-4: City Governance Structure - Delhi

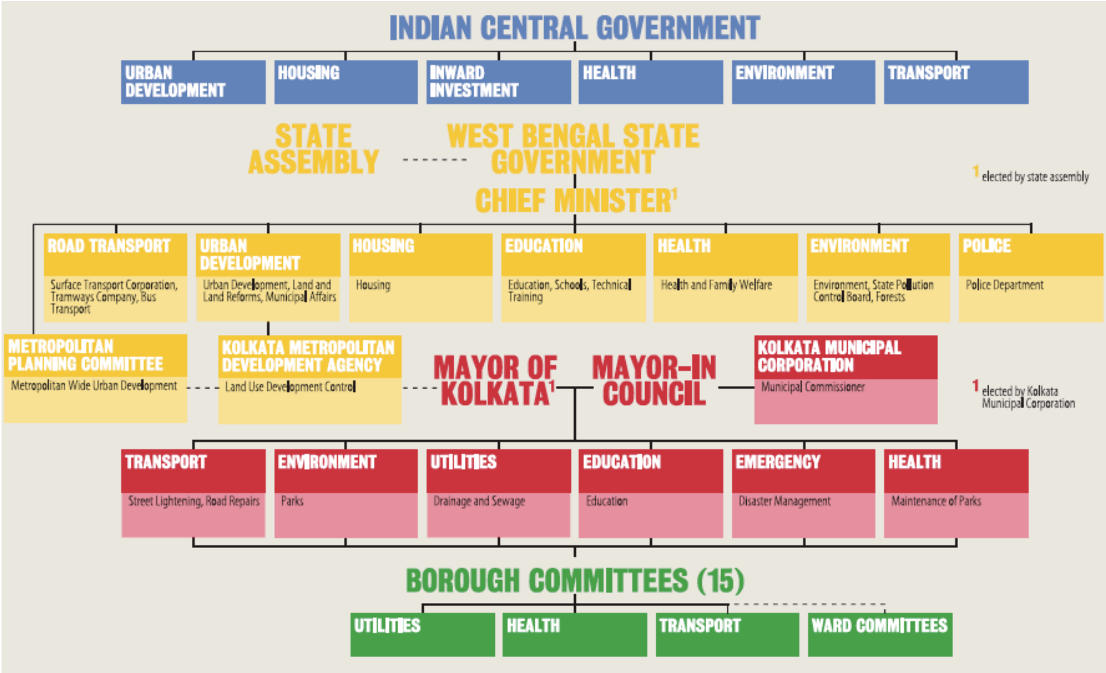


Figure 3-5: City Governance Structure - Kolkata

As can be seen the decision-making and policy monitoring in different cities is done at different governance levels. However, the process of policy-making usually follows standard steps that can be seen used globally. In a basic scenario, the process will start by having a vision for the development process, which in this case can be taken as sustainable development.

The objectives, to be more specific to the Indian context, will usually mean dealing with infrastructure deficiency and urban poverty as a priority. This is followed by an assessment of the current condition and the formulation of a policy. There could also be an assessment of various scenarios to achieve the goal. Finally, once the policy is implemented, there is a need to evaluate and assess its success.

Policy development process -

1. *Visioning or Goal setting*
2. *Objectives*
3. *Assessing current situation*
4. *Identify policy*
5. *Formulate scenarios*
6. *Evaluate / assess*

In this process, there are two key areas where the use of indicators has been found useful and is often used across the world. These are in assessing the current situation to inform policy and later to monitor the outcomes for benchmarking. Sustainability Indicators have come across as a useful tool for local government to diagnose problems, aid decision-making for policy and monitor the effects of policy implementation.

The varying city governance structure in the country makes it imperative for any study dealing with urban policy making to analyse in detail the local governance structure and its impact on the policy making process identifying the major actors and stakeholders in the decision making. Some of the key problems (Weist and Various, 2004, Vaidya, 2009) faced by Local Governments in India include –

1. Issues with the role - A number of local authorities face interference from state level; not giving them required authority to undertake reforms

The roles and responsibilities are not clearly defined between the state, parastatal agencies and the local authorities.

2. Issues of Administration and Revenue generation - The LA are poor in revenue collection failing to recover user charges due to poor administration and enforcement, weak information systems for billing and collection etc. (Weist and Various, 2004)

'Authority and financing are not congruent with Urban Local Bodies (ULB) responsibilities, leading to instances where ULBs bear the financial responsibility for decisions in which they had little or no say. This separation of the decision maker (often a state entity), from the financier, the service deliverer, and the ultimate beneficiary, results in the provision of infrastructure and services that do not match local preferences and needs, and are often not repaid nor maintained.'

3. Development Planning and Execution - Limited capacity for project development and implementation, LA's are often not involved in the planning process for development or reform.

The elected mayor usually does not have executive powers.

4. Issues related to capacity - The capacity of many local authorities below par in terms of work force and finances. There is a low level of technical staff at the municipal level.

5. Lack of Regulations – there is a lack of regulatory framework requiring authorities to provide a minimum level of service or to set a minimum cost for services.

3.1.3.2 Priorities and needs of the local authority

A local authority usually has a set of responsibilities that fall under its jurisdiction. It is responsible for these functions within the city and holds the executive power to make decisions regarding the same.

The twelfth schedule of the The 74th Constitutional Amendment Act (CAA74) in India has listed 18 functions and responsibilities to local bodies with an amendment in 1992. These are :

1. Urban planning, including town planning;
2. Regulation of land use and construction of buildings;
3. Planning for economic and social development;
4. Roads and bridges;
5. Water supply for domestic, industrial, and commercial purposes;
6. Public health, sanitation, conservancy, and solid waste management;
7. Fire services;
8. Urban forestry, protection of the environment, and promotion of ecological aspects;
9. Safeguarding the interests of weaker sections of society, including the handicapped and mentally retarded;
10. Slum improvement and up-gradation;
11. Urban poverty alleviation;
12. Provision of urban amenities and facilities such as parks, gardens, and playgrounds;
13. Promotion of cultural, educational and aesthetic aspects;
14. Burials and burial grounds; cremation grounds and electric crematoria;
15. Cattle pounds, prevention of cruelty to animals;

16. Vital statistics, including registration of births and deaths;
17. Public amenities including street lighting, parking lots, bus-stop, and public conveniences;
18. Regulation of slaughterhouses and tanneries.

As highlighted in the last section, due to unclear devolution of power from the state and para-statal agencies, not all Local Authorities have a clear set of responsibilities and roles.

A look into the ongoing urban reforms will give a clear direction to understand the priorities and needs of Local authorities in India. One of the major ongoing urban reforms in India at the moment is the JawaharLal Nehru National Urban Renewal Missions (JNNURM) and its component Urban Infrastructure Development Scheme for Small & Medium towns (UIDSSMT) initiated by the Ministry of Urban Development and The Ministry of Urban Employment and Poverty Alleviation. The main Mission of the JNNURM initiative is -

'The aim is to encourage reforms and fast track planned development of identified cities. Focus is to be on efficiency in urban infrastructure and service delivery mechanisms, community participation, and accountability of ULBs/ Parastatal agencies towards citizens.'

The initiative is focused on two areas of reform - Urban Infrastructure and Governance and Basic Services to the Urban Poor. The expected outcomes of the project include –

(1) Modern and transparent budgeting, accounting, financial management systems, designed and adopted for all urban service and governance functions

(2) City-wide framework for planning and governance will be established and become operational.

(3) All urban residents will be able to obtain access to a basic level of urban services

(4) Financially self-sustaining agencies for urban governance and service delivery will be established, through reforms to major revenue instruments

(5) Local services and governance will be conducted in a manner that is transparent and accountable to citizens

(6) E-governance applications will be introduced in core functions of Urban Local Bodies (ULBs)/Parastatal resulting in reduced cost and time of service delivery processes.

The UIDSSMT supports the JNNURM on an infrastructure project basis. Another ongoing project is Capacity Building Scheme for Urban Local Bodies (CBULB) aimed at strengthening urban local governments through capacity building for better governance and financial management as articulated in the 11th Plan.

It can be seen that the major areas of concern for local authorities are infrastructure; basic service delivery and a governance reform to help local authorities better manage their services as well as introduce transparency and better accountability. Four Regional Centres for Urban and Environmental Studies (RCUES) have also been established to support the Ministry's policy and programmes through training and research.

Another initiative from the Ministry of New and Renewable Energy relates to the introduction of Solar Cities. The Solar City programme aims -

- To enable and empower Urban Local Governments to address energy challenges at City - level.
- To provide a framework and support to prepare a Master Plan including assessment of the current energy situation, future demand and action plans.
- To build Capacity in the Urban Local Bodies and create awareness among all sections of civil society.
- To involve various stakeholders in the Planning process.
- To oversee the implementation of Sustainable energy options through public - private partnerships.

This demonstrates the government's intentions to promote energy self-sufficiency at the local authority level.

While there is a need for a reform in the urban governance structures of the local authorities, their priorities are to improve service delivery and strengthen the infrastructure for services as well as transport. Alongside, there is also an intention to promote sustainable pathways in promoting self-governance and self-sufficiency at the local authority level. From a sustainability and Climate Change perspective, it can be assumed that whilst the priorities might seem to ignore these aspects, sustainable pathways to achieve these goals can go a long way along with the reforms.

In terms of an assessment tool, the requirements of the Local Authorities can be translated as the tool being easy to use, uses least resources in terms of time, work force and money, and provides a useful measure that can be used to promote sustainability and to monitor it at low cost and effort regularly to encourage the authorities to implement and assess the impacts of their policy. Transparency in the process and result dissemination will also encourage public participation and Local Authority accountability.

3.2 The Case for a GHG Inventory

It has already been established that both sustainability assessment and the city metabolism are extensive and complex. As a result any attempt to comprehensively evaluate urban sustainability through measureable indicators is also difficult. This desire to cover the whole web of urban sustainability often leads to indicator sets becoming very large and data intensive. Thus, excessive information fails to achieve the desired results (Repetti and Desthieux, 2006). On the other hand, aggregation may also be misleading, as it does not reflect the urban complexity and tends to oversimplify the situation.

The purpose of such evaluations is three-fold as defined by Von Stoker et al. and iterated by (Repetti and Desthieux, 2006) – monitor the status over time, control by measuring the variation from target values and benchmark. The indicators must also be consistent with the local authorities goals and targets. Thus it can be inferred from the review in the previous chapter that aiming for a comprehensive indicator set that covers all aspects of urban sustainability presents a tall order and may not be as useful. Moreover, such an indicator set will require considerable investments of resources and time to be carried out which is unavailable in the context of cities in developing nations as discussed further in the research design in Chapter 4.

Although a comprehensive analytical tool is desirable, in the context of cities in developing nations and working within the existing constraints carbon footprint emerges as a good starting point for cities to start incorporating sustainability measures.

The choice of carbon footprint as a driving methodology for urban sustainability indicators is useful since varying approaches can drive carbon footprint factors. Carbon footprint can be seen as a factor of sectoral energy use within cities (environmental perspective), which is one of the most common ways of calculating urban carbon footprints. However in addition to this, Carbon footprint can also be looked at as a factor of income, markets, growth etc. (economic perspective) and also as a factor of socio-economic, cultural or quality of life (social perspective) as has been demonstrated by the following equations by Dhakal (2008b).

Energy Sectors (Residential, Commercial, Industrial, Transport)

Emissions = sum (sectoral and sub-sectoral disaggregations)

Economic (Income, Market role, Price)

Emissions = f (emission/energy, energy/income, income/person, population)

Emissions = f (economic growth, price signal, externality, market mechanism)

Social (Culture, Socio-economic Status, Quality of Life)

Emissions = f (population, organization, environment, technology, institutions, culture)

Emissions = f (mobility, shelter, food, lifestyle)

India has set a target of 20-25 percent (Ramesh, 2009) carbon reduction by 2020 from a 2005 baseline. This calls for a concerted effort at all levels of governance through various carbon reduction policies and projects. For local city governments in India, which are mostly struggling with infrastructure development to cope with the increasing population load on urban areas, this presents an additional challenge. However, it can also be a unique opportunity for municipal governments to incorporate sustainability and improve carbon efficiency in their cities/towns.

Carbon footprint is desirable as it is a quantitative assessment, easily comprehendible and the effects of policy reinforce an indicator that can be regularly monitored. A well designed local scale inventory method that relies on existing data availability and is quick and easy to complete will be taken up by more fast developing cities/towns than extensive indicator sets. Hence, in view of the applicability of the tool and also considering that carbon policy measures are easy to monitor and feed back, local authorities will be encouraged to adopt a simple inventory method.

3.2.1 GHG/Carbon Monitoring

A GHG inventory is a measure of the emissions from a city or allocated to a city calculated over a set time period (usually annual). There are several directions to the way a GHG inventory can be approached. Considering a lack of an international standard specific to the local authority scale, the city scale inventory has evolved in several ways. The inventories in use are usually based on international GHG standards for various other scales.

There also exist a number of standardized tools that are used by multiple communities on a global, national or sub national level. As a third approach, a number of academic studies have delved into calculating emissions' inventories from global cities along with some city governments taking the initiative independently. To summarize, there can be three ways to classify the inventory tools in use in the world [**Figure** 3-6].

This section attempts to review selected local GHG emission standards, tools and studies to highlight the differences in methodologies and also discuss the implications of adapting these different approaches in the Indian scenario. In Section 2.2.2 in the previous chapter the review focused on tools/methods in use by Local Government Authorities to assess sustainability in their cities with a wider perspective.

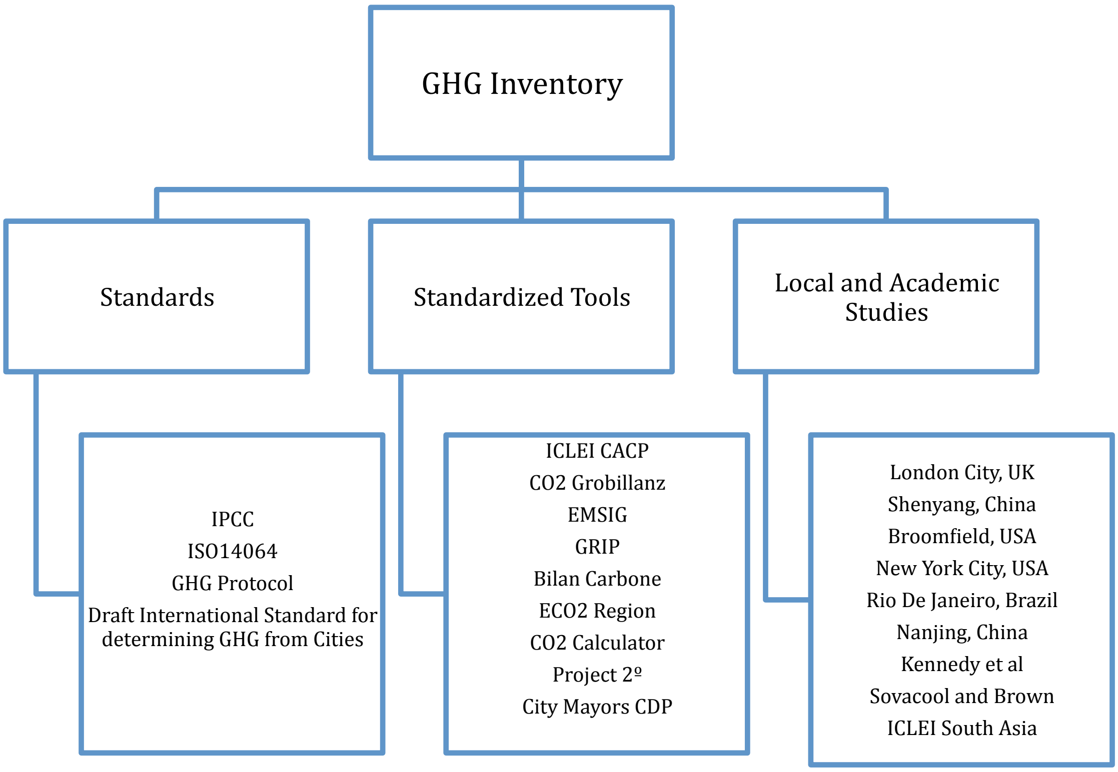


Figure 3-6: Classifying the GHG Inventory Approaches

As identified through the review and the study of the local context, this more focused analysis of GHG inventory tools provides an in-depth understanding of the potential and need of such tools in the given context.

The criteria for the comparative analysis have been drawn from (Kennedy et al., 2010, Kennedy and Sgouridis, 2011, Ramaswami et al., 2008, Xi et al., 2011), which are some key studies that have dealt with the urban carbon footprint methodology drawing from international protocols of national or product inventories and suggesting ways to adapt them to the complex urban scale. They also identify the methodological problems of defining the scope of emissions at an urban scale and their geographical, temporal, activity and lifecycle boundaries.

An analysis of these divergent methods of local emissions accounting and that of the local governance structure and data availability in Indian cities will enable the foundation of an accounting system based on global standards but tailored to the specific Indian scenario. The convergence of the methodology and data availability in Indian cities will also highlight areas of missing data or where more accurate data can be collected for future accounting. The results of the review will be used to inform a framework for local emissions inventory for Indian cities.

3.2.1.1 Standards Review

At the standards level, there are three major international standards to inventory GHG emissions – IPCC (IPCC, 2006), GHG Protocol (WRI and WBCSD, 2004) and ISO 14064 (ISO, 2006) along with a draft international standard being developed for determining GHG from cities proposed in 2010. Of these, ISO 14064 is an organization/project level methodology, the GHG protocol is a method of calculating emissions from industries and organisations and the IPCC deals with national level inventorying.

The ISO standards were published in March 2006 and have 3 parts. The standard ISO 14064-1 specifies principles for the organisation level whilst ISO 14064-2 specifies principles and requirements and provides guidance at the project level for quantification, monitoring and reporting of activities intended to cause greenhouse gas (GHG) emission reductions or removal enhancements. ISO 14064-3 provides guidelines for quality assurance and validation. The Standards provide organisations with certificates for Voluntary Reduction (D‚Äô Avignon et al.).

The WRI/WBCSD GHG Protocol is the best practice in organisation emissions inventory reporting. They introduced the concept of scope [**Figure** 3-7] that is now widely used even with regards to city scale inventories. Scope 1 emissions are those from sources such as boilers, furnaces and vehicles that are owned or controlled by the company (producer). Emissions from electricity consumed by the company are in Scope 2 (consumer); while other emissions that are a consequence of the company's activities, such as: extraction and production of purchased materials; transportation; and product use, are in Scope 3 (consumer) (Kennedy et al., 2009).

The GHG protocol provides various tools common to many industries or businesses or specific to sectors like cement or refrigeration. It advocates the principles of relevance, completeness, consistency, accuracy and transparency.

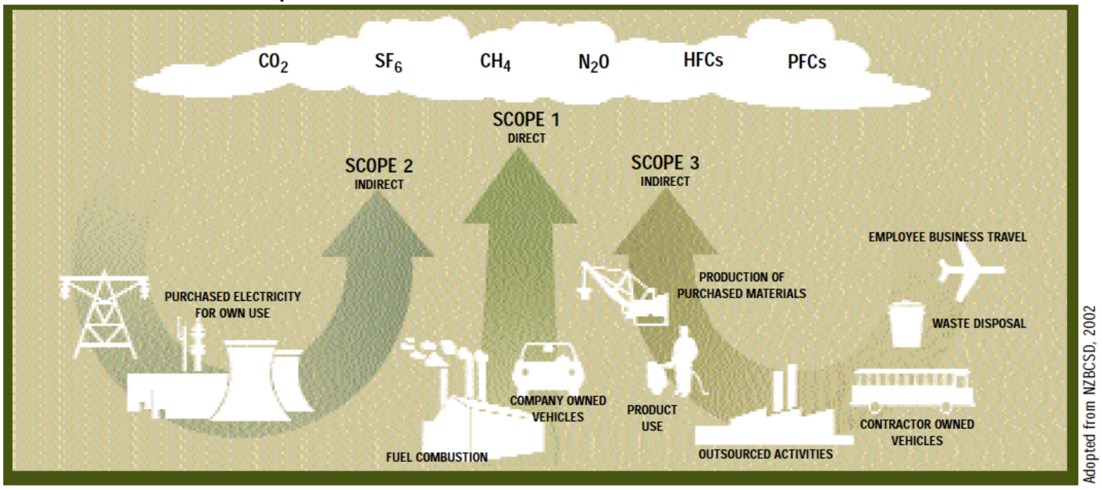


Figure 3-7: Defining Scope as per the GHG Protocol; Source: GHG Protocol Guidelines

While efforts are ongoing to create an international standard specific to city/municipal level of GHG inventory; city governments at present usually base their tools on the IPCC methodology. The IPCC national inventory uses sectors to divide the GHG emissions. These sectors [**Figure** 3-8] from the national level can be scaled down to the local municipal level for a local inventory.

The sectors include – Energy; Industrial processes and product use; Agriculture, forestry and other land use; waste and others. Emissions at a local level can also be quantifies under the same sectoral headings; hence, local governments opt to use the IPCC guidelines for their inventories. The Draft international standard for city level GHG inventory is being developed jointly by UNEP, UN-HABITAT, World Bank and supported by Cities Alliance and is based on the IPCC.

Most standardized tools for the calculation of GHG Inventories in cities are also based on the IPCC standard with reference to the GHG Protocol for defining the scope of emission sources included. Where local data is unavailable, tools can use the national inventory data from the IPCC and scale it down to the local level for an estimation of the emissions. Though IPCC guidelines are comprehensive and for use in national inventories, they can be adapted to the local scale. The IPCC has a three-tier system when it comes to the accuracy of data used. Tier 1 uses global Emission Factor data, Tier 2 uses Country specific data where available and Tier 3 uses more detailed measured/ specific data. Many tools adapt these levels to classify data accuracy at the city level too.

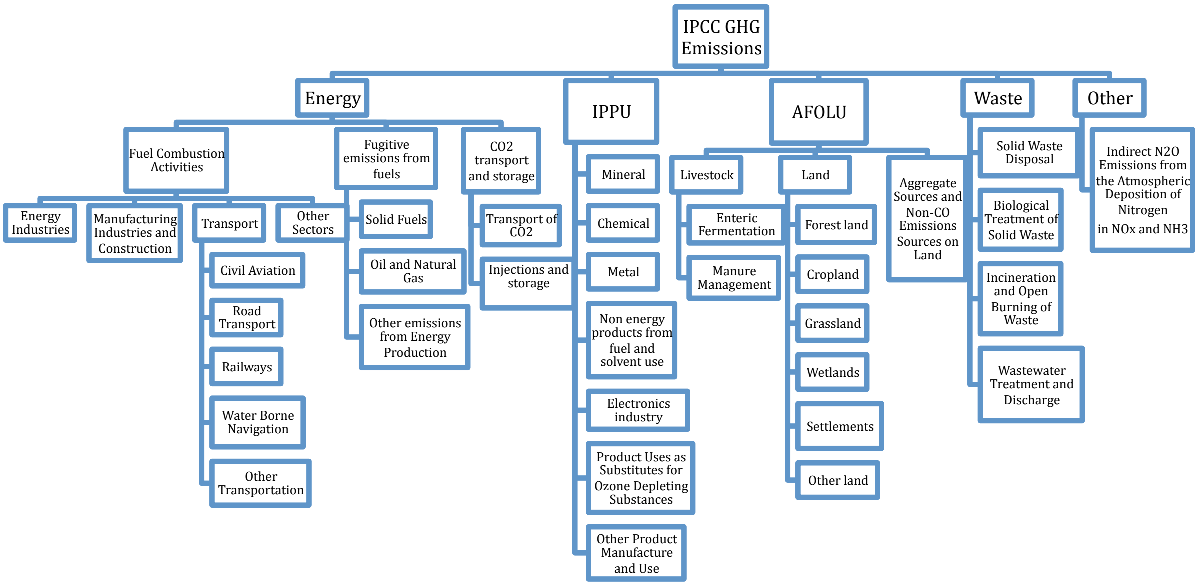


Figure 3-8: Sectors in the IPCC GHG Inventory recommendation

However, despite being based on the same international standard, local inventories differ on a lot of issues. They tailor the IPCC methodology to suit their local needs and issues, choosing some sectors and GHG gases and leaving others; differing in the way they define their municipal boundaries; choosing between IPCC scopes or differing in the attribution of emissions on a production or consumption basis; using different tiers of emission factors or different methods of activity data collection depending on availability. In the following review, these differences have been highlighted and the reasoning behind such differences discussed.

3.2.1.2 Standardized tools review

The review takes into account only tools that have been designed specifically for municipal level GHG inventorying. Although some urban and transportation planning tools incorporate a module for GHG emissions calculation, these have not been included in the review. This is due to the fact that the focus in these tools is mostly on the planning side and often the methodology used differs broadly from tools designed only for GHG calculation thus making it difficult to make comparisons between the two.

Table 3-1: Comparative Review of Standardized GHG Inventory Tools

	EMSIG	CO2 Grobbilanz	GRIP	BIlan Carbone	ECO2 region tool	The CO2 Calculator	ICLEI CACP	City Mayors CDP
Year	2002	2006	2001	2005	2002	2008	2009	2008
Methodology	Emissions factors	Emissions factors	Emissions factors	Emissions factors	Emissions factors	Emissions factors	Emissions factors	Emissions factors
Scope	1,2 ,3	1, 2	1,2	1,2,3	1,2,3	1,2	1,2,3	1,2
Territory	Point of use principle	Point of use principle	Point of Use	Point of use principle	Smart – Point of Use, Pro, Premium – Choice btwn Point of use /Gen	Point of use	Point of use	Based on tool used
Sectors	Heat, Electricity, Mobility, Waste Agriculture, Industrial processes, Solvent Use, Land Use	Heat, Electricity, Mobility, Waste Agriculture	Energy use, Grid Power generation, Transport, Waste, Process Emissions, Agriculture	Energy, Residential, Industrial Processes, Agriculture and Fisheries, Frieght, Transport, + *End of Life waste, Construction and roads, future waste fabrication and Tertiary*	Smart - Transport, Energy consumption by local economy, households and public authority Pro, Premium - Energy, Industrial processes, Solvent Use, Agriculture, LULUCF, Waste	Heat and Elec (Public and Individual), Transport and mobile sources, Industrial processes, Solvent Use, Agriculture, LULUCF, Waste	Electricity, Fuel Use and Waste Disposal	Buildings; Industry; Transportation; Waste; Fugitive emissions; Industrial process ;Utilities located outside the geopolitical boundary under municipal control Or Based on chosen method
Geographical scale	Community	Community	City/Local	Community and Local Authority	City	Municipalities	Community and Local Authority	Community and Local Authority
Temporal Scale	-	-	-	-	Annual	Annual	Annual	Annual
Measurement Variables	All 6 GHG Gases + CFC's	CO2, CH4, NO	All GHG	All GHG +CFC+ water vapour by planes	Smart - CO2 only Pro, Premium - All 6 GHG	CO2, CH4, N2O	All GHG, gives choice	All 6
Data	EF from Austria (GEMIS data); Stat. data by Austrian statistical services	EF from Austria (GEMIS data); Stat. data by Austrian statistical services	No preloaded EF; GWP based on 2nd Assessment Report	Preloaded EF for French Cities; GWP based on 4th Assmnt . Report	EF udated every Year – Eco Invent and GEMIS	GWP based on 3rd Assessment Report	Database of default EF	Based on Methodology chosen
Results	CO2-eq	CO2-eq	CO2-eq or Individual Gases	CO2-eq	Smart -CO2 eq; Pro/ Premium - Choice as per intl. convention	CO2-eq	CO2 Eq	CO2 eq
Visualisation	Spreadsheet	Web based	Web based	Spreadsheet	Web based	Windows Interface; XML database	Spreadsheet based	Online
Extra Features	-	-	Scenario modelling	Scenario modelling	Premium - Scenario modelling	Some Scenario Modelling	Scenario Modelling	-

The **CO2 Grobbilanz** tool was developed in Austria in 2006 as a simplified version of the EMSIG tool developed in 2002 by Energieagentur der Regionen. While the EMSIG tool includes all 6 gases from the Kyoto protocol as well as CFC's; CO2 Grobbilanz includes only CO2, CH4 and NO in its standard and expert modes. Both tools are based on data and Emissions Factors from Austria and display the result as CO2eq.

The tool is based on the point of use territory principle and includes the indirect emissions from electricity generated outside the territory. The territory principle does not apply to the transport. Transport outside the territory by the inhabitants is included.

All emissions by local industry, businesses, agriculture, stockbreeding, forestry are taken into account but freight transport is excluded in the CO2 Grobbilanz tool. EMSIG also accounts for life cycle emissions on an average basket of goods purchased by the inhabitants. CO2 Grobbilanz sectors include heat, electricity, mobility, waste and agriculture excluding industrial processes, solvent use and land use.

Emission factors are preloaded with Global Emissions Model for integrated Systems (GEMIS) data and statistical data provided by the Austrian statistical services and data calculated by the tool developers. EMSIG is an excel spreadsheet based tool and CO2 Grobbilanz is web based.

The **ECO2Region** tool was developed in Switzerland in 2002. The web-based tool has three versions – Smart, Pro and Premium. It has been used in 113 German and 83 Swiss cities and the Italian version has been tested on 10 cities. The Smart tool accounts for only CO2 while the Pro and Premium versions account for all 6 Kyoto gases.

The Smart tool includes the following sectors – Transport & Energy Consumption by the local economy, households and public authority. It does not include industrial processes, solvent use, land use, waste and agriculture. It accounts for primary energy i.e. emissions of whole fossil energy chain allocated to the point of use. Electricity generated within the territory but exported is not accounted for.

The Pro and Premium versions of the tool include all the sectors defined in the IPCC methodology along with all 6 GHG gases. The versions provide a choice of which territory principle to use – point of use or point of generation. These versions also include scenario modelling.

The starting mode of the tool takes two sets of data – Number of inhabitants in the territory and the number of employed persons working in the territory and creates the first estimates based on the average emissions for Germany, Switzerland and Italy. When this average estimate is replaced by more precise data, the difference has been observed at about 5%. The Emission factors are updated every year and inventory data for fossil fuels derived from Eco Invent and GEMIS. Whilst the basic version only includes energy and transport sectors, the pro and premium versions cover all IPCC section. The tool gives the option of using IPCC or Life Cycle Analysis (LCA) as the balancing method.

The very basic version of the ECO2 Region tool gives a very quick estimate of the energy use from electricity and transport in the city, which are two major contributors for any city. It's a good starting point and would encourage LA's to try the pro/premium version for a detailed analysis. It reports the results as per various international convention requirements and also facilitates scenario planning.

GRIP was developed in 2001 and calculates emissions of all six IPCC GHG gases. The result is presented as either CO2 eq of all gases or individual emissions of the gases. The sectors include energy use, grid power generation, transport, waste, process emissions and agriculture.

The tool has three levels of data entry depending on the accuracy. Level 3 is highest uncertainty data that comes from scaling down national or regional data and is depicted by a red entry field. Level 2 data is medium accuracy and comes from regional/local statistics or modelling and is represented by an orange data entry field while level 3 data is the most accurate usually being measured data and represented by a green data entry field. The tool does not provide any preloaded data for emissions factors etc. to encourage learning among city actors. The data on emission factors is usually sourced from the national UNFCCC reporting document or Eurostat webpage and the GWP values are based on the 2nd assessment report.

The tool is web based and is accompanied by a scenario-modelling tool, which explores the impact of differing energy demand, different fuel mixes and generation technology. While the inventory tool is free to use, the scenario tool is not.

The **Bilan Carbone**(ADEME) was developed by the French Environmental Agency in 2005, with subsequent version developed until version 5 in 2007. The initial versions were designed for companies and project. Version 5 of the tool includes a separate spreadsheet for local authorities. The tool calculates emissions of all 6 GHG gases specified by the IPCC as well as CFC's. It includes international aircraft and maritime transport. The tool is preloaded with French emission factors and uses GWP values from the 4th assessment report.

The tool was tested on 15 French territorial authorities in 18 months. Version 5 for local application has two modules – the heritage & services and territory. The two can be used independently or in conjunction. Like the ICLEI system, the heritage and services module calculates the GHG emissions from products and services owned and managed by the local authority, and works more like a companies GHG calculator.

The territory module refers to emissions attributed to the residents of the city and those resulting from the everyday processes in the city. It also investigates what combinations of emission reduction in different sectors will yield a total reduction of x. The tool uses a lifecycle analysis principle. It includes the GHG Protocol scopes 1, 2 and 3 emissions where applicable.

The tool is spreadsheet based and uses the IPCC guidelines. The margin of error is stipulated less than 20%, which is comparable to national inventories. An important principle the tool states and that must be reiterated is that the emission factors method works on orders of magnitude; the inaccuracies don't matter as long as the order of magnitudes can be used to instigate GHG reduction action. This is true for all tools. In the territory module, sectors are aggregated as per local application.

In addition to the IPCC sectors the tool also takes into account emission from the manufacturing of future waste – metal, plastic, glass, paper and cardboard. Emissions and sinks from forestland have been excluded as it is assumed that being intended for developed countries, there will be no deforestation. Also the benefits of carbon sinks from planting trees and fertilizing the ocean are difficult to quantify and much more research is needed to assess the effects. It includes construction and roads as one of the categories. It also tries to partially account for product use through the 'fabrication of future waste category'. Its uses the municipal emissions and territory emissions like the ICLEI method.

The **CO2 calculator** is a Danish tool developed in 2008 by the Danish environmental research institute. The sectors included in the analysis include – public electricity and heat, individual heating (household, industry, commercial and institutional), transport and mobile sources (road, rail, air, navigation, non road machines in industry, agriculture, forestry etc.), industrial processes, use of solvents, agriculture, LULUCF and waste. The model has over 400 input fields and the data entry is divided into tiers. The simplest tier estimates the emissions based on national inventory. The tool has a windows like user interface and uses xml databases.

The tool uses various tiers, so that at the simplest tier level, results are calculated based on national inventory to cover areas of data unavailability among municipalities. The tool also has the capability to provide GHG reduction potential for 37 mitigation measures. The tool is free, takes an estimated three weeks to compile and is to be used annually.

ICLEI CACP is software designed to help local governments quantify their operational and community GHG inventories by the International Council for Local Environmental Initiatives (ICLEI) – Local Governments for Sustainability Association. It is an international protocol that aims to help local governments calculate their emissions and also establish a global comparison framework. The methodology is based on IPCC sectors but is flexible, allowing local governments to choose what gases they account. It also has tiers for emission factors and activity data allowing the local government to use whichever accuracy level of data is available. While it requires governments to calculate all scope 1 and 2 emissions, scope 3 emissions are optional and can be reported separately. The success of the protocol owes it to this flexibility.

Local governments can mould the tool depending on the data and resources available to them. Quantifying the emissions separately for the organisational emissions of the municipal authority and those of the community defined by the municipality's geopolitical boundaries allows the local authority to focus its mitigation efforts first at its directly managed activities. The tool has been used by many cities across the world.

City Mayors CDP is a Carbon Disclosure Project that started with companies and has been adapted to cities in 2008. Whilst it does not require the cities to follow a set methodology, it encourages cities to report their emissions using any of the internationally available or locally created emissions inventory. It is an online reporting system to be used annually where cities are required to input qualitative information about the city and quantitative data about the emissions profile and the details of the calculation methodology.

It requires cities to report their emissions as CO2 eq and include scope 1 and 2 emissions. The CDP project collects the data and publishes a report each year on the status of GHG emissions from cities from various sources. It is useful to create a database of emissions profiles and provide benchmark data for cities.

3.2.1.3 Academic/Local Studies

There have also been many studies by individual cities to use GHG inventory as a policy tool. Many cities like New York, Broomfield, London, Shenyang, Rio Di Janeiro and Sao Paulo have attempted to inventory their emissions using standard tools or their own methodology.

Also, Several studies (ICLEI, 2009, Kennedy et al., 2009, Sovacool and Brown, 2010, Xi et al., 2011, D‚Äô Avignon et al., 2010) have calculated the carbon footprints of individual cities and a few others have compiled and analysed the emissions from a number of cities globally and nationally. The review presented here follows the same criteria as those used for the review of standardized tools. The review is in no way comprehensive and only takes into account selected reports and published studies.

The aim of the review is two-fold, first to identify the methodological differences and common factors to inform the creation of a framework for GHG inventory method for Indian Cities and second to compile a set of benchmarks that can be used later in the study to validate the results as well as identify drivers of emissions in Indian cities to inform policy.

The variations in the way a GHG inventory is conducted in cities is evident from both the tools' review as well as these individual studies.

Table 3-2: Comparative Review of GHG Inventory Reports and Studies

	New York City	London	Broomfield	Shenyang	Rio Di Janeiro	Sao Paulo	44 world cities	12 Metropol. Cities	54 South Asian Cities
Year	2005-2008	2008 based on some 2006 data	2007	2007	1990-1998 (prep. 2003)	2003	2005/2006	2009?	2007
Methodology	LGOP, Emissions factors	Emissions factors	Hybrid LCA, LGOP	Draft International Std for City GHG Inventory	Dev. By Alberto Luiz Coimbra Eng. Grad. School & Research Center	Emissions factors based on IPCC	Emissions factors based on IPCC	Various	Based on ICLEI CACP and LGOP
Scope	1,2 ,3	1, 2	1,2,3	1,2	1,2	1,2	1,2,3	1,2	-do-
Territory	Point of use principle	Point of use principle	Point of Use principle	Point of use principle	Point of Generation principle	Point of use & generation	Point of use	Point of use & generation	-do-
Sectors	Heat, Electricity – Buildings, Mobility, Waste, fugitive + Aviation and Marine	Heat, Electricity, Gas, Non-Transport Petroleum, Water	Building electricity & Gas, Surface & Air Transport, Waste + Key Embodied Materials	Energy, Industrial Processes, AFOLU, Waste, Marine, Aviation	Energy, Tranport, AFOLU, Agriculture , Waste, Sewage, Power Gen	Energy, land use, agriculture, waste, sewage, Aviation	Energy+ IPPU, AFOLU, waste, Aviation, Marine	Transport, Energy in Bldngs & Industry, Agriculture and Waste	-do-
Geographical scale	Community and Local Authority	Square Mile (Core of the city)	Community	Community	Community	Community and Local Authority	Community	Metropolitan Area	-do-
Temporal Scale	Annual	-	Every 2 yrs intended	-	-	-	One time Benchmark	One time Benchmark	One time Benchmark
Measurement Variables	All 6 GHG Gases	Only CO2	CO2, CH4, N2O	CO2, CH4, N2O	CO2, CH4	CO2, CH4	All GHG	-	-As Per ICLEI CACP-
Data	EF from LGOP and CACP 2009	EF from DEFRA services	Elec EF calculated for city mix, ICLEI	2008 EF for China	EF IPCC	IPCC	Collated from various Studies	Various	-do-
Results	CO2-eq	CO2	CO2-eq	CO2-eq	CO2-eq	CO2-eq	CO2 Eq	Carbon	-do-
Available as	Report	Report	Report	Published Paper	Published Paper	Published Paper	Published Paper	Published Paper	Report
Prepared by	City hall NYC	URS corporation ltd.	University of Colorado	Xi et.al	Avignon et. al.	Avignon et. al.	Kennedy et. al.	Sovacool & Brown	ICLEI South Asia

Whilst the tools do provide the option to compare inventories made using the same tools; the comparability gets harder in the case of individual city inventories where methodologies may be highly divergent. For example, in the review above, the study by Sovacool & Brown (Sovacool and Brown, 2010) on the 12 metropolitan city regions provides the results in Carbon, which cannot be compared directly with the results from the other inventories.

The inclusion and exclusion of sectors and scopes presents another challenge, with cities like London limiting their calculation boundary to a rather confined area compared to other inventories. City inventories like those of New York, Sao Paulo, Shenyang and Broomfield are more extensive with New York City being the most extensive of all, covering all gases and all sectors of the inventory. The year the inventories were calculated in and their subsequent follow -up should also be considered in a comparative study. While some cities follow annual update procedures, others may not. Mostly, these studies are either conducted by the city authority themselves or in partnership with organisations like ICLEI or Universities and Research Centres.

So far as the compilation studies go, these are usually meant for creating databases for benchmarking emissions from cities against each other. These can be very useful for studies like this thesis, to help validate the results of the inventory conducted. Figure 3-9 and Figure 3-10 present the findings of two international comparison studies. In the first study (Kennedy et al., 2009), 44 urban regions were examined. All the cities in the analysis follow the IPCC methodology with the WRI concept of scope 1/2/3 emissions. There are differences in what sectors are accounted for especially with regards to the accounting of aviation and marine fuel. Figure 3-9 presented here includes cities GHG emissions excluding the marine and aviation results. The results are calculated in tonnes CO2 equivalents per capita.

It must be noted that in Figure 3-10 the unit for measurement is carbon instead of CO2. This study (Sovacool and Brown, 2010) examines 12 global cities. Again there are a few differences in the sectors accounted for. This study also compares the per capita carbon emissions with the national averages. The national averages data has been sourced from the IEA and WRI.

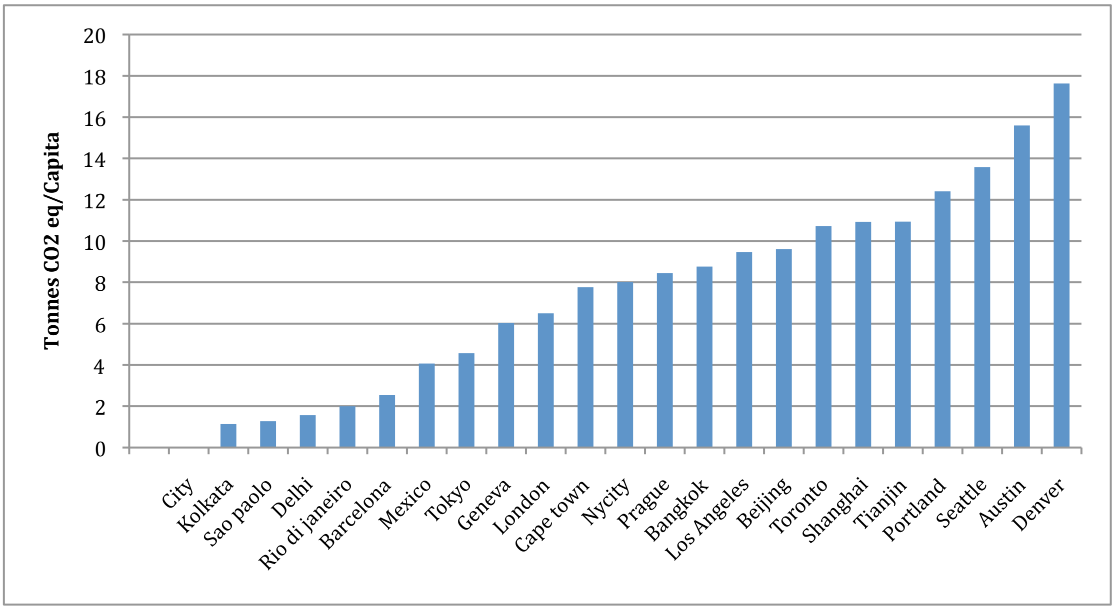


Figure 3-9: Per Capita CO2 eq. Emissions from Global cities Excluding Aviaton and Marine; Source: Kennedy et.al.

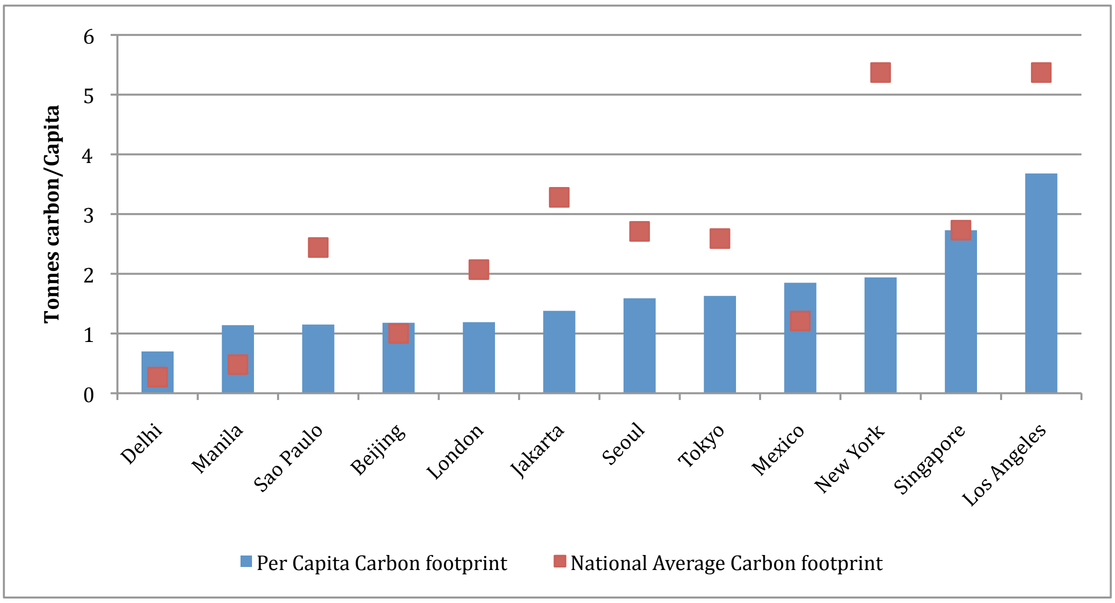


Figure 3-10: Per capita Carbon (C) Emissions From metropolitan regions compared to National Averages; Source: Sovacool & Brown

Both the studies found that carbon footprints varied a lot from city to city despite accounting for the slight variations in methodological approaches. Kennedy et al. recommend ways to streamline the GHG inventory process across cities and call for more work in the area of consumption based urban accounting. Sovacool and Brown (Sovacool and Brown, 2010), on the other hand, try to identify the factors that affect carbon profiles of cities summarising that compactness and density, sustainable transport, low carbon electricity and limited incomes bear a positive correlation with low carbon emission.

The ICLEI has reported emissions from 54 South Asian cities (ICLEI, 2009), 41 of those in India, and the report can be seen as an apt source of benchmarking data for Indian cities. The methodology is based on the IPCC and is well established. As per this report, emissions [Figure 3-11] from cities in India ranges from 0.14 t/cap/yr to 2.76 t/cap/yr. The average range for most cities is around 0.76t/cap/yr; higher emissions come from largely industrial towns.

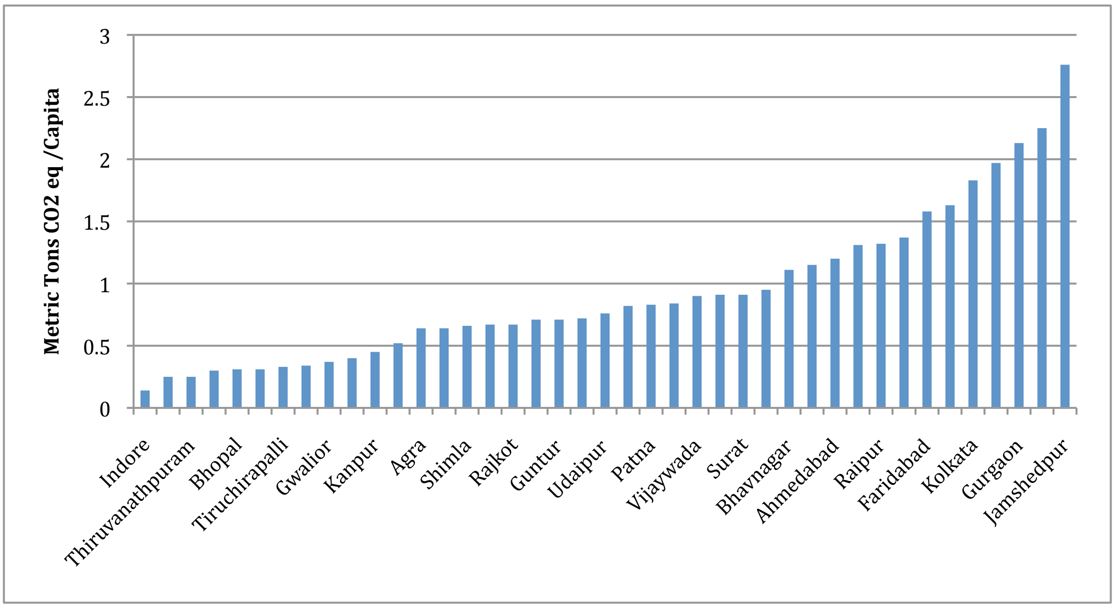


Figure 3-11: Per Capita CO2 Eq Emissions from 41 Indian Cities 2007; Source: ICLEI South Asia

The ICLEI method accounts for emissions from 5 major sectors – Residential, Transportation, Commercial, Industrial and Waste. In most cities, keeping aside industrial towns where the industry emissions dominate, the residential sector consumes the most energy, followed by transportation.

However, there is a lack of much research on the embodied energy and corresponding carbon emissions in urban areas, it needs further investigation. More so in developing nations where a lot of investment is geared towards adding and updating city infrastructure including buildings, roads and other service network. This would give an opportunity for developers and policy makers to not only reduce the operational emissions but also the embodied carbon in the city. A case study (Fridley, 2010) on embodied and operation emissions from a city in China has shown that the embodied energy content forms 74% of the total energy use in the city of Suzhou, corresponding to 8647596 T/yr embodied carbon. Within this embodied energy – the residential living consumption partakes 79%, city infrastructure 7%, embodied energy/carbon in residential buildings 10% and other buildings 4%. It shows that embodied energy is an important part of the carbon inventory and should be considered.

A similar case can be made for cities in India, and further investigation will help policymakers direct policies towards reducing the embodied carbon in cities along with the operation emissions.

3.2.2 Review Discussion

The review indicates that even though based on the same principle, local GHG tools in use today differ on a broad number of issues including the methodologies, scope, territory, geographical and temporal scale, measurement variables, results and result visualisation. Most tools use a top down method estimating the emissions by scaling down national/regional data using the IPCC guidelines as the basic principle but differ in the gases that are accounted for and the scope, sectors covered and the IPCC tier used. These inconsistencies make it difficult to make direct comparisons but also highlights that there are a lot of differences in local governance methods and data availability at the local scale which influences these tools.

Although the incongruity is a setback for global comparisons, it is also indicative of the importance of local priorities and enables local governments to mould the tool to most efficiently cover the areas that their municipalities need to focus on in order to achieve maximum GHG reduction. It must be noted that this list of tools is not exhaustive; the tools in the list have been selected because they are strictly meant for local authorities GHG calculations and are the most quoted/reviewed tools for the purpose. Information availability was also a concern in the selection. The language used was a matter of concern for the review and posed some problems but they were not constraining.

The discussion can be focused on two areas – Methodological Issues and Benchmarking Data.

3.2.2.1 Methodological Issues

Flexibility is the key to local scale inventorying. As can be seen from the review, most tools have inbuilt flexibility to allow Local authorities to customise the tool according to available data.

Data availability, thus, is another key factor. Most Local authorities would like to work with what data is available, since trying to look for better data will be both time and resource consuming for the Local authorities and often considered an unnecessary expense. So where local data is unavailable, provision for downscaling national data is provided. For most Local authorities this flexibility is much appreciated but when it comes to having a common tool to facilitate global comparisons, this becomes a problem. Although it can be assumed that comparability on a national scale will be comparatively easier to achieve, since the data collection practices as well as the context within a country will be analogous.

Transparency in the methodological and data assumptions is important to allow for validation and for the results to be replicated and compared. Since there are provisions for choosing between scopes and methods, this emerges as an important requirement.

Another important point that emerges is regarding the units used for comparison especially on a global scale. While on a per capita basis the results of emission may seem very low, it is important to keep in mind that India is the second most populous nation in the world and is fast approaching China in population numbers. So on an aggregate level, the low per capita emissions eventually add up to large numbers owing to the high population.

3.2.2.2 Benchmarking Data

The review of the GHG emissions data from cities around the world reveals that there is a large range in the per capita emissions. While cities from developing countries mostly have low per capita emissions, those from developed nations can go as high as 18 tons per year. To cities in a developing country this statistic may present a false sense of security and a resignation to taking any action, but it is also a great opportunity to check, if not reduce, the emissions that are continually on a rise.

It can't be denied that development and emissions are intrinsically linked in the current world scenario, so as these developing nations improve their economic well-being and lifestyles, population in urban centres soars and so does the energy use and emissions. Thus, it is only natural for governments in developing nations to learn early from the mistakes of the west and strive for sustainable development.

Considering the large difference in emissions from cities in India compared to cities in the west, it does not seem very useful to use international benchmarks as a comparison for Indian cities. This also reinforces the need for a country specific methodology and benchmark data.

3.3 Conclusion

Cities form the stage for the human-environment interaction and the goal of urban sustainable development aims to balance this so that the economic growth is maintained without negative pressure on the environment. Thus the metabolic process of cities is important to sustainable development. With reference to the purpose of this research, this differentiation of sustainability being perceived as a process rather than a goal is essential. From the review of the literature on city process and sustainable development, several fundamental inferences can be made.

The goal is to promote a sustainable city process, moving away from the unsustainable linear model of city metabolism and also shifting from a deterministic planning ideal to one of relativity and embracing the chaos represented in the city system instead of fighting it. It is also important to shift the longstanding tradition of disaggregated governance structures in cities, particularly in the Indian context, towards more holistic thinking and better coordination.

Whilst the goal is always important, in the context of this study, the background of the urban governance context and the problems that it presents in the form of unclear roles and responsibility of the city agencies and the lack of revenue and capacity make it essential to approach this research from a process perspective.

The choice of GHG inventory as the driving indicator for cities in developing nations to promote urban sustainability comes as an inference from the study of global issues of climate change and global warming and the need for sustainable development and also the problems large indicator systems bring and most importantly the local context of urban Indian cities and their priorities and problems. The need for sustainable development is indisputable and the local context of adverse impacts and the high vulnerability as well as the high development rate and its related opportunities make Indian mid sized cities the ideal scale to introduce policy intervention measures. And with a GHG inventory, these cities can address one of the most vital issues faced by our generation while also getting a chance to generate revenue and promote a better quality of life.

A GHG inventory interlinks all three dimensions of sustainability. It evidently is an environmental issue but economy is also a key driver for the anthropogenic emissions and as such needs to be addressed as part of the mitigation strategies. The social choices of lifestyle and quality of life can make a significant impact on the emissions and thus, it is not only an environmental issue but the relationship between the socio-economic-environmental processes in the city that all need to be focused on to address the issue of global warming.

The final research question that is formed as the result of this review of associated literature is -

'How can a GHG inventory be used as a policy tool for promoting sustainability in Indian Cities – its process, method and applications?'

Lastly, for the methodological basis, the review of the GHG tools and methods provides some key inferences that will drive the research approach. While all tools and studies are based on the same IPCC base methodology, they are still diverse in the issues addressed and the process and data used. The two key elements that have been iterated in the design of each tool or method are its flexibility in terms of data use and issues inclusion.

There is always more stress on the local issues and availability of data than on the need to standardize the process to ensure global comparison. The prime issue that needs to be addressed for any GHG inventory is the choice between Global standardization and comparability or Local priorities and monitoring. The focus of the research is not on the accounting tool itself rather on its process and its application as a policy instrument.

A critical observation for the benchmarking data is that when using per capita values, the cities should be benchmarked against their Indian or other developing nations counterparts, whereas, to benchmark against global city emissions, aggregate total emissions data must be used to avoid a false sense of security at the low per capita values and give a clearer understanding of the scenario.

The last two chapters have been instrumental in gaining a deeper understanding of this research's context and have helped focus its research aim, questions and objectives. As illustrated in the research process diagram in Figure 4-1, the literature review exercise helped identify the gaps in the current knowledge base that will be addressed through this research.

This research is a case study based investigation into the possibility of calculating GHG emissions from cities in developing countries using data already available with the local government and its use for policy making. This chapter describes the method used for this research, the argument for the case selection, the procedure for conducting the research and the ways of analysing and presenting the results.

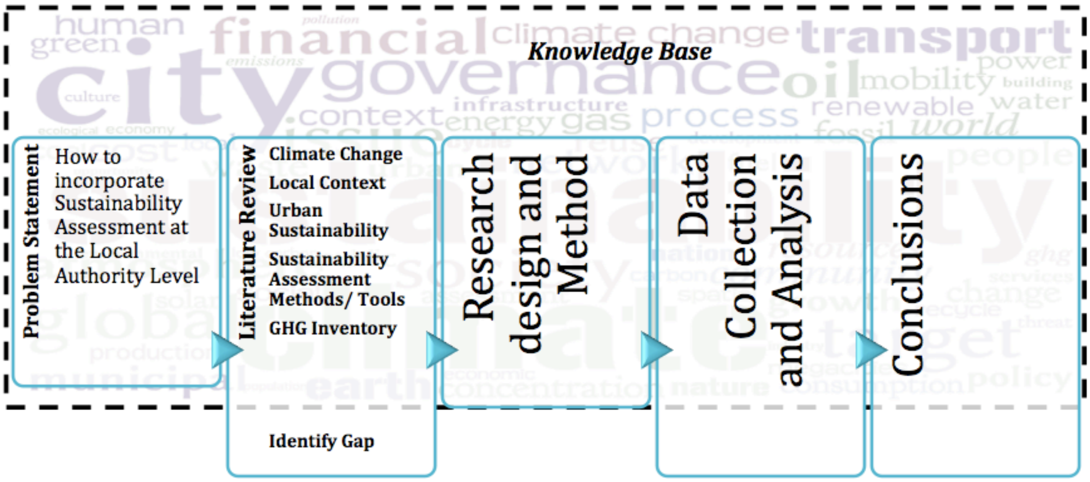


Figure 4-1: Research Process progress

4.1 The Rationale

The previous chapters gave an overview of the need to reduce GHG emissions with a special focus on cities in developing nations in an overall global context. In the literature review, comparative analyses of tools used by municipal communities and an appraisal of local context in cities in India led to the inference that the use of tools with many indicators that are data and resource intensive may not be viable in the local context.

The context, as described in the literature review, is rather different for developing nations. The issues concerning local authorities in developed nations differ significantly from developing nations, as do the resources at their disposal. Whereas local authorities in developed nations are mostly concerned with improving service delivery, local governments in developing countries are plagued with issues of expanding infrastructure, providing basic amenities and dealing with squatter settlements as a priority. As such, while a number of authorities in developed countries now have sustainability and GHG monitoring at the top of their agendas and can invest resources into the development and implementation of tools and policies to this effect; these issues rank low in the priority list for local governments in developing countries.

In such a context, to encourage local authorities to adopt a GHG emissions inventory, mitigation and monitoring, the tool used will have to be specifically designed to use minimal resources and time and address the issues most relevant to them. It will be a step forward in promoting sustainability in developing communities. As has been noted a quantitative assessment method, that can be monitored regularly to assess the effect of policies is more acceptable to authorities.

Having established the case for a GHG inventory, the previous chapter also explored the various methods of doing it. Whilst the specific protocol for urban scale GHG inventory is in draft form and the currently used methodologies and tools are adaptations of the IPCC standard for national inventories, it was found in the literature review that often, the top down methodologies based on the international standard and scientific methodology for GHG calculation are not compatible with the local scenario in terms of data availability.

This results in modifications being made at the local scale to accommodate the data paucity and thus compromises the comparability potential of emissions across various cities. An inventory is designed to help local governments identify their emissions' scenario and implement policies. As such, the requirements for any inventory tool are to be comprehensive, easy to use and, time and resource efficient.

The basic top down methodology is built on the literature review of international standards taking the draft version of the international standard for urban GHG and IPCC guidelines as the foundation and corresponding local applications as guides for adaptation. The conceptual methodology is assumed to sit in an ideal context with no constraints. It is evident from the comparative analysis of local GHG methodologies/tools, that amid real world constraints, these methodologies need to be modified and adapted to suit local conditions and needs. The evaluation helps choose a methodology suitable for this research taking into account the data that is available and the system boundary and time constraints that bound the research.

4.2 Method

A Case study research method has been employed in this research. The argument for the use of a case study method can be inferred from the literature review. The literature review shows that the international methodologies and guidelines are based on an ideal case assumption and often need to be modified for local application. Although most tools use the same international standard – IPCC, there are as many adaptations of the guidelines as are tools. Even when using the same tool, inventories may differ in the data/method used as per their data availability as identified with the ICLEI tool. Several studies have identified this gap in international protocol's data requirements and local governments data availability (Kennedy et al., 2009, Ramaswami et al., 2008, Xi et al., 2011).

In the real world scenario, the recommended data for calculations is often not available. Such cases of data paucity require an intervention in the methodology to find alternative data and methods to estimate the emissions.

A case study based research design has been used since an action-based research with a case study helps test the framework and develop it within the real world constraints. The aim is to start with a top down methodology, apply it to the case study city, and explore the inconsistency in the recommended and available data and then, to modify the methodology as per the data available. Since local standards for data are still not in place and the recommended data is spread over a number of government organisations, the process of data collection also gains importance. An exploration of the process will help identify the problems and associated gaps and thereby help in streamlining the process and improving data quality in the future.

Xi et al. (2011) identify that, 'Most protocols and methods focus on accounting for the total amount of GHG emission but are not specifically designed in a manner that fits local statistical data for inventorying and facilitates urban decision makers to prepare their low carbon development policies.' And the 'need for local governments to understand not only the total emissions but also detailed perspectives from different sectors and geographical areas within their territory.'

Adding to these observations, Weisz and Steinberger (2010) highlight the prevalent problems in the area – of lack of data, no common definition of a city or urban region, openness of cities with material flows happening at global scale, dematerialization vs. securing access or the problem of overcoming energy poverty while trying to reduce energy use especially in the developing countries and the relevance of urban scale or identifying which components of material and energy systems are specific to urban scale.

As Xi et al. (2011) recommend, "*There is a need to initiate case studies so that a feasible method of presenting the whole carbon emission picture at city level can be raised*."

Moreover, the utility of such a tool is to specifically inform policy makers to facilitate decision-making. Hence, a third component is the possible application of the inventory in the policy making process.

4.2.1 What is a Case study research?

A case study as a research method looks at the setting as a whole, describing the context, the actors involved and the process as well (Gagnon, 2010). A case study can have several purposes – 'provide description, test a theory or generate a theory (Eisenhardt, 1989)'.

The case study research method in this thesis is employed to test a theory and refine it with an aim to look at the real life context and relate the theoretical idea to practical implementation. A case study may have singular or multiple cases and can be descriptive, comparative or analytic. (Gagnon, 2010, Gillham, 2000, Davies and Beaumont, 2007)

Case study research involves three stages – Pre-processing, Processing and Post-processing. In the preprocessing stages, the research question is established, case/s selected and data sources and analytical techniques defined. The processing stage is where data is collected and evaluated or analysed. The post-processing involves reporting the process and results.

Pre-processing (Gagnon, 2010, Soy, 1997, Yin, 2009)

1. Frame the research question
2. Choose Case study (Single/Multiple)
3. Determine data sources and analysis techniques

Processing

4. Collect data
5. Analyse and interpret data

Post-processing

6. Report the results

It is also essential in case study research to ensure the validity of the process and the reliability of the results. The following four points (Davies and Beaumont, 2007, Gagnon, 2010) must be considered –

1. Construct validity – The selection of the case must be suited to the research objectives. The method of analysis must be carefully selected, as should be the process of data collection and the sources of data.
2. Internal validity – The process, data and analytical method must be described, and where possible different methodological tools should be used to triangulate data.
3. External validity – The results should be comparable to other cases and replicable.

4. Reliability – Confirm the accuracy of the results by proving other researchers would lead to the same conclusions in the given scenario.

As part of the preprocessing, Robert K. Yin (Yin, 2009) identifies five important components of research design – 'A study's questions, its proposition, its unit of analysis, logic linking the data to proposition and criteria for interpreting the findings.'

4.2.1.1 Study's questions

The main research question in this study is – 'How can a GHG inventory be conducted (its process and method) in cities in developing countries and how can it be used to inform policy?'

The question is to first see how the established methods of GHG inventory can be adapted to the said context with a focus on the data requirement, availability and collection process. Secondly, conduct and analyse the GHG inventory for the case study city by seeking alternative methodologies as per the data availability. And finally, to explore the applications of the tool and analysis results as a policy instrument to introduce GHG reduction.

Four major components can be identified through this research question – the process, the method, analysis and the applications, which form the four focus areas of this research.

4.2.1.2 The Proposition

The aim of the research is to create, test and apply GHG inventory as a policy tool for local governments. The research looks at conforming the local data to existing GHG inventory method with a view of using data available with the local government to minimize the use of resources.

The purpose of the thesis thus, is not only to calculate the emissions from the case study city, but also to highlight the process of applying a top down methodology to a local case. And in doing so, to identify the sources of data, gaps in recommended data availability and to help streamline the collection and calculation process. Finally, the thesis proposes policy guidelines based on the results of the calculation.

4.2.1.3 Unit of Analysis

The basic unit of analysis or the case is a city, geographically bounded by its municipal boundaries. A city can be defined in material terms by the infrastructure that makes and supports it, that is, the buildings, the roads, the sanitation, water supply infrastructure etc.; and in process terms by the movements of goods and services and the socio-economic dynamics that make it.

Carbon emissions in the city result from an interaction of these elements. Energy is used in making and running as well as within the buildings, in the modes of transport that support the movement of people in the city, and in the making and running of the infrastructure support network that feeds the city, it all leading to GHG emissions.

4.2.1.4 Logic linking data to proposition

The data collection must be focused on the requirements of the research question. The data for this research is collected in the form of both quantitative data as well as observational qualitative data. The quantitative data is based on this research's adaptation of recommended methodology for GHG inventory. In case this data is unavailable, alternative methodologies are explored and requisite data collected. The observational qualitative data is a record of the process of data collection and any challenges faced therein.

4.2.1.5 Criteria for interpreting the findings

Several methods are used to interpret the findings. For the process, a descriptive analysis of the city's governance structure and its policy making process. The method and analysis includes several kinds of data interpretation techniques including time-series and comparative analysis to establish the validity of the results and also seek patterns over time. The applications are supported by predictive analysis.

4.3 GHG Inventory Analysis

GHG inventories are a complex goal and various methodologies make it even more perplexing. There can be various top down or bottom up methodologies to estimate the emissions from a city – region. A study (Hamilton et al., 2008) on two cities in Australia assessed the differences in the result that arrive from using three different approaches to the inventory. The first was top-down from state level statistics on a per capita basis based only on population; the second was a hybrid methodology much like the objective of this study that identifies data and uses Emissions Factor (EF) to estimate the emissions and the third was based on the Cities for Climate Protection (CCP)[7] data.

The results show a large variation in total emissions estimates with the Top down methodology overestimating to a large extent. Between the two bottom up hybrid methods there was much more consensus with lower estimates that relate better to the local scenario.

The following sections explore the various methodological options and issues related to urban GHG emissions inventory and define the basic final framework of the method used in the case study. The first section explains the international protocol for the calculation of GHG inventories. Based on the previous section of the context analysis that identifies the needs and requirements of a local scale inventory, the final section, a framework for a local scale inventory is proposed, based on the international protocol but modified to suit the local scenario.

It is imperative to clarify the scope, territory, geographical and temporal scale, measurement variables and methodologies used when accounting for greenhouse gas emissions. In other words, explore the what and how of a GHG inventory. This includes the following questions –

4.3.1 What is being measured? – The GHG gases and the sectors

The 2006 IPCC protocol covers the following gases - carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), nitrogen trifluoride (NF_3), trifluoromethyl sulphur pentafluoride (SF_5CF_3), halogenated ethers (e.g., $C_4F_9OC_2H_5$, $CHF_2OCF_2OC_2F_4OCHF_2$, $CHF_2OCF_2OCHF_2$) and other halocarbons not covered by the Montreal Protocol including CF_3I, CH_2Br_2 $CHCl_3$, CH_3Cl, CH_2Cl_2 .

[7] http://www.environment.gov.au/archive/settlements/local/ccp/

The Kyoto Protocol refers to the following gases: CO_2, N_2O, CH_4, sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

However, the literature review of the GHG tools showed that most tools choose what gases to report for. While a few report emissions of the six Kyoto protocol gases, others choose to report only for CO_2 or CO_2 and CH_4, which are the two main contributors to global warming.

CO_2 being the most abundant and contributing almost 75-85% of GHG emissions, it may be decided to calculate CO_2 emissions only. In case emissions of other GHG gases are included, they will usually be converted into CO_2 equivalent (CO_2e) units.

The IPCC refers to four major sectors to be included in national inventories - Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Use (AFOLU), Waste, Other (e.g., indirect emissions from nitrogen deposition from non-agriculture sources) with each sector further subdivided into several categories.

The draft International Standard for Determining Greenhouse Gas Emissions for Cities (UNEP et al., 2010) recommends the use of the same sectors in quantifying GHG emissions but identifies that in some cases, emissions from some sectors can be almost insignificant and would be a waste of resources to try and quantify them. It mentions, "To be pragmatic, cities may follow the IPCC guidelines for identifying and reporting on *key categories* of emissions, the sum of which represent at least 95% of total emissions. In many cases, AFOLU emissions for cities may be too insignificant to report; IPPU emissions may also be insignificant for some cities."

Among the IPCC sectors, energy i.e. stationary and mobile emissions are the main contributor in the urban scenario, followed by emissions from waste. In industrial cities the IPPU sector may have a larger share. In most cases, AFOLU will have only a marginal impact.

4.3.2 How is it being measured? – The quantifying method

There are four main methods of quantifying GHG emissions defined in consistency with IPCC (IPCC, 2006) and WRI guidelines (Bader and Bleischwitz, 2009)

4.3.2.1 Emissions factor based method

This is the most widely used method owing to its simplicity and limited data requirements. There is no need for site-specific GHG data in this method. It uses a coefficient (Emissions Factor) that quantifies the GHG emission based on activity. So that only activity data is required to estimate the emissions. It uses the following equation –

$$E = A*EF \quad \textbf{Equation 4-1}$$

Where, E – Emissions from a defined activity in Tons CO2

A – Activity Data like fuel use (Tons) or electricity use (MWh)

EF – Emissions Factor for fuel use (Tons CO2/Ton Fuel used) or electricity use (Tons CO2/MWh)

A list of emissions factors from various activities is available from the IPCC.

4.3.2.2 Mass balance method

This is a process-based method that uses the law of conservation of matter and follows the carbon cycle in a process. This can only be applied where data is available on the input/output streams and all chemical reactions. The mass balance method can be represented as -

$$Input = Output + Emissions \quad \textbf{Equation 4-2}$$

4.3.2.3 Predictive emissions monitoring system (PEMS)

This method uses direct measurement as well as predictive calculations. A correlation test is used to determine the relationship of different process parameters with GHG emissions using measured data and is fed as input into mathematical models that calculate GHG emissions.

4.3.2.4 Carbon emissions monitoring system (CEMS)

The last and most difficult is the Carbon emissions monitoring system where actual emissions from a process or facility are measured. It is the most accurate but cannot be applied to large-scale GHG inventories.

The CEMS and the PEMS methods require measured data and are thus unsuitable for large-scale inventories. These are more suited to process inventories for industrial applications. The mass balance method requires inputs for the whole carbon cycle that is difficult to define in an urban inventory since the scope is variable.

Among these four methods, the only method directly applicable to urban GHG inventorying and the one used in most urban inventories is the emissions factors based method. Using the emissions factor based method; different approaches can be applied for quantifying urban GHG emissions.

It can thus be established that the emissions factors based method for calculating city emissions is the most efficient and cost and time effective way to address the issue of carbon emissions from cities.

4.3.3 What are the factors influencing quantification method?

A number of factors influence the GHG inventory depending on the data used as well as how the scale and the range to be included in the inventory are defined. Another important factor that influences GHG accounting is the attribution of the emissions.

For instance, as defined by the IPCC, electricity emissions fall under indirect emissions where in the energy (electricity) may be used within the city but the generation is outside its geographical boundaries i.e. the actual emissions take place outside the system boundary. Emissions in this case can either be accounted on a ‘point of generation’ or a ‘point of use’ principle. The ‘point of generation’ principle accounts for the emissions at the power plant which makes it possible to use the third tier of the methodology.

The actual emissions from a power plant can be measured to give an accurate measure. However, when inventorying emissions from an urban region, it is more common to use the 'point of use' principle and allocate the emissions to the end user i.e. the buildings and infrastructure in the city. The draft International Standard for Determining Greenhouse Gas Emissions for Cities stipulates that out of boundary emissions from generation of electricity must be accounted for in the cities. Using the emission factor based method and the 'point of use' principle; emissions from electricity use by different sectors in the city will be calculated.

The three-tier system of the IPCC methodology applies to the use of emissions factors that can be IPCC standard (Tier 1) or country specific (Tier 2). Tier 3 would usually use detailed emissions modelling or CEM measurements and hence will not require emissions factors. The three-tiers can also be applied to the activity data where the detail of the data will determine the tier and accuracy of the emissions estimation.

In an ideal scenario, a tier-3 activity data level would refer to measured electricity use data for each building in the city. Collecting the data at the individual building scale in a city however, is cost and time prohibitive. As a top-down tier-1 approach, data from the electricity sales within the city available from the electricity companies may be used. The data is usually available on a sectoral basis for the city.

This though would only provide an aggregate sectoral emissions scenario for the whole city. To provide a more comprehensive smaller scale emissions scenario, zonal sales data, if available can be used to enable better analysis of the geographical distribution of the emissions. A variation of the bottom up tier-3 scenario can be to use energy audit data for public/institutional buildings, which may be more readily available, combined with benchmark data for different building types and/or modelled consumptions where benchmarks are not available. This level of detail is especially useful when modelling future scenarios to assess the effect of building scale interventions to reduce emissions.

From the above example, several important issues related to GHG calculations can be extracted. When making a GHG inventory, it is important to define the

Scope, Territory, and System Boundary as well as to make clear the Tier used both for activity data and the emissions factors. While all efforts should be made to calculate tier 3 emissions, the availability of data at different scales needs to be carefully considered.

4.3.3.1 Scope

GHG generation on an urban scale can be classified into three types (IPCC, 2006).

1. Direct emissions

These are emissions that are produced within the geographical boundaries of the city through direct use of Primary energy sources like oil, natural gas and coal. In urban boundaries these emissions would come from cooking, heating and cooling of buildings, transport, industrial use, power generation, solid waste treatment and urban agriculture. These are the easiest to account for and are usually calculated on a sectoral basis. The sectors include – Transport, Residential, Industrial, and Commercial/Institutional etc.

2. Indirect emissions

These account for emissions from secondary energy produced from primary energy (Electricity) consumed within the city but produced outside its geographical boundaries, meaning the actual emissions take place outside the city.

3. Emission from goods and services consumed within the city

This is the most difficult of the three to account for and includes emissions from all goods and services consumed within the city boundaries regardless of where they are produced i.e, where the actual emissions take place.

Scope [Figure 4-2] refers to the three above-mentioned types of GHG emissions. To provide a true picture of urban GHG emissions, it’s important that the scope is defined forthwith and will depend by and large on the availability of data. Whilst the data for direct and indirect emissions is relatively easy to find, emissions from goods and services are more elusive to define.

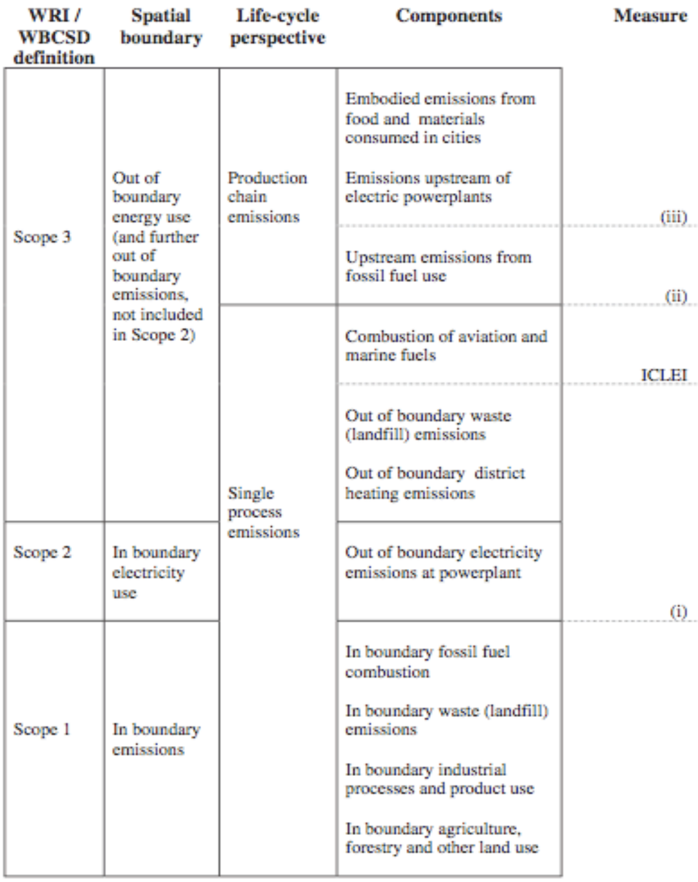


Figure 4-2: Definition of Scope; Source: Kennedy et. al. (2009)

The draft International standard for determining GHG emissions (UNEP et al., 2010) for cities identifies that it is impractical to account for all emissions from goods' consumption in a city. It requires cities to include –

· Out-of-boundary emissions from the generation of electricity and district heating which are consumed in cities (including transmission and distribution losses);

· Emissions from aviation and marine vessels carrying passengers or freight away from cities;

· Out-of-boundary emissions from waste that is generated in cities.

4.3.3.2 System Boundary

The system boundary will define the geographical and temporal boundary. With ever growing urban boundaries, especially in the fast developing Asian cities, it becomes essential that the geographical area is well defined. The temporal scale for emissions is important in fast developing cities as the emissions dynamics can change very rapidly. Hence, emissions need to be calculated at frequent and regular intervals to understand the energy use and emissions dynamics and also to monitor policy effects.

Most cities use the municipal boundary as the geographical extent and one year as the temporal scale for GHG accounting.

4.3.3.3 Territory

Along with that it should be made apparent for indirect emissions accounting if the calculations are done on a 'Point of use' principle where emissions are allocated to the city where energy is used or on a 'Point of generation' principle where the emissions are allocated to the city where the energy is produced.

4.4 Research Design

The Aim of this research is to '*investigate the process and method of using a GHG inventory as a policy tool in tier III Indian Cities within their local governance structure and using existing datasets to identify the opportunities and barriers.'*

Table 4-1 presents the research question in the four modules of the fourfold approach of this thesis.

Table 4-1: Research questions

	Research Questions
Process	What is the governance structure of the city and how does it affect data collection?
	What are the major sources of data and how can they be accessed?
	How coherent is the available data with the theoretical requirements and what are the alternatives?
Inventory	How is a GHG inventory conducted and what are the data requirements?
	What alternative methods can be used to overcome data paucity?
	What is the Carbon footprint of the case study and how **does** it relate to benchmarks?
	What is the sectoral structure of GHG emissions in the case study city?

Analysis

	What are the highest and lowest emitting sources of GHG emissions?
	What are the driving forces behind GHG emissions in Indian Cities?
Application	How does the governance structure affect the policy making and implementation?
	In what ways can the results be used to inform policy for reducing emissions?
	How will the municipal government benefit from this?

And the objectives of the research are –

1. To document the process of conducting a GHG inventory for a mid size city in the Indian context and to understand the governance structure and its implications on the data collection process and policy making for cities
2. To identify data gaps and alternative calculation methods with available data and highlight issues with data quality
3. To benchmark and analyse the results of the inventory and identify the driving factors for urban GHG emissions in Indian cities
4. To explore policy options that use the GHG results to spearhead sustainability in the Indian cities

An Empirical Case Study Research has been identified as the main research tool to use to fulfil these objectives. In the next few sections, the research design for this thesis is presented drawing from the literature review and the discussions on the process of case study research and the methodological requirements of GHG inventories presented in sections 4.2 and 4.3.

4.4.1 Research Process

The requirements of an Empirical Case Study Research have been discussed in Section 4.2. A summary of the five major components of case study research and how they apply to this thesis are presented in Table 4-2.

Table 4-2: Components of Case Study Research In relation to this study

Summary	This research
Study's questions	'How can a GHG inventory be conducted (its process and method) in cities in developing countries and how can it be used to inform policy?'
Proposition	The aim of the research is to create, test and apply GHG inventory as a

	policy tool for local governments.
Unit of Analysis	City's municipal limits
Logic linking data to proposition	Qualitative and quantitative data collected from local government to explore process and calculate the emission profile.
Criteria for interpreting the findings	Descriptive, comparative and time-series, predictive techniques for the four components

While these five components describe the basis of the case study, a case study must be identified that fits the requirements of this research.

4.4.1.1 Choosing the Case study

Dehradun has been chosen as a case for this study since it is a mid size city rapidly expanding and given a change in its status since 2001. The city, which was termed an educational and retirement town in the past, is fast becoming an administrative capital of a new state. The governance structure of the city is an exemplar of the issues that were identified in the literature review with many state and para-statal agencies involved in the city. This gives an opportunity to study the effect of such disaggregation of responsibilities and powers at the local level and its implications for policy making.

The city falls in the Tier III category of cities as per the Indian cities' classification and is thus an exemplar of the 68 cities that are projected to have a population of more than 1 million by 2030(Sankhe et al., 2010) and will be the centres of urban growth, more so than the world's largest cities (UCLG, 2010).

The local government is encountering a number of new issues with increased immigration and service delivery. A lot of new projects are being introduced in the city to improve service delivery. Work is ongoing under the JNNURM mission and the city is also part of the Solar Cities Programme.

If at this stage of the city's development process, a conscious effort is made by the authorities to reduce emissions from the city, the adoption of the reduction strategies can work alongside these development projects. Another factor that had a bearing on the choice is that the author is familiar with the city and hence, the data collection process can be carried out more easily. The city and its structure are described in detail in the next chapter.

4.4.2 Approach

Based on the research question and the associated objectives, a four-stage approach [Figure 4-3] to conducting the case study was arrived at. The first stage – Process - deals with documenting the process of data collection to fulfil objectives [Section 4.4] 1 and 2. In the second stage – Inventory – the calculations are carried out with a focus on objectives 3. The third stage of Analysis helps close objective 3 and finally objective 4 is fulfilled through the last stage – Application.

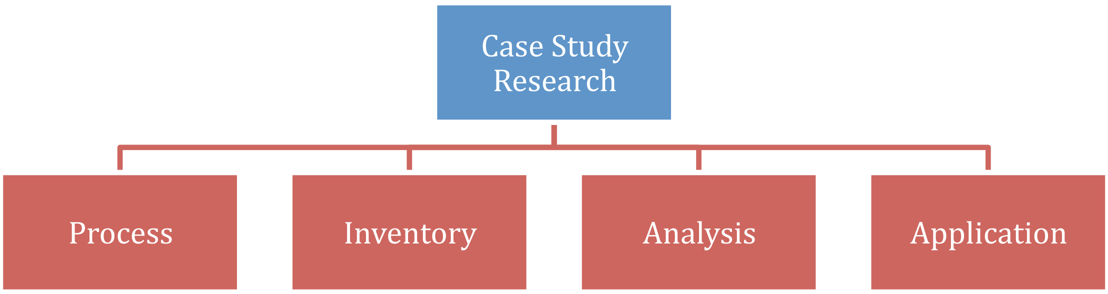


Figure 4-3: The Four Fold Approach of this Research

The following sections describe the underlying tools, method, assumptions, data requirements and Validation process associated with each of the four stages of the research process.

4.4.2.1 Process

Since this stage of the method concerns data collection the tool used is that of descriptive analysis to describe in detail the process of finding data sources and collecting the data where available or looking for alternative data in case of data gaps being encountered. The descriptive analysis also helps highlight the problems faced due to the local governance structure.

The underlying methodology is that of observational analysis through a data collection diary. Where possible multiple sources of data can be accessed to cross check the validity and accuracy of the data. The inventory calculation requires annual usage data to be collected. For the purpose of this study, an attempt has been made to collect data from the years 2007-2011 to study the trend of GHG emissions from the city.

The initial set of data requirements [Table 4-3] have been collated from the recommended methodology based on the IPCC framework that is being used for the GHG inventory module.

Table 4-3: Data requirements from recommended methodology

	Activity Data Required	Emission Factor Data Required
Electricity Use in Buildings	Electricity use preferably by sectors (residential, commercial, institutional etc.) including T&D losses	EF $tCO2/MWh$ from national estimates or where supply mix is known – specific EF for local/regional scale
Fuel Use in Buildings	Amount of fuel used by type of fuel in residential/ commercial/ industrial/ public sector buildings	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Transport Fuel Use	Fuel consumption or by vehicle kilometres travelled (VKT)	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Land Use Change	Ha of land use change areas - forestland/cropland/settlement etc.	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Agriculture	Rice Cultivation, Fertilizer use in agriculture	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Livestock	Livestock Population	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Municipal Solid Waste	Amount of Waste disposed of in disposal sites, DOC, DOCf, MCF etc	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Waste Water	Population, Fraction of population in income groups, degree of utilization of discharge pathways	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Water Supply	Energy used in Water Supply	Default (Tier 1) or country-specific (Tier 2 and Tier 3)

4.4.2.2 Inventory

Based on the methodological study in the literature review section 3.2.1 and section 4.3 of this chapter, the methodological choices and assumptions that have been made with regards to this study must be clarified. As per the IPCC national inventory protocol, there are four sectors that each country needs to report its emissions for – Energy, Industrial processes and product use, Agriculture, forestry and other land use and Waste. Adapting these to a local urban scale requires some modification.

For instance, while emissions from industrial processes are very important at the national level, and even at an organisation level, where they present an opportunity for Clean Development Mechanism (CDM) projects; on an urban scale, they will be important for a predominantly industrial town. But otherwise, since, the municipality has little control over industrial processes and often polluting industries are located outside the municipal boundaries, calculating these emissions is both exhaustive in terms of resources and time and would contribute little to the municipal policy making. Hence, many urban GHG inventories choose not to include industrial processes in their calculations. Similarly, when it comes to product use, the scale and complexity of monitoring product consumption across the whole city makes it often unviable to include it on an urban scale inventory.

Of the remaining three sectors, the energy and waste sectors are the key in municipal inventories. The former includes energy use from stationary and mobile combustion, which in an urban context can be translated as emissions from fuel use for cooking, heating/cooling, hot water etc. and emissions from transport within the city. And the latter includes emissions from waste management i.e. Municipal Solid waste and Wastewater.

Learning from international protocols as well as the local Indian context of fast developing cities, the focus of these GHG inventories needs to be carefully considered. The purpose of the GHG inventory in a fast expanding mid-scale Indian city is to inform the city policy makers, of the emissions' scenario and its projections. So, the usefulness of a GHG inventory depends on how helpful it is for the policy makers to plan to mitigate emissions. As the stakeholders are the municipal government, the inventory should inform them on policy sectors that can be directly or indirectly influenced by them. Moreover, the timescale is an important factor in designing an inventory framework for fast developing cities. Since the emissions' dynamics in such a scenario can change at a rapid pace, it is essential to have an emissions' estimate fast enough for policymakers to introduce mitigating interventions.

To add to the operational emissions as defined by the international protocols, cities are also concentrations of embodied emissions. And in a rapidly developing Asian city, the embodied content can be much more (Fridley, 2010) than the operational emissions. Since the city is continuously evolving with new buildings as well as infrastructure, the embodied carbon content in new developments is a major policy area that needs to be considered by the city-planners/ managers in their bid to mitigate carbon emissions from the city.

Considering all the above factors, Figure 4-4 illustrates a framework designed to represent the GHG scenario specific to cities and highlight the sectors most relevant to urban policymakers. This forms the basis of the GHG Sectoral disaggregation used in this study. Although based on the four sectors defined in the IPCC methodology, the sect oral disaggregation in urban GHG inventories is different. Considering the focus areas for a municipal entity, the sectors are reorganised with further disaggregation in some sectors. The energy sector is thus disaggregated not by fuel type but building (type) and transport.

As illustrated in Figure 4-4, a city's carbon emission may be divided into two major sectors – the embodied energy in the city's infrastructure and the operational energy use with in the city. Further these emissions can be categorised into sectors as per the IPCC guidelines– Buildings, Transport, Land use changes, Infrastructure and Goods consumption.

For this research, goods consumption and industry fuel use have not been included in the calculation boundary, to avoid the complications associated with these metrics. A cumulative result for the whole city, illustrated using the same figure, will give an overview of carbon emissions from different sectors. This will help the local authorities prioritize on which sectors need immediate measures.

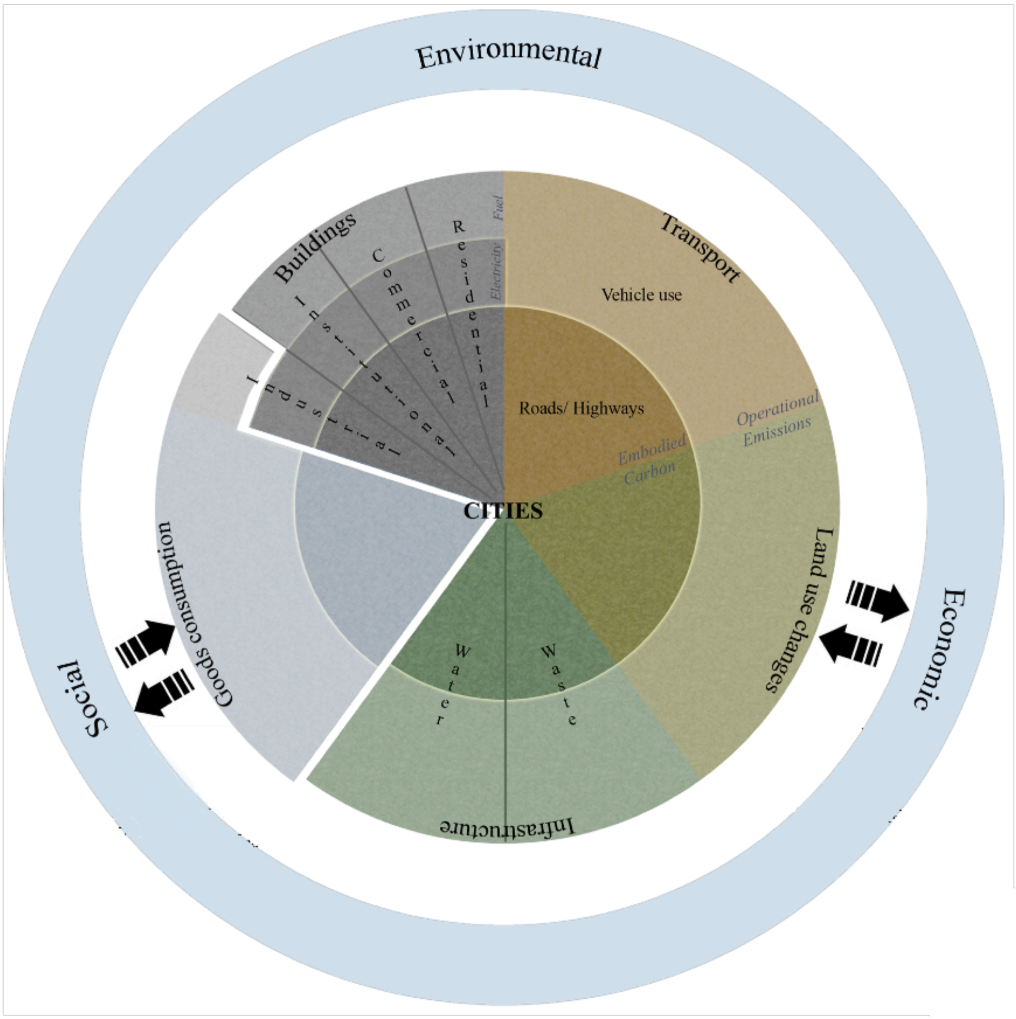


Figure 4-4: Research Design Framework for City GHG Scenario

The final modified framework includes five major sectors – Buildings, Transport, AFOLU, Waste and Goods consumptions. Such a reorganisation of the IPCC recommended sectors is a part of the adaptation of the international protocol to the local requirement. The reorganised sectors represent a clearer picture of a city's GHG scenario and fall within the urban governance framework, so that policymakers have the power to influence these in direct or indirect ways to promote GHG reduction.

Although goods' consumptions and industrial fuel consumption contribute to the GHG emissions of the city, the methodological complexity and the intensive data requirements for these two make it unviable to include these in a time and resource bound project of a PhD. Hence, these have been excluded from the calculation boundary.

Finally, Table 4-4 summarise the choices and assumptions that have been taken into account for the purpose of conducting a GHG inventory of the case study city based on the International recommendations but adapted to the local and this research's context. Annual activity data collected, as part of the process module, will be used for the inventory calculations and the results will be benchmarked with the help of the data collected as part of the Literature Review Section 3.2.1.

Table 4-4: Summary of Choices and Assumptions made for the GHG inventory Module in this Study

Summary	Protocol	This Research
What is being measured?	Six GHG gases in terms of CO2 equivalents	CO2 and CH4 in terms of CO2 equivalents
Sectors	Energy; IPPU; AFOLU; Waste; Other	Energy; AFOLU; Waste
How is it being measured?	Emission factor method; Mass balance method; Predictive emissions monitoring system; Carbon emissions monitoring system	Emission Factor method
Scope	Direct emissions; Indirect emissions; Emissions from goods and services used in the city	Direct and Indirect emissions
System Boundary	Geographic – Municipal boundary or Development authority region Temporal - Yearly	Geographic – Municipal boundary Temporal - Yearly
Territory	Point of use or point of generation	Point of use

4.4.2.3 Analysis

The analysis section of this research has two objectives. First, to analyse the results of the case study inventory and identify the relative contribution of emissions from various sectors and the trends of change over the five year period studied with an aim to identify the sectors where policy interventions can be applied. Second, to use the benchmark data for Indian cities and study its correlations with various socio-economic factors to investigate the major driving forces behind the GHG emissions scenario in cities, again, with an aim to use this knowledge to streamline and target policy measures in the city.

4.4.2.4 Application

The main purpose of this research is to establish the use of GHG inventory as a tool to inform policy making by local authorities to reduce their emissions. Following the previous step of calculating the GHG emission of the case study city and recording the inferences from an analysis of the data, post processing involves the use of these inferences to recommend policy measures and look for ways to implement the policies to reduce emissions from the city, through scenario modelling. It uses several examples to illustrate how the inventory can be used as an essential policy instrument and the results of the policy regularly assessed through monitoring.

4.5 Conclusion

The usefulness of a GHG inventory as an introductory sustainability assessment tool for cities in the local Indian context of mid scale fast growing cities with minimal resources was established through the literature review. This chapter followed to form the basis of the methods used in this research. While the major methodology is that of a case study research, the various sections of the research involve other tools and methods that have been described in this chapter. The four fold approach to the research helps in streamlining the process and in organizing the way the research results are presented.

Through the four fold research methodology, this research attempts to not only create a locally specific GHG inventory model for Indian developing cities but also to study the process of collecting data, the structure of the Local Government and the impact of these in the success or failure of a GHG inventory as a policy tool. Also trying to identify the drivers of emissions in the case study city as well as factors that lead to the low emissions profile of cities in developing countries and using this analysis to inform policy. The methodology has been designed as a case study research to test the theoretical model in the real world scenario and highlight issues relating to the implementation of a GHG inventory as a policy tool in Indian cities.

For the main module of the GHG Inventory, Figure 4-4 presents the final research design framework for the disaggregation of sectors used in this research. In the summary Table 4-2 and Table 4-4 the major decisions made in relation to the GHG inventory methodology of the research have been presented whilst Table 4-3 lists the data requirements as per the final research framework that will initiate the data collection process described in the next chapter.

Figure 4-5 illustrates the progress within the research process flow at the end of this chapter.

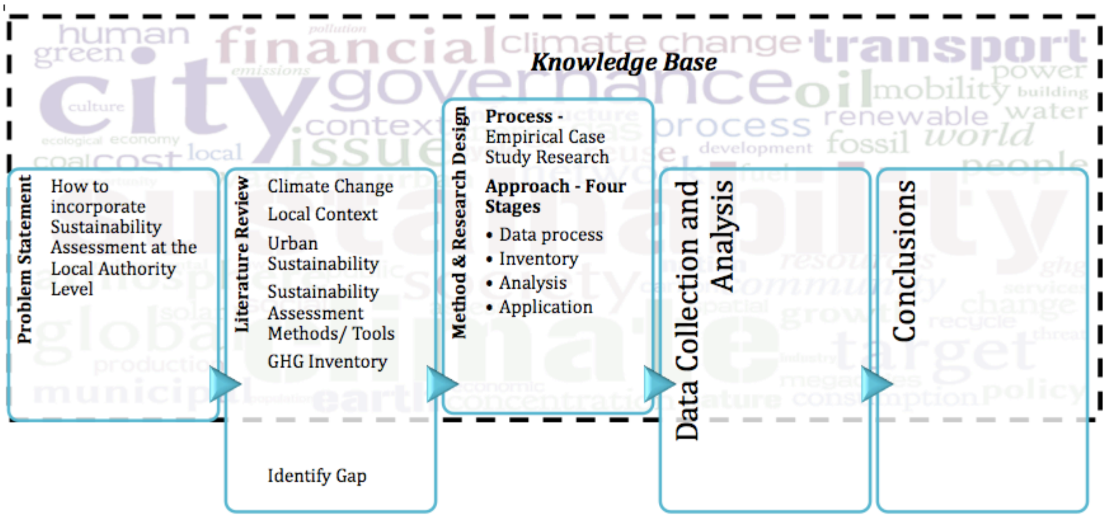


Figure 4-5: Research Process Progress

From here, the thesis has been divided into four sections in accordance with the four-stage approach of the research design. Chapter 5 describes the process of data collection, Chapter 6 presents the Inventory calculation and results benchmarking, Chapter 7 analyses the data and Chapter 8 explores the policy implications. This helps organize and present the research findings in a coherent and easily comprehendible format that can be related back to the research design methodology.

Chapter 5 Process

One of the key elements of this research is to look at the process of conducting an inventory for cities in the local Indian context. It has already been established in the literature review that the data used for inventories is very contextual. The purpose of this chapter is to identify what data is available and from where i.e. its source. Along with identifying the data paucity or quality issues, this also helps identify the key stakeholders in the inventory process and its application.

The process in this research refers to the collection of data for the calculation of the GHG inventory. As mentioned earlier, to encourage local authorities in developing nations to take up sustainability assessment, the tool should use existing data and minimal resources. It was also identified that the governance structure of cities in the nation is fragmented and thus, makes it difficult to collect the requisite data.

The purpose of this chapter is to describe the process of locating data sources, collecting the data, checking its compatibility with the requirements and looking for alternative data where needed. With this, the section aims at identifying the problems associated with collecting data from fragmented governance structure, the data paucity and the quality of data availability. This part of the research focuses on streamlining the process of conducting a GHG inventory and improving data availability and quality issues in the future.

The chapter starts with a description of the case - Dehradun City and then follows the process of collecting data associated with the sections presented in the research design in the previous chapter. The list of data requirements [Table 4-3] collated as part of the research design is used as a starting point for the collection. The compatibility of the data with this proposed requirement is illustrated through summary tables at the end of each sectoral section.

5.1 About Dehradun

Dehradun city is located at the foothills of the Himalayas in the northern state of Uttarakhand and serves as the capital city since the formation of the state in

2001. As per the 2001 census, the city had a population of 5,30,263 person (GOI, 2001). The city is spread over 300 sq. km. Historically, Dehradun has been an important residential and institutional town and a summer retreat with some well-known educational, training and research institutions based here. Since the conception of the Uttarakhand state, it has taken on an administrative role as well. Although this has meant more economic growth for the city, it has also put a lot of pressure on the city's infrastructure, to absorb the sudden influx of population from neighbouring areas.

Figure 5-1: Location of Dehradun

5.1.1 Geography and Climate and its impact on Energy use and Emissions

It is located between 29 ° 58 'and 31 ° 2' 30 "north latitude and 77 ° 34 '45" and 78 ° 18' 30 "east longitude at an elevation of 670 m (International et al., 2007). The Doon valley has Himalayas at the north, the Shivalik range to its south, river Ganges in the east and river Yamuna in the west. The city itself lays between the Song River in the east and river Tons in the west, with the Himalayas flanking the north and Sal forests in the south. The valley is known for its salubrious climate and natural beauty.

The mean minimum and maximum summer temperature in the city varies from 16.7ºC to 36ºC while the winter temperature ranges between 5.2ºC and 23.4ºC. The monsoon season occurs between late June and mid August when the city receives most of the 2000 mm annual rainfall.

Energy use for heating and cooling in the city is minimized due to the usually mild climate. The annual heating degree-days and cooling degree-days with a baseline temperature of 18ºC are 520 and 1634 respectively (ISHRAE). It should be noted that the comfort zone for the local population in India is different from the assumptions used in calculating the degree-days (based on US standards). Hence, it will be safe to assume that the cooling degree-days will in fact be fewer. It is evident then that the energy used for heating and cooling in the region is not very high and hence the emissions should also be proportionally reduced.

5.1.2 Demographic Profile and its impact on Energy use and Emissions

In the two decades before 1991-2001, the decadal population growth in Dehradun was 21.33 and 21.85%. This shot up to 39.73% in the 1991-2001 decade (International et al., 2007). This sudden jump in growth rate can be attributed to the separation of Uttarakhand state from Uttar Pradesh and consequently to the establishment of Dehradun as the capital of the newly formed state.

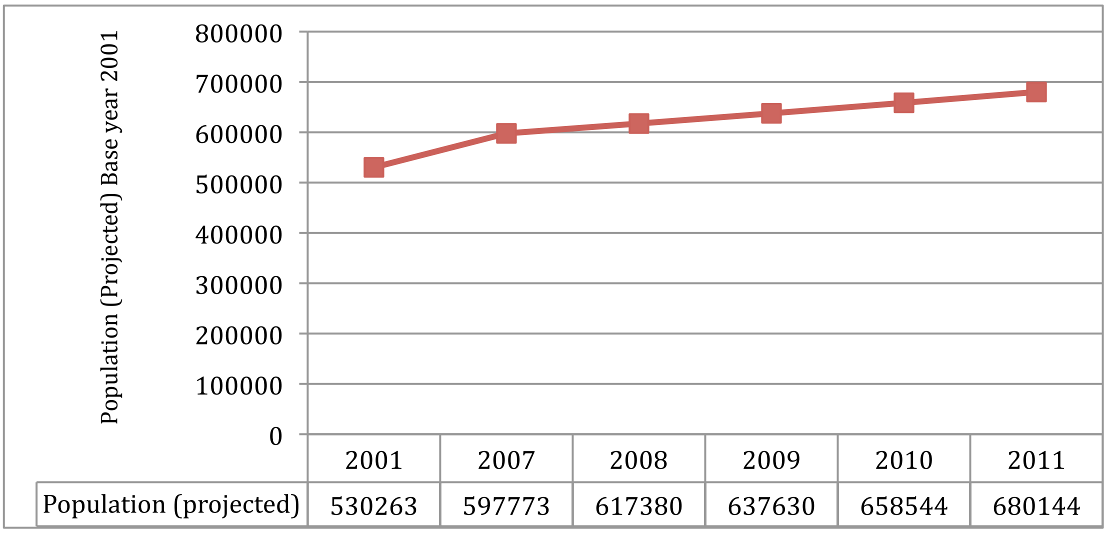


Figure 5-2: Population Projection for Dehradun City Area; Source: CDP, Dehradun

As population size in a city increases, so does the energy and infrastructure demand, both contributing to a rise in carbon emissions. Since the establishment of Dehradun as the capital city, a rapid population rise has been projected. To accommodate this growth, the city will need to expand its infrastructure, leading to embodied emissions. And the growing population will also demand more energy, again leading to carbon emissions.

5.1.3 Socioeconomic Profile and its impact on Energy use and Emissions

The socioeconomic status is an important indicator of the lifestyle of people and lifestyle is an important determinant of energy use habits. Thus, the socioeconomic profile of a city is of great consequence. More than 50% of the population in Dehradun city falls in the middle-income group. The mean per capita income is Rs.2372.40 and the mean household income is Rs.10460.60 as per the 2001 census.

About 8% of the population lies below the poverty line (BPL) group. The city registers (TCPO, 2008, International et al., 2007) a 96.7% literacy rate. 29.8 % of the population is student, 28% are employed in service and 11.6% self-employed, 25.4% are housewives and only 0.1% are farmers. The highest population is in the age group of 15-44 i.e. students and part of the working group.

Whilst the 8% BPL population uses less energy, they often resort to more polluting fuels for cooking. In Dehradun, a high percentage of the BPL and poor households use gas as a cooking fuel with only 13% BPL and 8% poor households using kerosene and 10% BPL and 4.9% poor using wood. Similarly, 93% BPL and 97.5% poor households have access to electricity (GOI, 2001).

5.1.4 Planning and Governance and its impact on Energy use and Emissions

Until the 1960's there were no formal planning norms for the city. It was in the year 1963 that that 'Dehradun regulated area' was declared under the provision of UP regulation of building operations acts, 1958. In 1984, the UP urban planning and development act, 1973 notified the 'Mussourie – Dehradun development Area'. Two master plans have been prepared since. The first master plan for 1982-2001 came in effect in 1982 and the second plan conceived for 2025 is in draft form (TCPO, 2008). The city experienced a leap in population growth in the decade 1991-2001 with close to 40% growth rate (International et al., 2007).

Table 5-1: Agencies responsible for Public Services in Dehradun City (Source: CDP, Dehradun)

Functions under Schedule XII of 74th CAA	Planning and design	Execution	Operation and maintenance
Urban planning including Town planning	MDDA and TCPO	MDDA and TCPO	MDDA and TCPO
Regulation of land use and construction of buildings	MDDA	MDDA	MDDA
Planning of economic and social development	Planning and social welfare departments	Different government departments	Different government departments
Roads and Bridges	PWD, MDDA	PWD, MDDA, DNN	PWD, MDDA, DNN
Water Supply for domestic, industrial and Commercial purposes	UPJN, UJS (for small projects)	UPJN, UJS (for small projects)	UJS
Public health, sanitation, conservancy and solid waste management	DNN	DNN	DNN
Fire Services	State police **dep't**.	State police **dep't**.	State police **dep't**.
Urban forestry, protection of environment and promotion of ecological aspects	Forest Department, UEPPCB, DNN	Forest Department, MDDA, DNN	Forest Department, MDDA, DNN
Safe guarding of interests of weaker sections of society, including handicapped and mentally retarded	Planning and social welfare departments	Different government departments, SUDA, DNN	Different government departments, DNN
Slum improvement and up-gradation	MDDA, DNN, SUDA	DNN	DNN
Urban poverty alleviation	SUDA, DNN	SUDA, DNN	DNN
Provision of urban amenities, and facilities such as parks, gardens and play grounds	Sports **Dep't**. , DNN	Sports **Dep't**. , DNN	Sports **Dep't**. , DNN
Provision of cultural, educational and aesthetic aspects	Department of culture, DNN	Department of Culture, DNN	Department of Culture, DNN
Burial and Burial grounds, Cremations, cremation grounds and electric crematorium	DNN	DNN	DNN
Cattle ponds; prevention of cruelty to animals	DNN	DNN	DNN

Vital statistics including registration of births and deaths	DNN	DNN	DNN
Public amenities including street lighting, parking lots, bus stops and public conveniences	UPC, DNN, MDDA	UPC, DNN	DNN
Regulation of Slaughter houses and tanneries	DNN	DNN	DNN
MDDA: Mussouri Dehradun Development Authority; TCPO: Town and Country Planning Organization; DNN: Dehradun Nagar Nigam **(Municipal Authority of Dehradun)**; UPJN: Uttarakhand Pey Jal Nigam **(Uttarakhand Drinking Water Board)**; UJS: Uttarakhand Jal Sansthan **(Uttarakhand Water Corporation)**; PWD: Public Works Department; UEPPCB: Uttarakhand Environment Protection and Pollution Control Board; UPC: Uttarakhand Power Corporation; SUDA: State Urban Development Agency.			

Owing to the fact that Dehradun is the capital city of the state, various state level agencies are operating here and are responsible for some of the major infrastructures/services provision for the city. The responsibility often is limited to the planning, designing and execution of the projects, which are then transferred to the agencies directly responsible for the provision of infrastructure facilities. It is difficult to express the governance structure of the city as a hierarchical system and as such a matrix of the responsibility of different organizations to provide different services in the city has been presented in Table 5-1.

The governance structure of the municipal authority (DNN) (International et al., 2007) is divided into two wings viz., elected wing and administrative wing. The Corporation consists of 60 elected members from 60 wards [Figure 5-5]. The Mayor, who is elected directly by the people at large of Dehradun, is the Chairperson of the whole body – the Corporation. The elected members of the Corporation elect the Deputy Mayor. The Executive Committee broadly oversees the entire corporation administration. The Ward Committees have been constituted on the basis of 1:9 electoral wards. That means the Corporation has presently 5 (five) ward committees. Figure 5-3 illustrates the political organization of the Dehradun Municipal Body.

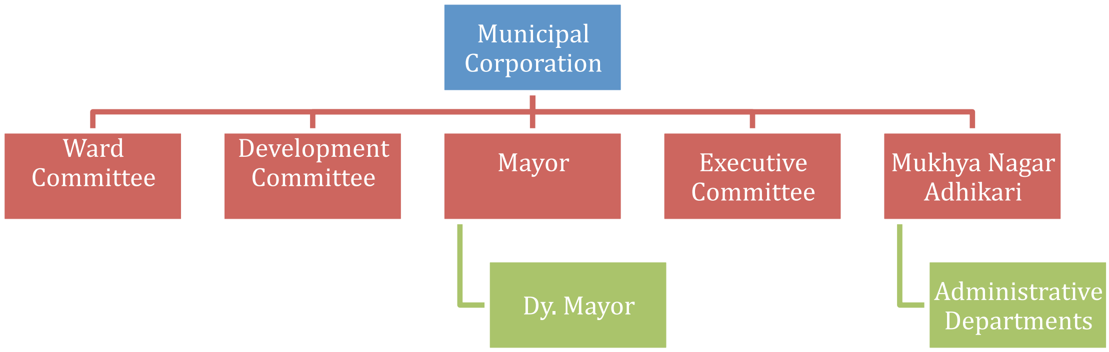


Figure 5-3: Political organization of Dehradun Nagar Nigam (Source: CDP, Dehradun)

Shown in Figure 5-4 is the organizational structure of the Administrative wing of the Dehradun Nagar Nigam. The Chief city officer oversees the corporation with Deputy city officer, an Executive Engineer, the Municipal Health Officer and the Accounts officer reporting to him.

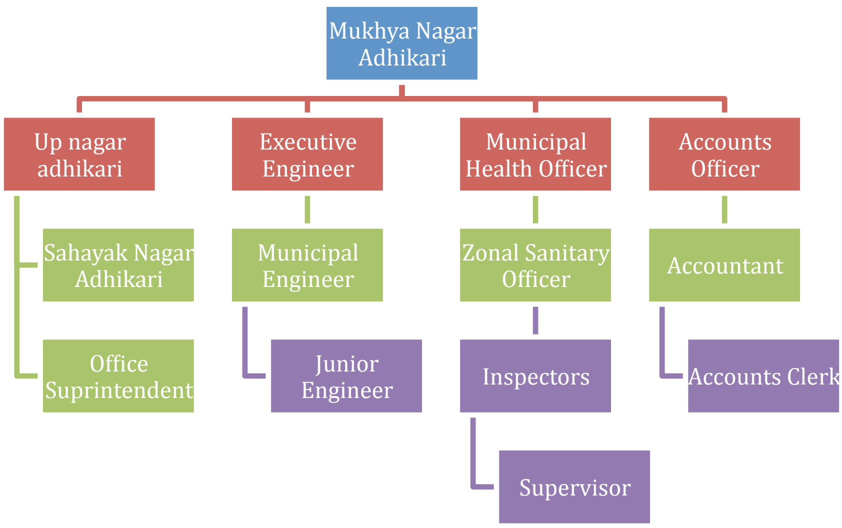


Figure 5-4: Administrative organization of Dehradun Nagar Nigam (Source: CDP, Dehradun)

Dehradun Nagar Nigam has very few functions in the municipal domain. Unlike city corporations elsewhere in India, DNN has a very limited role to play in the city's planning, development and infrastructure provision. In fact, solid waste management is the main function of DNN. Conventional municipal functions such as water supply, sewerage, roads, etc. are in the hands of either para-statals or state agencies.

Figure 5-5: Ward map for the Dehradun Municipal Corporation (Source: Uttarakhand.org)

This finding complicates the issue of inventory ownership and responsibility since where conventionally the municipal corporation would be the leading authority; the DNN does not hold much sway in the governance of the city's service delivery. There needs to be a careful consideration of the roles of the different organizations operating in the city.

5.2 Data Collection Process

Most of the data used in this study is from government records while some comes from published reports or other secondary sources. First exploring the city master plan (TCPO, 2008) and the city development plan (International et al., 2007) prepared by the JNNURM cell and investigating the role of different government offices found data sources and other agencies involved in providing services in the city. The author collected the data by visiting various governments offices related to the different sections of the inventory between October 2010 and March 2012 and also from national survey data. The collection process however, was not continuous. It was divided as per the inventory sectors and each addressed individually. The collection of data for each sector was accompanied with the calculation/analysis for the sector, to ensure that the data requirements were complete. And only then data for the next sector was sought.

In the sections below, each inventory sector reports on data availability at the local scale, the administrative structure of the agencies involved, problems encountered in the process of data collection and are summarized in the tables at the end. The concurrence shows how compatible the collected data was to recommended methodology as low, medium, high and ideal.

5.2.1 Buildings

The buildings sector includes the electricity used by buildings and the fuel used for cooking/ heating/ cooling. Building type – Residential, Commercial, Institutional and Industrial, disaggregates the electricity and fuel use in this sector. Fuel use from the Industrial sector has not been included in the scope of this thesis.

5.2.1.1 Electricity use

The Uttarakhand Power Corporation Limited (UPCL) supplies electricity in the city. Under the UPCL head office, there are two regional offices for the city of Dehradun – Dehradun Urban and Dehradun Rural, which manage divisional offices. The urban region has three divisional offices for the North, South and Central zones, whereas, the rural region has two divisional offices for city rural and district rural zones. These divisional offices collect revenue and are responsible for the primary data collection on the sale of electricity in their zones. They also supervise zonal substations and manage complaints.

Data collection started at the head office of the corporation, which could only provide statewide electricity consumption data. They directed the researcher to the local offices for the city consumption profile. However, they did provide data on the supply mix for the state, which is useful for estimating a regional emission factor. They also furnished data for the Transmission and Distribution (T&D) and Aggregate Technical and Commercial (AT&C) losses.

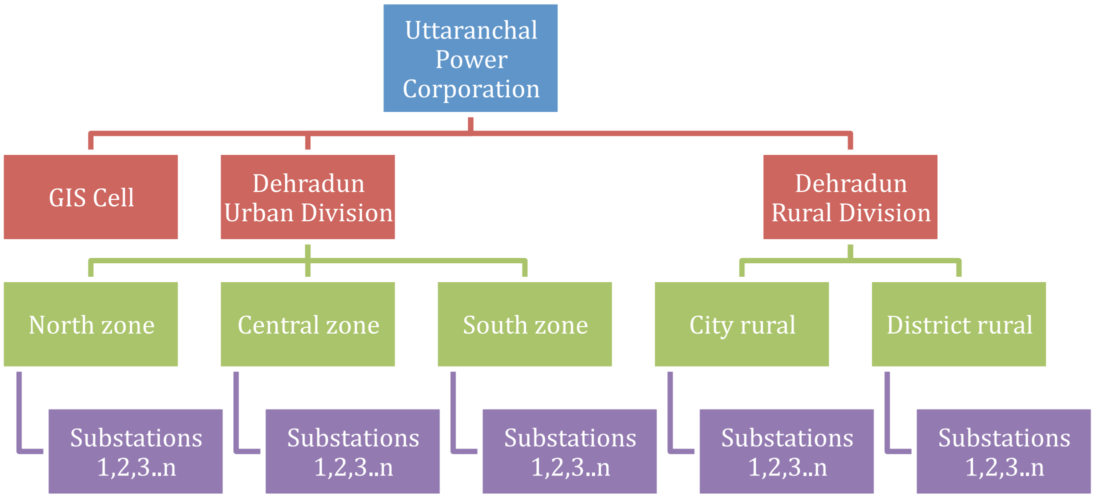


Figure 5-6: Administrative structure for Electrical operations in the city

The divisional offices collect monthly data on sector wise sales for their zones in a standard spreadsheet named CS3. The CS3 has data on the number of consumers, connected load weight, sale of energy during the month and sale of energy progressive, which is cumulative data for the financial year. The head office directed the query to the divisional offices. Since the divisional offices for each zone are located separately, collecting data from these, though possible, would have meant visiting four offices.

The divisional office therefore redirected the researcher to the regional offices (urban and rural), which collect data from all the divisional offices, and collate it into a single CS3 format file. For each financial year, the CS3 for the month of March was collected, so it provided the cumulative totals of units sold in the year.

Data on Electricity use by sectors for the years 2005/06 to 2010/11 was collected, although there is inconsistency in the categories. The rural zone includes villages that come under the Mussourie Dehradun Urban Development area. Since these fall outside the municipal boundary, only the urban electricity sales data is used for calculation. The geographical boundaries for these zones are not well defined; the divisional offices could only provided a vague list of areas that fall in each zone. A newly formed GIS cell is working on mapping every consumer but the work is in progress and the data is classified.

In addition, the north city zone includes supply to the hill town of Mussourie, which is 35 kms from Dehradun. The exact distribution of electricity use in

Mussourie is unknown, Officials reported that about 1/3 of the electricity use of the north zone could be attributed to Mussourie.

UPCL reports electricity sales in the following categories as per its CS3 norm – Residential (With a separate category for UPCL employee residences), Commercial (including temporary supply for construction work etc.), Institutional, Industrial (Small and medium & Large scale), Public water works (Jal sansthan and Jal nigam), Private and state owned tube wells and pumps, Street Lighting. The categories are based on the tariff, so proper disaggregation has not been made. The Commercial category includes all commercial and institutional users since the chargeable rate for both sectors is the same. The institutional category is used exclusively for offices of the power corporation itself.

The data collection required multiple visits to offices at all levels from local substations to the head office. There was a tendency to delegate the task to a higher or lower office unless the data requirement was precisely specified and insisted that they should be the ones to provide it. Officials usually lack interest in what is being asked and the purpose. As such, the initial exchange to explain what kind of data was needed and whether they collected it was difficult. However, once it was established that the data was collected in the form of the CS3 spreadsheet, it became easier to just specify the spreadsheet at the other offices.

The national northern zone average EF of 0.72 tCO_2/MWh was sourced from the CO_2 baseline database for the Indian power sector 2007 (CEA, 2007).

Although, regional EF specifically for the state of Uttarakhand is not available, the UPCL head office does provide the supply mix for the state from 2007/08 to 2010/11. The supply mix can be used to estimate the regional Emissions Factor, which may be lower since electricity in the area is sourced mostly from renewable sources like hydro and nuclear.

Table 5-2: Summary for Electricity Data

Activity Data	Emission Factor

Recommended	Electricity use preferably by sectors (residential, commercial, institutional etc.) including T&D losses	EF tCO_2/MWh from national estimates or where supply mix is known – specific EF for local/regional scale
Available	Electricity use by sectors for the years 2005/06 to 2010/11 with some discrepancies. AT&C losses	National northern zone average/ Supply mix for Uttarakhand state
Source	UPCL divisional offices	CO_2 baseline database for the Indian power sector 2007/ UPCL head office
	High	Ideal

5.2.1.2 Fuel Use

In Dehradun, the major use of fuel is only for cooking and very occasionally heating since most of the heating and cooling is done with electrical appliances. Hence, for estimating the emission from fuel use, data needs to be collected for the amount of fuel used by various types of fuel and number of households for cooking and that used by the commercial sector. Data for fuel use is rather hard to find. Among the possible sources of data, oil and gas companies usually provide the fuel use data from sales data. In a bottom up approach, energy modelling is useful for places where heating is a predominant use. In a tropical country like India though, fuel use is mostly restricted to cooking and occasionally heating in the winter months.

The use of fuels in buildings is comparatively harder to quantify in the Indian scenario. Unlike the developed nations where gas supply is organized like electricity supply and is usually the only or the largest source of fuel for heating and cooking; in India the fuel market is open. Households use different types of fuels for cooking depending upon their income level. Although most urban households use LPG, there is a considerable number of households that still rely on kerosene or biomass for their daily fuel requirements (GOI, 2001). What adds to the complexity of the data collection is the presence of numerous suppliers. LPG is supplied in pressurized cylinders and kerosene is also sold in the open market. Hence to accurately collect data for fuel use by various sectors becomes a challenge.

For household fuel use, a reliable and key data source will be the Census of India (GOI, 2001), which surveys every household and records their fuel choice. In this case though, the fuel quantity used has to be estimated by average household consumption patterns in Indian households, which are usually based on econometric analyses. Another drawback in this data source is the fact that the census is conducted only once in 10 yrs.

Table 5-3: Summary for Fuel Use data

	Activity Data	Emission Factor
Recommended	Amount of fuel used by type of fuel in residential/ commercial/ industrial/ public sector buildings	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Available	No. of houses/households using different fuels in the year 2001; Fuel sales data for LPG for 2009-10 and 2010-11; Fuel sales data for Kerosene for 2007-2011	Country Specific default
Source	Census of India, District Supply Office, IOCL	IPCC
Concurrence	Low	Ideal

Alongside the census data, the amount of annual kerosene consumption has been sourced from the District Supply office, which oversees the distribution of kerosene (at subsidized rates) to the economically weaker section of the society. Some data for the use of kerosene and other fuels was sourced from the Indian Oil Corporation Ltd.'s regional offices and area sales managers.

The disaggregation for building sectors could only be found for LPG where the cylinders come as the 14.2 kg domestic and 19 kg commercial. However, it must be noted here that a number of small commercial establishments often use domestic LPG since the government subsidizes it. Customers are charged Rs. 345 for a 14.2 kg domestic gas cylinder whereas the price of a 19 kg commercial LPG cylinder is Rs. 1,000.

5.2.2 Transport

The data requirement for transport emissions is the amount of fuel used for transportation in the city.

5.2.2.1 Fuel use

The Transport sector in the city is managed by a number of different departments. The Road Transport Office(RTO) manages the registration of new vehicles in the city. Uttarakhand Transport Corporation (UTC) is responsible for the public transports in the city i.e. the city buses. The roads are managed by the MDDA and PWD as well as DNN. The UEPPCB, though, not directly associated with transport management, collects vehicular pollution statistics at some junctions in the city.

Figure 5-7: Transport related offices in Dehradun

The requisite data of fuel consumption by vehicle kms travelled (VKT) disaggregated by vehicle types was not available. Hence, as per an alternative methodology, the RTO provided the number of vehicles registered each year by vehicle type as well as the number of on-road vehicles from 2007-2011 by vehicle type. Although not directly compatible with the recommended activity data, the figures were used to estimate the VKT's by vehicle category with the help of national estimates of vehicle mileage from a Central Pollution Control Board (CPCB) study mentioned in the India Infrastructure Report (IIR) 2010 (Network, 2010).

In 2005, JNNURM sponsored a study of transport conditions in the city and RITES ltd. conducted it (RITES, 2005). The report also finds mention in the City Development Plan (CDP) prepared for the JNNURM project. Finding the report required visiting all the related offices in town, from JNNURM cell at DNN, being directed to UTC and thereafter to the MDDA where the report was eventually found after some reluctance from the officer. The study includes traffic volume counts and travel survey information. According to the report, the total per capita trip rate is 1.27. However, it does not provide segregated VKT estimates for the different modes of travel.

Emission factors for different vehicle types were taken from the IIR 2010 report (Network, 2010), which cites the Automotive Research Association of India (ARAI) 2007 estimates.

Table 5-4: Summary for Transport data

	Activity Data	Emission Factor
Recommended	Fuel consumption or by vehicle kilometres travelled VKT	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Available	No. of on road vehicles	Country specific EF (g/km)
Source	RTO	IIR 2010
Concurrence	Low	High

5.2.3 Land use, Agriculture and Livestock

This sector involves data for estimating emissions from the changes in land use category; emissions categories from agriculture include rice cultivation and urea fertilizer use and emissions from the rearing of livestock by type.

5.2.3.1 Land use changes

The requisite data for this sector is the area of land use changed from one land use category to the other. Some data is available on the change in land use from 1982 to 2004 as part of the Dehradun metropolitan area Master plan. But the data is not compatible with the requirements as it only gives the total area changed in each category while the calculation requires this data to be in the form of how much land was converted from forestland to agriculture land or forestland to settlement. Moreover the data does not fall within the timescale chosen for this research.

Table 5-5: Summary for Land use Data

	Activity Data	Emission Factor

Recommended	Ha of land use change areas - forestland/cropland/settlement etc.	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Available	Change in land use 1982-2004 for the Dehradun Mussourie Development Area (larger than the municipal boundary)	IPCC Default
Source	TCPO, MDDA	IPCC
Concurrence	Low	High

5.2.3.2 Agriculture

Rice cultivation is one of the major agriculture activities in the region with many types of rice being cultivated. One of the most famous varieties of rice – the Basmati rice originates from this area. The cultivation of rice is a major source of methane and is addressed separately in the IPCC methodology. The data needed to estimate emissions from agricultural activities in the city includes the area of rice cultivation and the amount of fertilizer use. Both the data was obtained from the Directorate of Agriculture based in the city.

Table 5-6: Summary for Agriculture Data

	Activity Data	Emission Factor
Recommended	Area and method of Rice Cultivation, Fertilizer use in agriculture	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Available	Fertilizer use in agriculture, Area and method of rice cultivation	IPCC Default
Source	TCPO, MDDA, Agriculture Dept.,	IPCC
Concurrence	Medium	High

5.2.3.3 Livestock

The number of livestock by type was collected from the Animal husbandry department in the city. Two livestock censuses have been conducted in the last 10 years – one in 2003 and the other in 2007. Data for both was collected. The Emission Factor data was sourced from the IPCC national defaults.

Table 5-7: Summary of Livestock Data

	Activity Data	Emission Factor
Recommended	Livestock Population	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Available	Livestock population by type	IPCC Default
Source	Animal husbandry dept.	IPCC
Concurrence	Medium	High

5.2.4 Infrastructure

The infrastructure section is further disaggregated into the waste and water sectors. The waste sector includes both the municipal solid waste and wastewater.

5.2.4.1 Municipal Solid Waste

Municipal Solid waste (MSW) emissions come from the CH4 produced from decomposing waste. Methane emissions from MSW are a major contributor to GHG emissions. Especially in developing countries in a tropical climate, the dumping of solid waste is often not managed and leads to high emissions. The tropical climate creates the right conditions for methane production from the decomposition of solid waste. If managed properly, methane can be captured and flared or used to reduce emissions.

Waste collection, treatment/dumping are part of the DNN's responsibilities. In Dehradun, the waste generation is estimated at 0.43 kg/capita/day in 2007. The system for waste collection is not properly in place, many residents openly dumping the waste on streets, drains, and rivers or down the hill slope. Higher income groups usually appoint private workers for solid waste collection and they pay for this monthly. About 20 percent of the residents burn waste in the locality. According to a municipal survey in 2007, although solid waste is not separated at source, about 87 percent sell old newspaper, plastic, glass, bottles, etc. to informal recycling agents.

Data was collected from the Dehradun Nagar Nigam. Although data is not calculated annually the municipal body did an assessment of the Solid Waste Disposal System (SWDS) in 2007. Samples of waste collected from different ward areas were analysed for content and characteristics. The collected data includes the estimated per capita generation of waste for the year 2007 and projections of waste generation based on population projections up too 2011. Other requirements including the EF were sourced from IPCC defaults.

Table 5-8: Summary for Waste data

	Activity Data	Emission Factor
Recommended	Amount of Waste disposed of in disposal sites, DOC, DOCf, MCF etc	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Available	Amount of waste generated and disposed	Country specific EF
Source	DNN	IPCC
Concurrence	High	Ideal

5.2.4.2 Wastewater

The IPCC (IPCC, 2006) identifies that the availability of data for wastewater is limited and thus proposes a default method based on population and income groups. In Dehradun, the collection of wastewater is limited and till now there has been no facility for treatment. The current sewerage system covers 50% of the population. The city has an ongoing project to construct two wastewater treatment facilities and is also currently expanding the collection base by constructing sewer lines.

At present, however, what waste is collected is disposed of without treatment into the two rivers i.e. Rispana and Bindal that flow through the city. Most houses use septic tank systems for on site treatment of waste. Some of the slum areas in the city have open sewers. In the absence of sewer line, houses have soak pits. According to the CDP (International et al., 2007) analysis, Ninety eight percent of the households have a latrine in the house.

The data collection for this sector was from the Census of India (GOI, 2001), 2001 and then population projections. IPCC defaults were used for the other data requirements.

Table 5-9: Summary for Wastewater data

	Activity Data	Emission Factor
Recommended	Population, Fraction of population in income groups, degree of utilisation of discharge pathways	Default (Tier 1) or country-specific (Tier 2 and Tier 3)
Available	Population projections, IPCC Defaults	Default Tier 1
Source	Census of India, IPCC	IPCC
Concurrence	Medium	High

5.2.4.3 Water Supply

Groundwater is the main source and contributes 76% of the 102 million litres per day (MLD) supply in the city. There are two water treatment plants with a total capacity of 34 MLD. Water is supplied twice a day for four hours. The governing organizations for the supply of water in the city are Uttarakhand Peya Jal Nigam (UPJN) and Uttarakhand Jal Sansthan (UJS), both state level agencies. Average per capita supply is about 124 litres per day. For the purpose of the inventory, data gathered from the electricity section, which provides the energy, used for pumping and treatment, is used.

5.3 Discussion

In the next few sections, observations related to data collection and the processes are presented. The section identifies four issues – the availability of data, its accuracy, reliability and quality related to the data itself and the inventory responsibility owing to the local governance context.

5.3.1 Data Availability

Some problems were encountered in the availability of requisite data. The lack of metadata meant that it was difficult to establish what data was available with various organizations. While the organization responsibility table from the CDP proved to be a good starting point to start the data search, there were problems identifying what data is available. A lot of time was thus lost on trying to find out which agencies collected what data and in which format and frequency and whether it was useful for the inventory. In cases like transport, alternative data had to be collected since the requisite data was unavailable.

5.3.2 Data Accuracy

It can be seen from the narrative that not all data conforms to the standards of the inventory requirement. Most often the problem lies in how the data is disaggregated. The disaggregation is usually different from the recommendations of the inventory. As an example, the electricity data is disaggregated by the sales cost and so some of the different categories are clubbed together. Moreover, even with the geographical boundaries, there is no clear distinction between the consumption in Mussourie and Dehradun.

5.3.3 Data Reliability

Since most of the data is sourced directly from the government agencies or published studies/reports, it can be assumed reliable. However, in the case of fuel use, due to the open and black marketing of fuel, data reliability can be questioned.

5.3.4 Data Quality

The quality of data available is usually tier 1 level as per the IPCC methodology and such there is ample scope for upgrading the data quality to tier 2/3 level. However, this would require the authority to invest some resources in the collection of data. Since, the priority here is to encourage the authorities to start using the inventory as a continual policy and monitoring tool, the issue of data quality can be addressed at a later stage when more resources are available to the city.

5.3.5 Inventory responsibility

As is clear from the process of data collection, a number of agencies operating in the city had to be approached for the required data. Considering the fragmented structure of the city's major service delivery departments, it can be difficult to create, manage and apply the inventory. Ideally, the responsibility for the inventory would be that of the overarching city municipal corporation, but in this context, it has been identified that there is little interaction between the various departments.

Moreover, the DNN is not recognized as the leading body in the city's administration. As such, there arises a question of who has the power and the resources to be responsible for conducting and maintaining the inventory and also have the jurisdiction to inform policy or is there a need to unify the city's service delivery under one governance body? As a precedent, the case of JNNURM project presents an interesting analogy where a separate cell had to be created for conducting the studies related to the project since its scope included many organizations in the city.

5.4 Conclusion

To conclude this Chapter, an attempt has been made to elaborate on the three research questions that were identified in the methodology -

1. What is the governance structure of the city and how does it affect data collection?

2. What are the major sources of data and how can they be accessed?

3. How coherent is the available data with the theoretical requirements and what are the alternatives?

One of the key problems that emerged out of the study concerning the idea of sustainable development in Indian cities is the fragmented structure of the Governance model. There being no central source for the data requirements, the data had to be collected from various government agencies. The segregation of different government departments is so much so that there is an almost complete lack of communication between them. This is perhaps the biggest hurdle in the kind of holistic planning/governance approach that sustainable urban planning stands for. Even when looking only at the GHG emissions, any reduction policies would inevitably involve more than one sector. A policy to reduce transport emissions will have to deal with the urban form and as long as the different departments do not start collaborating or are merged within one governance body, these policies will be difficult to make and implement.

In the context of this research, the data collection process was spread over a year and five months. Whilst most of the data was collected in 2011, some of the data like the Census of India 2011 data, only became available in 2012. Considering an annual GHG inventory, the time taken for data collection might seem prohibitive at first glance. However, it must be clarified that the data collection was not a continuous process, owing in part to the sectoral approach of collection and calculation and also due to the author's work commitments.

Locating data sources required much time and effort because of the lack of metadata available in most agencies that might guide someone about what data is collected by the agency. However, it is assumed that the identification of the data sources and their documentation as part of this research will make the task of a future inventory less time intensive. In many instances, where the recommended data as per the methodology was not available, it became very difficult to determine what alternative data was available that could be used for the estimation. The lack of metadata and interest of the concerned officials proved to be a big hindrance in the collection process. The introduction of E-Governance as part of the JNNURM project will be a step forward in eliminating this problem to some extent if all service related organizations were made part of it.

No data was found for land use changes in the city whereas alternatives were found for transport and fuel use data that can be used for estimating emissions. An attempt was also made to collect data to estimate the embodied emissions in the city buildings and infrastructure but it was too large in scope to be included in the time and resource constraints of this research. Even with these constraints, enough data was collected for the inventory to be conducted over a period of five years. A key concern that arises in this situation is to identify who has the executive power and ability to draw together the involved agencies to be responsible for the inventory process and its subsequent follow up with policy.

Finally, the quality of data and its accuracy can be much improved with a little effort from the conducting authority to streamline the process and standardize the data that is required. The frequency of data collection should also be considered if the inventory is to be used as an annual monitoring tool as well. Table 5-10 provides a summary of the data availability based on the data requirements presented in Chapter 4.

Table 5-10: Summary of Data requirement and Availability

	Activity Data Required	Activity Data Availability	Emission Factor Data Required	EF Data Availability
Electricity Use in Buildings	Electricity use preferably by sectors (residential, commercial, institutional etc.) including T&D losses	Electricity usage with sector with some sectoral and geographical divergence	EF tCO2/MWh from national estimates or where supply mix is known – specific EF for local/regional scale	Country and Region Specific
Fuel Use in Buildings	LPG and Kerosene	Fuel use by residential and commercial (LPG and Kerosene); Census data on residential fuel use	Default (Tier 1) or country-specific (Tier 2 and Tier 3)	Country Specific
Transport Fuel Use	Fuel consumption or by vehicle kilometres travelled VKT	No. of on road vehicles in different categories	Default (Tier 1) or country-specific (Tier 2 and Tier 3)	Country Specific
Land Use Change	Ha of land use change areas - forestland/cropland/settl ement etc.	NA	Default (Tier 1) or country-specific (Tier 2 and Tier 3)	-
Agriculture	Rice Cultivation, Fertilizer use in agriculture	Ha of land for rice cultivation; amount of fertilizer used	Default (Tier 1) or country-specific (Tier 2 and Tier 3)	IPCC Default
Livestock	Livestock Population	Livestock census	Default (Tier 1) or country-specific (Tier 2 and Tier 3)	IPCC Default
Municipal Solid Waste	Amount of Waste disposed off in disposal sites, DOC, DOCf, MCF etc	mount of waste enerated and ercentage disposed	Default (Tier 1) or country-specific (Tier 2 and Tier 3)	IPCC Default
Waste Water	Population, Fraction of population in income groups, degree of utilisation of discharge pathways	Population projections based on 2001 census	Default (Tier 1) or country-specific (Tier 2 and Tier 3)	IPCC Default
Water Supply	Energy used in Water Supply	Electricity used for pumping from the Electricity use data	Default (Tier 1) or country-specific (Tier 2 and Tier 3)	Country and Region Specific

Chapter 6 Inventory

This Chapter reports on the calculation of the inventory for the case study city – Dehradun from the data collected and thereafter an analysis of the results. As described in the method and presented in Figure 4-4, the GHG inventory is disaggregated into four sections – Buildings, Transport, Land Use Changes and Infrastructure. The sectors were further subdivided into categories where necessary to facilitate data collection and better comprehend the results. For instance, the buildings' sector has been divided into institutional, industrial, residential and commercial sub-sectors.

This Chapter is so structured that each sector is presented as a subtopic with the recommended methodological guidelines for emission calculation; the various alternative methods employed by other regional inventory tools that were reviewed as part of the literature review and; the data requirements as per these standards. Then, the emissions are calculated using the international standards as they are where data is available or through alternative means bridging the data gap where applicable.

The final section presents the results for the overall city emissions profile and also benchmarks the sectoral data by comparing it to the emissions data from other Indian Cities with a view to help validate any divergent methods/ data used. The detailed analysis of the results by sectors and an investigation into the driving agents behind urban GHG emissions follows in the next chapter.

6.1 Inventory Calculation

6.1.1 Buildings

As discovered from the benchmarking data, buildings, especially residential buildings use the most energy in a city and consequently on a consumption accounting basis are also the sources of the most CO_2 emissions. Quantifying emissions from the energy used in buildings in the form of electricity and fuel use gives municipal policymakers a clear picture of what building types or what uses require policy intervention. The buildings' sector has been subdivided into Institutional, Industrial, Residential and Commercial to capture the different design, construction and usage profiles for the different types of buildings. The operation of buildings involves the use of electricity (indirect emission) and fuel (direct emissions). These constitute the sources of operational emissions from this sector. The energy used in the materials and construction of the buildings forms the embodied content.

In the subsequent sections, calculations for the electricity and fuel use in the city disaggregated by building type [where possible] are presented.

6.1.1.1 Electricity Use

Electricity use emissions from buildings can be calculated using top down or bottom up methodology. This is one of the areas where a city level inventory differs from the IPCC recommendations. While the IPCC accounting allocates the emissions on a production basis, at the urban level it is recommended to use consumption based accounting. This is because the energy generation is usually outside the city boundaries and thus even though the energy is used in the cities, the emissions happen elsewhere. Thus, from an equity perspective, it is recommended that the emissions be allocated to the end user.

Using the emissions factors method, the total emissions can be calculated using the following formula (Kennedy et al. 2006)-

$$E_{electricity} = C_{electricity} \times L \times I_{electricity}$$

Equation 6-1

Where,

E = Emissions,

C = Consumption

L = Line loss factor

I = Emissions factor

For an aggregate city scale calculation, the total electricity consumption/sales data from electricity companies can be used with estimated line losses and emissions factors. To take the calculation to another level of detail and assist policy makers with more information sales data for different sectors, like the residential, industrial, commercial and institutional, within the city can be used.

Another level of detail can be added by introducing a spatial element. Sales data for municipal zones can be used to calculate the emissions from different zones in the city and mapped using a Geographic Information System (GIS). This would further help the policy makers by presenting a spatial map to assess where the carbon hotspots in the city lie. Where local data is unavailable, emissions factors can be sourced from the national inventory. However, for a more accurate calculation, the emissions factor would depend on the local mix of power generation in the region.

A completely bottom up approach, on the other hand, would involve mapping the emissions from each building. This would be extremely useful for policy makers to create scenarios for various interventions. Several tools attempt to do this at various levels using energy modelling. As consumption data for each building in the city is usually unavailable, the next best approach is to model energy consumption from buildings. This bottom up approach, although useful for scenario modelling is very time and resource intensive and hence, for a start-up analysis, the top down approach is recommended.

Calculation

IPCC recommended methodology

$$tCO2\ Emission_{Elec} = \text{Electricity use data(MWh)} \times \text{CO2 Emission Factor (t/MWh)}$$

Equation 6-2

The calculations for the electricity sector in the city are based on the consumption-based accounting and thus Eq. 6.1 is used for the calculations. The available data does not conform completely to the disaggregation recommended for the sector, and therefore it is essential to list these shortcomings. The data made available by the UPCL is the annual sales data from the year 2006-2007 to 2010-2011 in million units (MU) or GWh, disaggregated by Residential and Industrial, Commercial and Institutional combined together, UPCL offices, Public water works and Water pumping for Agriculture.

The data corresponds to three zones in the city – North, South and Central. Another issue as noted in the previous Chapter is the inclusion of Mussourie in the North Zone. Although, accurate data for units sold in Mussourie was not available, adjustment has been made based on the information given by the UPCL employee and the MVA ratio of the Mussourie substations to that of the North zone.

The reduction factor for the North zone has been assumed at 1/3 of the total to account for the electricity used in Mussourie. Since there is a high rate of electricity theft, AT&C losses were used for calculation instead of the T&D losses to get the right scenario of electricity use. Aggregate Technical and Commercial [AT&C] losses include losses during transmission and distribution as well as those by theft and pilferage while Transmission and Distribution [T&D] losses correspond to the difference in generated and distributed units only i.e. the losses due to transmission inefficiency. For the regional EF, the percentage supply mix was used with average specific emissions from power technologies in India (Sethi, 2010). Since the region has a higher share of renewable sources, the adjusted EF improves the accuracy of the results. The average regional emissions factor for Uttarakhand is calculated to be 0.5 tCO_2/MWh.

Results

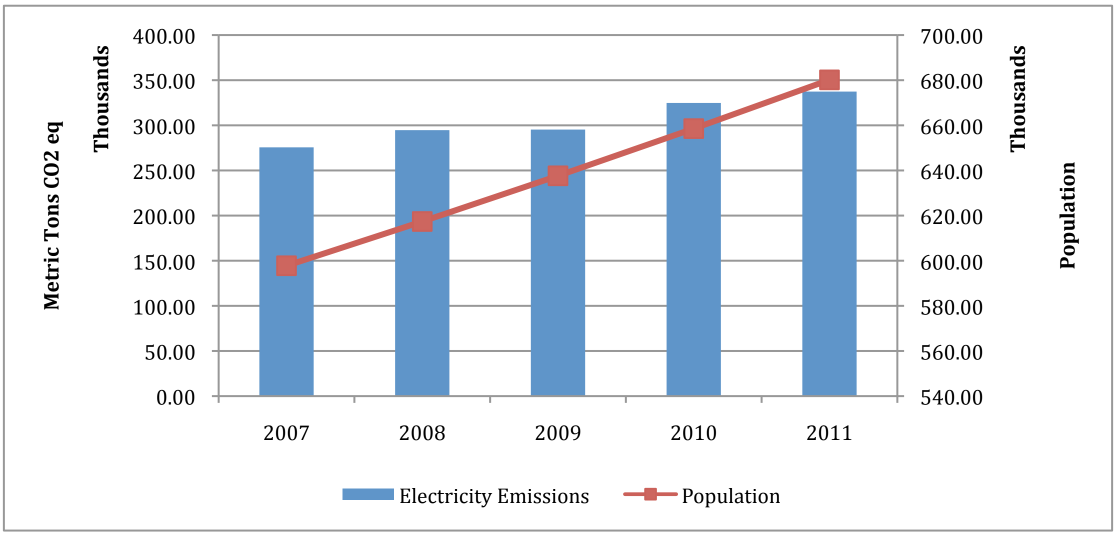


Figure 6-1: Overall City CO2 Eq Emissions from Electricity use in Buildings

The overall electricity usage records show that the annual electricity consumption excluding AT&C losses of the city has increased from 435 GWh in 2006-07 to 545 GWh in 2010-11 and 551 GWh in 2006-07 to 675 GWh in 2010-11 including AT&C losses.

This corresponds to CO_2 emissions [**Figure** 6-1] of 275618 Metric Tons and 337378.25 Metric Tons respectively using the emission factor of 0.5 tCO_2/MWh. This indicates a 22% increase in emissions over the five-year period. The AT&C losses reduced from an average of 27.49% to 23.10% across the three zones. The per capita emissions have risen from 0.46 metric tons to 0.50 metric tons in the five years.

6.1.1.2 Fuel Use

Similar to building electricity use, fuel use in buildings can be quantified by top down and bottom up methods. While the top down method mostly uses fuel sales data from various sources in the city, the bottom up methodology would include measuring or modelling the fuel use for each building in the city. Modelling methods for fuel choice and related emissions typically use econometric analysis and are based on the income groups. The emission factors used are either IPCC defaults or country specific based on stove efficiency when related to cooking fuel use etc.

The IPCC tier 1 approach is based on the amount of fuel used by type of fuel and a default emissions factor [**Equation** 6-3]. Tier 2 method requires the use of country specific emissions factors. Tier 3 however takes into account the fuel combusted by type and combustion technology and the emissions factor by fuel and technology type, thus including factors like operating conditions, control technology, maintenance quality and equipment age. The calculations here are a tier 2 approach with data on fuel combusted and country specific emissions factors.

Calculation

The IPCC recommended method use the following formula-

$$\text{Emissions}_{\text{GHG, Fuel}} = \text{Fuel consumption}_{\text{Fuel}} \times \text{Emissions factor}_{\text{GHG, Fuel}}$$

Equation 6-3

Where,

$Emissions_{GHG, Fuel}$ = Emissions of a given GHG by type of fuel

$Fuel\ consumption_{Fuel}$ = amount of fuel combusted

$Emissions\ factor_{GHG, Fuel}$ = default emissions factor of a given GHG by type of fuel.

The calculations for fuel use have been based on data sourced from the Census of India which provides the number of households using different types of fuel – Firewood, Crop residue, Cow dung cake, Coal, Lignite and Charcoal, Kerosene, LPG, Biogas and Others. Data for the energy intensity per household (GJ/HH) of each fuel type has been sourced from a study on emissions from the household sector in Delhi (Kadian et al., 2007). The same source also provides the Emissions Factors related to each fuel type based on a study of emissions from small scale combustion devices in developing countries.

As the data is not completely in line with the requirements, the following equation was used to calculate the Fuel Consumption by fuel type.

$$Fuel\ consumption_{Fuel} = No.\ of\ Households_{Fuel} \times Energy\ Intensity_{Fuel}$$

Equation 6-4

Where,

$No.\ of\ Households_{Fuel}$ = number of households by type of fuel used for cooking

$Energy\ Intensity_{Fuel}$ = quantity of annual fuel used by fuel type per household in GJ/HH

Being based on the Census of India, the data is only available for the year 2001 and 2011. As such to get a better understanding of the emissions from fuel use, further data was collected for the two maximum used fuels in Dehradun – LPG and Kerosene. Data for other fuel types is difficult to collect, as there is no defined distribution system and also their usage share is less and declining. Data for Kerosene is available from 2006-07 to 2010-11 and that for LPG use by residential and commercial sectors from 2006-07 to 2010-11.

Kerosene usage is in Kilolitres allotted for use in Dehradun. The EF value of 2.52 Metric Tons CO2/KL is based on data from India's national greenhouse gas emissions report (GOI, 2010). Equation 6-3 was used to calculate the annual emissions from kerosene usage in Dehradun for the years 2006-07 to 2009-10.

For the emissions' calculations from LPG, data was available as the number of cylinders used in the Commercial and Residential sectors for the year 2009-10 and 2010-11. The residential sector is supplied LPG in 14.2 kg cylinders while the commercial sector uses 19 kg cylinders. This gives us the total Kilograms of annual LPG use. The EF value of 2.98 TCO2/Ton LPG is based on data from India's national greenhouse gas emissions report (GOI, 2010).

Results

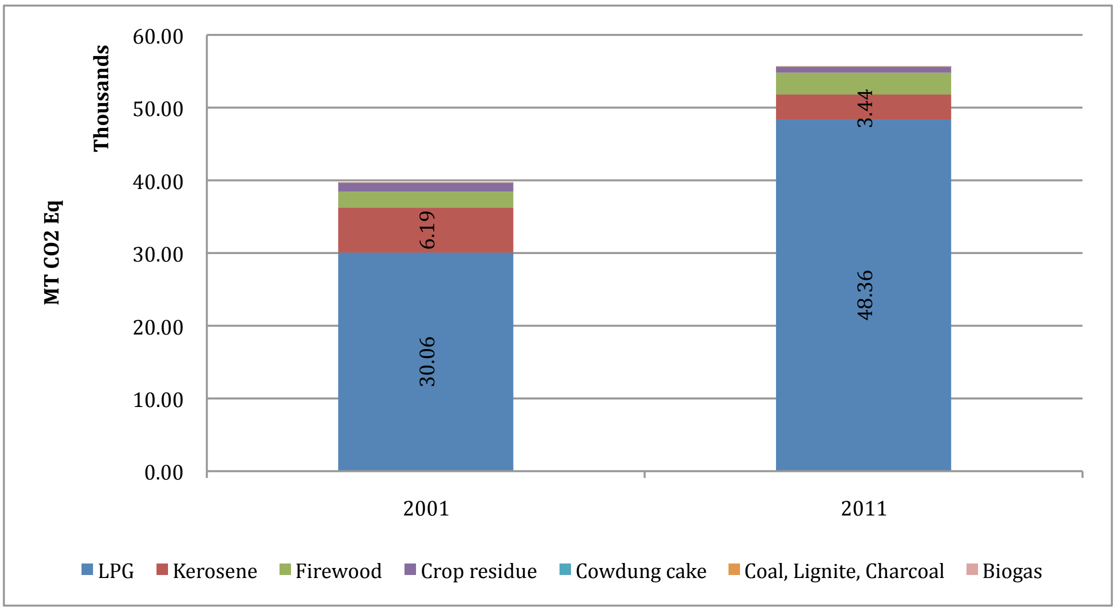


Figure 6-2: Overall City CO2 Eq. Emissions from Residential Cooking Fuel Use

Based on the Census data, **Figure** 6-2 shows the overall emissions from fuel use for different fuel choices in residential households. It can be seen that the major fuel used for cooking in Indian household is LPG followed by Kerosene and marginal usage of other fuel types. In the decade from 2001 to 2011 the total emissions from residential fuel use grew from 39777.18 MT CO2 eq to 55726.51 MT CO2 eq.

As noted earlier, due to the dominance of LPG and Kerosene as the major fuel used in buildings as well as the unavailability of reliable data for other sources, further calculations for the time period between 2007 and 2011 have been based on the two major fuels for including the residential as well as the commercial sector.

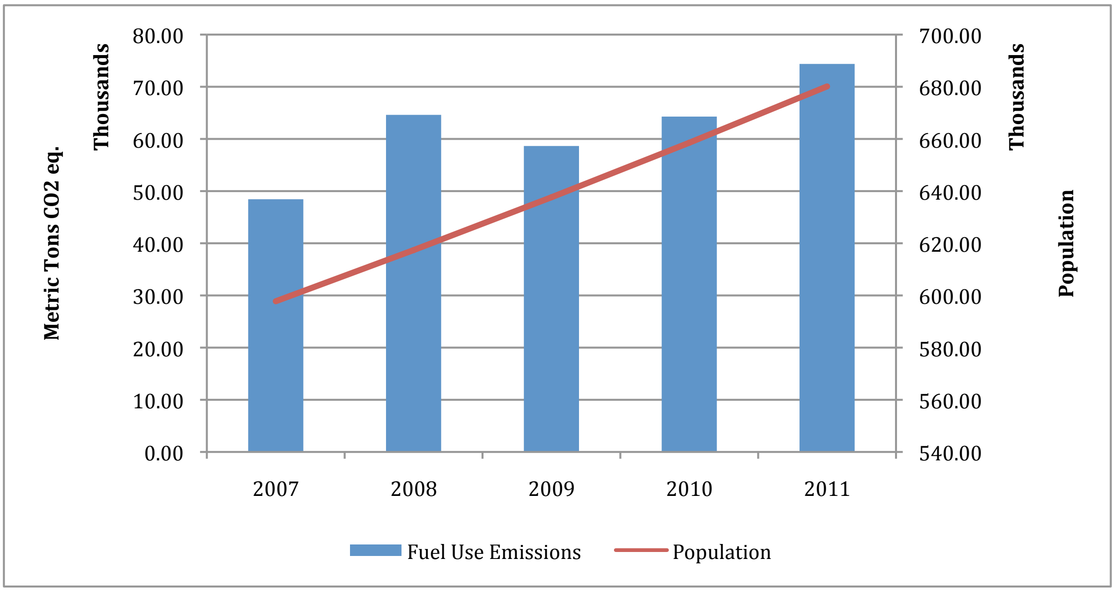


Figure 6-3: Overall City CO2 Eq Emissions from Fuel Use(LPG and Kerosene) in Residential and Commercial Buildings

The overall emission [**Figure** 6-3] from residential and commercial fuel use (LPG and Kerosene) based on the data from the District Supply Office (DSO) in 2007 for Dehradun was 48439 MT CO2 Eq. In the year 2011, this rose to 74380 MT CO2 Eq. registering a 53.5% increase in emissions. Emissions in 2008 show a steep rise that again falls in 2009. The overall trend is of a rising emissions profile consistent with population growth and rising fuel choice of LPG among households. The per capita fuel use grew from 0.08 MT/cap to 0.11 MT/cap as more households switch to LPG and Kerosene for their fuel needs.

6.1.2 Transport

Transport is the second of the top two energy and carbon intensive areas in cities after building energy use. There are several methods of calculating emissions from transport in cities that are discussed below. Within cities road transport is the most important sector. The inclusion of marine, aviation and rail emissions is recommended by some inventories along with cross-boundary emissions from travel beyond the city boundaries. While marine transportation does not apply to this case study, emissions from aviation and rail transportation and cross boundary travel have also been excluded in this study.

The transport sector includes the operational emissions from vehicle use in the city In response to the methodology, the operational emissions are calculated as per vehicle types - cars, two-wheelers, three wheelers, taxis, buses and LCV/HGV.

6.1.2.1 Fuel Use

As per the Tier 1 approach recommended by the IPCC, the emissions from fuel use in road transport can be calculated using the following method –

$$\text{Emission} = \sum_a [\text{Fuel}_a \times \text{EF}_a]$$

Equation 6-5

Where,

Emission = CO_2 emissions
Fuel_a = Fuel sold by fuel type a
EF_a = emission factor that is equal to the carbon content of the fuel multiplied by 44/12

Tier-2 method includes more details along with the fuel type. It also considers the vehicle type and the emission control technology.

$$\text{Emission} = \sum_{a,b,c} [\text{Fuel}_{a,b,c} \times \text{EF}_{a,b,c}]$$

Equation 6-6

Where,

Emission = CO_2 emissions
$\text{Fuel}_{a,b,c}$ = Fuel consumed by a given mobile source activity
$\text{EF}_{a,b,c}$ = emission factor
a = fuel type (diesel, gasoline, natural gas, LPG etc.)
b = vehicle type
c = emission control technology(uncontrolled, catalytic converter etc.)

Tier 3 method is based on the vehicle kilometres travelled by different vehicle types with different control technology in different operating conditions.

$$\text{Emission} = \sum_{a,b,c\,d}[\text{Distance}_{a,b,c,d} \times \text{EF}_{a,b,c,d}] + \sum_{a,b,c,,d} C_{a.b.c.d}$$

……………Equation 6-7

Where,

Emission = CO_2 emissions

$Distance_{a,b,c,d}$ = distance travelled (VKT) during thermally stabilized engine operation phase for a given mobile source activity (km)

$EF_{a,b,c}$ = emission factor

$C_{a,b,c,d}$ = emissions during warm-up phase (cold start) (kg)

a = fuel type (diesel, gasoline, natural gas, LPG etc.)

b = vehicle type

c = emission control technology(uncontrolled, catalytic converter etc.)

d = operating conditions (e.g., urban or rural road type, climate, or other environmental factors)

Most urban inventories use the VKT method to calculate the road transport emissions. Lacking Passenger Kms (PKM) travelled data by Vehicle type; the VKT can be calculated from the number of registered on road vehicles in the city and the estimates of annual/ daily mileage for different vehicle types available from national/regional data.

In some coastal cities, marine transportation can also be included and rail and air transport is also considered in several urban inventories. There are several methodologies in use for the allocation of air and marine transportation. One approach is to exclude the air travel emissions arguing that the emission occurs outside the urban boundary and that they are outside the municipal governments' jurisdiction. A second approach as recommended by the UNFCCC is to account for domestic aviation and only take off and landing for international emissions. Finally one approach is to account for all emissions based on the fuel loaded from the airport in the city. For this study the first approach has been chosen since the municipal governments cannot influence air travel, this has been excluded.

IPCC methodology uses the fuel sale data to estimate the emissions from transport. It also recommends as best practice the use of VKT methodology to validate the top-down fuel method estimates.

Calculation

IPCC recommended method -

$$Emission = \Sigma_a[Fuel_a.EF_a]$$

Equation 6-5

Where,

Emission = Emissions of CO2 (kg)

$Fuel_a$ = fuel sold (TJ)

EF_a = emission factor (kg/TJ). This is equal to the carbon content of the fuel multiplied by 44/12.

a = type of fuel (e.g. petrol, diesel, natural gas, LPG etc)

The first step for calculating emissions from transport included using the total on-road vehicles' data to estimate the annual VKT travelled by vehicle type with the help of annual mileage estimates from CPCB (Ghate and Sundar, 2010).

$$Estimated\ fuel = \Sigma_{I,j,t}[vehicles_{i,j,t}\ .\ distance_{i,j,t}\ .\ consumption_{i,j,t}]$$

Equation 6-8

Where,

Estimated Fuel =total estimated fuel use estimated from distance travelled (VKT) data (Reusswig et al.)

$Vehicles_{i,j,t}$ = number of vehicles of type i and using fuel j on road type t

$Distance_{i,j,t}$ = annual kilometres travelled per vehicle of type i and using fuel j on road type t (km)

$Consumption_{i,j,t}$ = average fuel consumption (l/km) by vehicles of type i and using fuel j on road type t

i = vehicle type (e.g., car, bus)

j = fuel type (e.g. motor gasoline, diesel, natural gas, LPG)

t = type of road (e.g., urban, rural)

Equation 6-8 is used to calculate the estimated fuel use based on the number of vehicles by type and the annual national mileage estimates by vehicle types. The Regional Transport Office(RTO) office in Dehradun provided the number of total on-road vehicles. Country specific emissions factors (gCO2/Km) by vehicle mode were also sourced from ARAI estimates in the India Infrastructure Report (Ghate and Sundar, 2010). The carbon emissions were then calculated for the different vehicle modes – Buses, Cars, Taxis, Three Wheelers, Two Wheelers, and Jeep. Heavy-duty vehicles were excluded from the calculation since their emissions are mostly cross boundary.

Results

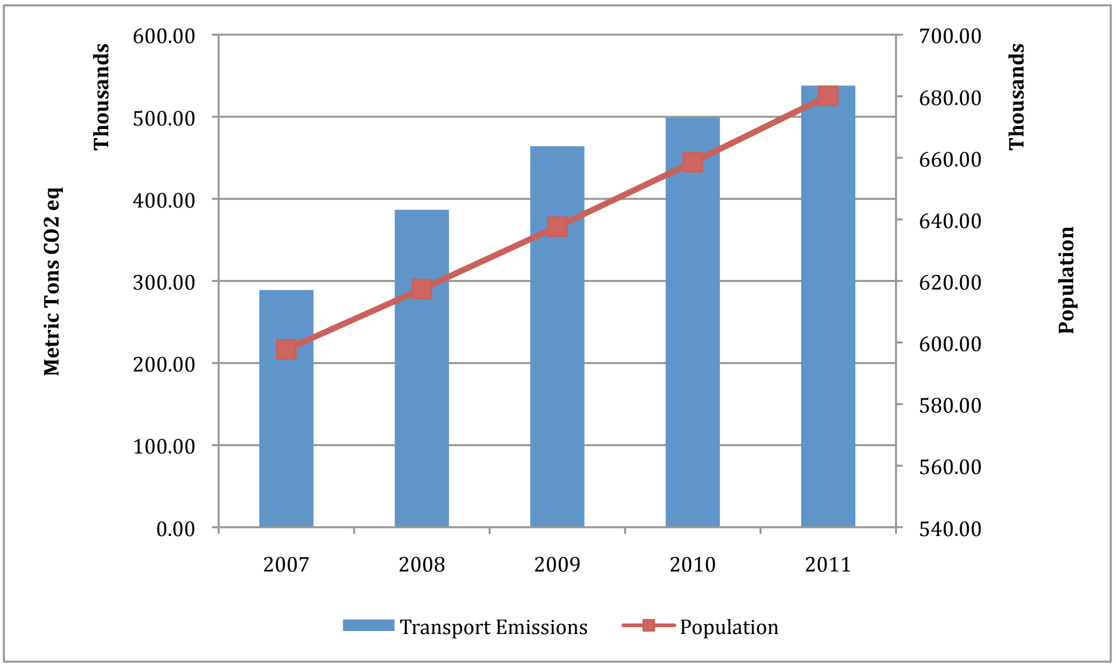


Figure 6-4: Overall City CO2 Eq Emissions from Transport Fuel Use

The total annual CO2 emissions from transport [**Figure** 6-4] in the city have increased from 288955 MT CO2 eq in 2006-07 to 537961 MT CO2 eq in 2010-11. This indicates an almost twofold increase. The number of privately owned vehicles has increased steadily, with car ownership registering an increase of 97%, while two-wheeler ownership has increased by 53%. The number of public transport vehicles fluctuated through the five years. The per capita emissions from transport have risen from 0.48 MT CO2 eq/cap to 0.79 MT CO2 eq/cap in the years from 2006-2011.

6.1.3 Agriculture, Forestry and Land Use

Agriculture, Forestry and other land uses contribute nominally to a city's carbon footprint. The main GHG gases in this sector are CO_2, CH_4 and N_2O.

The atmosphere and ecosystem exchange CO_2 by the processes of plant photosynthesis (removal from atmosphere) and respiration, decomposition and combustion of organic matter (addition to atmosphere). N_2O is a byproduct of nitrification and denitrification and CH_4 is emitted from processes like rice cultivation (methanogenesis under anaerobic conditions in soils), enteric fermentation and incomplete combustion of organic matter.

6.1.3.1 Land Use

2006 IPCC guidelines define six land uses in this category –

- Forest Land
- Cropland
- Grassland
- Wetlands
- Settlements
- Other Land

$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{OL}$

Where,

ΔC = Carbon Stock Change

And Indices

AFOLU = Agriculture, Forestry and Other Land Use

FL = Forest Land

CL = Crop Land

GL = Grass Land

WL = Wetlands

SL = Settlement

OL = Other Land

The net carbon stock change is measured from each of the biomass, dead organic matter and soil categories for each land use. Also for each category the calculations are done for land remaining in the same land use and the land converted to new land use.

There are two methods that can be used for calculating carbon stock change in all land use types for land remaining in the same land use. The first method is the Gain Loss method where the carbon loss is subtracted from carbon gain for biomass, dead organic matter or soils. The generic equation for this is

$\Delta C = \Delta C_G - \Delta C_L$

Where,

ΔC = Annual Carbon stock change in the pool tonnes C /yr

ΔC_G = annual gain of carbon, tonnes C / yr

ΔC_L= annual loss of carbon, tonnes C / yr

The alternative method is the Stock Difference method that can be used when carbon stocks in the pool are measured at two points of time. The representative equation is

$\Delta C = (\Delta C_{t2} - \Delta C_{t1})/t2-t1$

Where,

ΔC = Annual Carbon stock change in the pool tonnes C /yr

C_{t1} = carbon stock in the pool at time t1, tonnes C

C_{t2} = carbon stock in the pool at time t2, tonnes C

For land converted to another land use, the generic equation for assessing carbon stock change is

$\Delta C = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$

Where,

ΔC = Annual Carbon stock change in the pool tonnes C /yr

ΔC_G = Annual gain of carbon on land converted to another land use

ΔC_L= annual loss of carbon on land converted to another land use

$\Delta C_{CONVERSION}$= initial change in carbon stock on land converted to another land use

Urban municipal boundaries usually do not include large areas under forest or cropland use. Land use planning, however, has been a major policy tool for regulating urban growth and when it comes to carbon emissions on a local scale, it can play a defining role in mitigating the emissions through careful planning and preservation and introduction of carbon sinks. However, the lack of requisite data is found prohibitive in the calculation of emissions from this sector. An alternative methodology could not be found to fill the data gap.

One of the main aspects of this section of the inventory is also to assess the carbon storage potential in the region. In 2009 the area under agriculture and urban greens within the Dehradun Municipal Boundary was 20.86 sq.km or 31.5% of the total area (Sharma and Jalan, 2013). The total carbon sequestration potential for the state of Uttarakhand was found to be 3795.8 Gg of carbon storage (Ramachandra and Shwetmala, 2009) with around 24,442 sq.km, which is 45.70% area under forest cover and 7,487 sq.km or 14% in use for agriculture state-wide(Directorate, 2009).

6.1.3.2 Agriculture

The following subcategories from the IPCC guidelines are applicable in the Indian scenario and the context of this study. Emissions from agriculture include CH4 emissions from rice cultivation, which is abundant in the Dehradun region, and CO2 emissions from the use of Urea as a fertilizer. CH4 emissions from livestock enteric fermentation and manure management are also included in this category.

Calculation

CO_2 emissions from Urea fertilization

Urea when applied to soil is converted to ammonium (NH_4^+), hydroxyl (OH^-), and bicarbonate ion (HCO_3^-) that subsequently convert to produce CO_2 and water. The use of Urea in India as a fertilizing agent is widespread. To calculate the emissions from urea use, the IPCC recommends the following method –

CO_2-C Emission = M x EF **Equation 6-9**

Where,

CO_2-C Emission = annual C emissions from Urea application, tons C/yr
M = annual amount of urea fertilization, tons urea/yr
EF = emission factor, tons of C / ton of urea

The default emission factor (EF) is 0.20 for carbon emissions from urea applications. The resultant CO_2-C emissions can be converted to equivalent CO_2 emissions by multiplying the result by 44/12.

CH_4 emissions from Rice Cultivation

Methane is produced in flooded paddy fields as a result of anaerobic decomposition of organic material. The number and duration of crops grown, soil type, temperature, irrigation method, and inorganic and organic soil amendments determine the amount of CH_4 emissions.

The emissions can be calculated using the following method –

$$CH_{4\ Rice} = \sum_{i,j,k} (EF_{i,j,k} \times t_{i,j,k} \times A_{i,j,k} \times 10^{-6})$$ **Equation 6-10**

Where,

$CH_{4\ Rice}$ = annual methane emissions from rice cultivation, Gg CH_4 yr^{-1}
$EF_{i,j,k}$ = a daily emission factor for *i*, *j*, and *k* conditions, kg CH ha^{-1} day^{-1}
$t_{i,j,k}$ = cultivation period of rice for *i*, *j*, and *k* conditions, day
$A_{i,j,k}$ = annual harvested area of rice for *i*, *j*, and *k* conditions, ha $yr-^{1}$
i, j, and k = represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH_4 emissions from rice may vary.

Data sourced from the Agricultural Directorate in the city is used with default IPCC factors to calculate the emissions as per the tier 1 level. The CH4 emissions are converted to CO2 equivalents using the GWP factor of 21(IPCC, 2006).

Overall, emissions from agriculture form a very insignificant contribution in an urban inventory. In the case of Dehradun emissions from Rice cultivation and Urea use in the city's agricultural land totalled an emission of 170 MT of CO2 eq in 2011. The total emissions from livestock in 2007 amount to 14,880 MT CO2 eq.

Urea Fertilization

The emissions from the use of urea as a fertilizer in Dehradun have increased from 5.51 metric tons a year in 2007 to 8 metric tons in 2011. In the overall city profile these emissions are minimal. But the rising trend of urea use cannot be overlooked especially considering that the cultivation area in the city is declining.

Rice Cultivation

The total emissions from rice cultivation in the city have been steadily decreasing with a decrease in the area of farmland within the municipal boundaries. Where in 2007 paddy cultivation accounted for 356 MT of CO2 eq. emissions, in 2011 this has reduced to 162 MT.

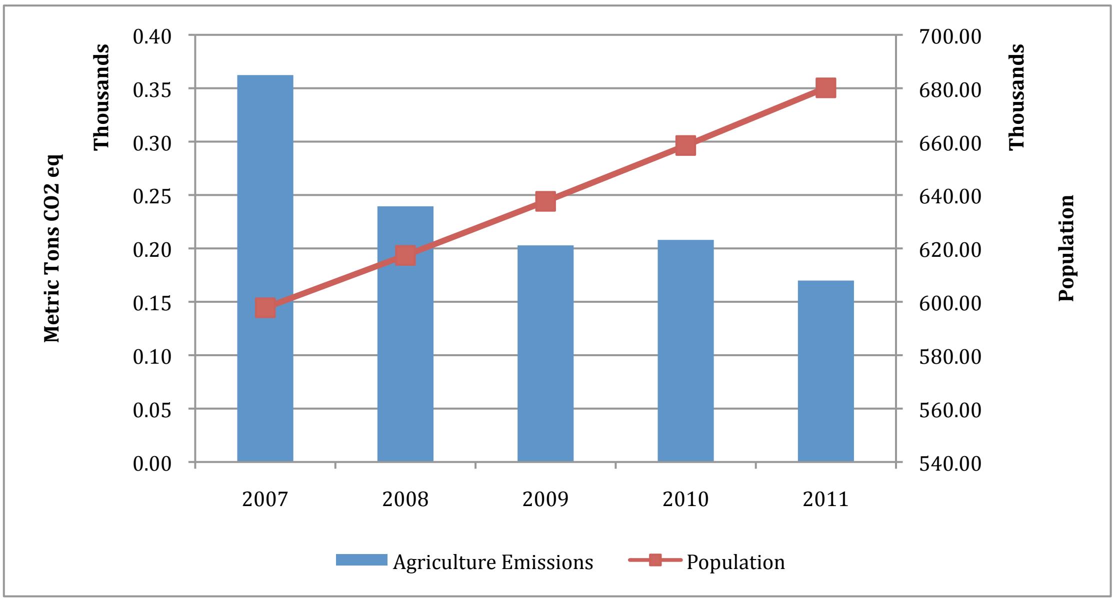


Figure 6-5: Overall City CO2 Eq Emissions from Agriculture

In the case of Dehradun, **Figure** 6-5 shows emissions from Rice cultivation and Urea use in the cities agricultural land totals an emission of 170 MT of CO2 eq in 2011 a sharp 53% decline from 2007.

6.1.3.3 Emissions from Livestock

Since India has a large number of livestock populations, even in urban centres, this category gains importance. Methane is a by-product of enteric fermentation in domestic livestock. The amount of methane that is released depends on the type of digestive tract, age, and weight of the animal, and the quality and quantity of the feed consumed.

Calculation

To calculate the total emissions from livestock using the IPCC Tier 1 methodology, emissions factors are applied to the population in the various species and the results aggregated.

$$\text{Emissions} = EF_{(T)} \times [N_{(T)}/10^6]$$ **Equation 6-11**

Where,

Emissions = methane emissions from Enteric Fermentation, Gg CH_4 yr
$EF_{(T)}$ = emission factor for the defined livestock population, kg CH4 head^{-1} yr^{-1}
$N_{(T)}$ = the number of head of livestock species / category T in the country
T = species/category of livestock

And the aggregation is done as -

$$\textbf{Total } CH_{4\,Enteric} = \sum_I E_i$$ **Equation 6-12**

Where,

Total $CH_{4\ Enteric}$ = total methane emissions from Enteric Fermentation, Gg CH_4 yr
E_i = is the emissions for the ith livestock categories and subcategories

IPCC provides default emission factor values for various livestock species and from various regions. CH_4 is also produced during the storage and treatment of manure from the livestock. The decomposition of manure under anaerobic conditions (i.e., in the absence of oxygen), during storage and treatment, produces CH4. Using the Tier 1 method, livestock population data can be used to estimate the emissions.

$CH_{4\ Manure} = \sum_{(T)} [(EF_{(t)} \times N_{(T)})/10^6]$ **Equation 6-13**

Where:

$CH_{4Manure}$ = CH_4 emissions from manure management, for a defined population, Gg CH_4 yr^{-1}

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4 $head^{-1}$ yr^{-1}

$N_{(T)}$ = the number of head of livestock species/category T in the country

T = species/category of livestock

Data for this sector is not available on an annual basis as the livestock census is only performed once in about 5 years. Hence, data was collected for the number of heads by cattle type for the years 2003 and 2007, which were the last two years the census was conducted from the Animal Husbandry department in Dehradun. The data for emissions factors was sourced from the IPCC defaults for both enteric fermentation and manure management. The calculations were based on the tier 1 methodology using the equations listed above. The CH4 emissions are converted to CO2 equivalents using the 21 GWP factor.

Results

The total emissions from livestock in 2007 amount to 14,880 MT CO2 eq [**Figure 6-6**] up from 12,763 MT CO2 eq in the year 2003.

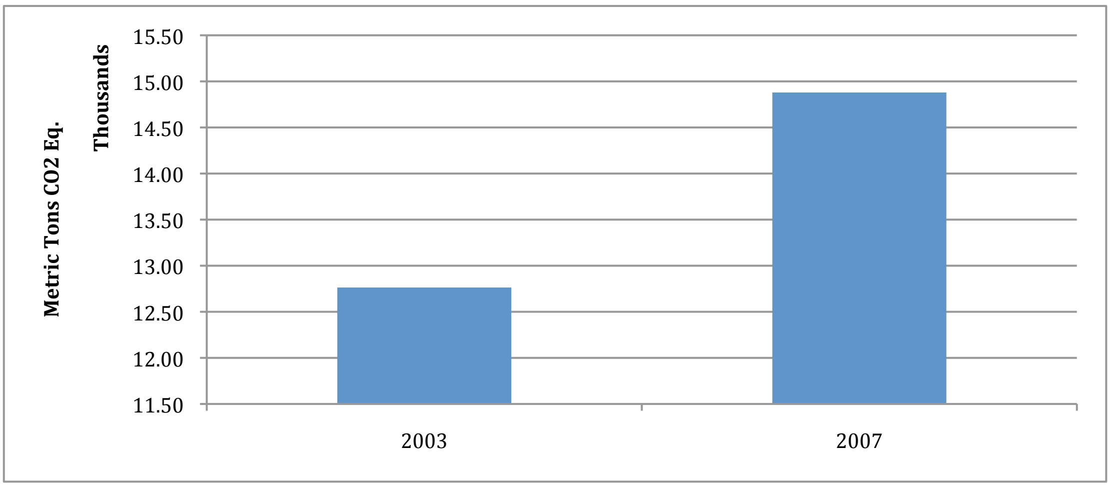


Figure 6-6: Overall City CO2 Eq. Emissions from Livestock

Enteric fermentation

Total CO2 eq emissions due to enteric fermentation from Livestock amounted to 11,574 MT CO2 Eq in 2003 and rose to 13,568.5 MT CO2 eq in 2007.

Manure management

When it comes to manure management the 2003 total emissions from the category equalled 1189 MT CO2 eq and those in 2007 amounted to 1311 MT CO2 eq. Dairy cows and buffalos are responsible for the most emissions in this category followed by cattle and swine.

6.1.4 Infrastructure

One of the key features of an urban settlement is the public infrastructure that supports the population. The extensive networks of water supply and waste disposal also form an important element in the city's carbon tally. This sector is subdivided into water and waste.

Energy used for treatment and pumping of the water supply has been included in the electricity calculation and hence is not repeated here. The waste subsector is further disaggregated as Municipal solid waste and waste water. CH4 emissions from both have been calculated.

6.1.4.1 Municipal Solid Waste

Waste is an important sector from the perspective of carbon emissions, first because it is the major source of CH_4 on an urban scale and also because it offers a successful Clean Development Mechanism (CDM) potential for local authorities. Waste in cities is categorized by solid waste and waste water, both dumped and treated separately.

Calculation

2006 IPCC recommends the First Order Decay method for inventorying emissions from Solid Waste Disposal Systems.

The basis for a first order decay reaction is that the reaction rate is proportional to the amount of reactant remaining, in this case the mass of degradable organic carbon decomposable under anaerobic conditions (DDOCm).

First Order Decay Equation –

$DDOCm = DDOCm_0 * e^{-kt}$

Equation 6-14

Where,

DDOCm = mass of degradable organic carbon that will decompose under anaerobic conditions in the disposal site at time t
DDOCm0 = mass of DDOC in the disposal site at time 0, when the reaction starts
k = decay rate constant in y-1
t = time in years.

To calculate the mass of decomposable DOC(DDOCm) from the amount of waste material (W)

DDOCmd(T) = W(T) * DOC * DOCf * MCF **Equation 6-15**

Amount of deposited DDOCm remaining not decomposed at the end of deposition year T:

DDOCmrem(T) = DDOCmd(T) * e^(-k((13-M)/12) **Equation 6-16**

Amount of DDOCm decomposed during deposition year T

DDOCmdec(T) = DDOCmd(T) * (1-e^(-k((13-M)/12)) **Equation 6-17**

Amount of DDOCm accumulated in the SWDS at the end of year T

DDOCma(T) = DDOCmrem(T) + (DDOCma(T-1) * (1-e^-k) **Equation 6-18**

Total amount of DDOCm decomposed in year T

DDOCmdecomp(T) = DDOCmdec(T) + (DDOCma(T-1) * (1-e^-k) **Equation 6-19**

Amount of CH4 generated from DOC decomposed

CH4 generated (T) = DDOCmdecomp(T) * F * 16/12 **Equation 6-20**

Amount of CH4 emitted

CH_4 emitted in year T = (∑xCH_4generated (x,T)-R(T)) * (1-OX(T)) **Equation 6-21**

Where:

T=the year of inventory

X=material fraction/waste category

W(T)=amount deposited in year T

MCF=Methane Correction Factor

DOC=Degradable organic carbon (under aerobic conditions)

DOCf= fraction of DOC decomposing under anaerobic conditions

DDOC = Decomposable Degradable Organic Carbon (under anaerobic conditions)

DDOCmd(T) = mass of DDOC deposited in year T

DDOCmrem(T) = mass of DDOC deposited in inventory year T, remaining not decomposed at the end of year

DDOCmdec(T) = mass of DDOC deposited in inventory year T, decomposed during the year

DDOCma(T) = total mass of DDOC left not decomposed at the end of year T

DDOCma(T-1) = total mass of DDOC left not decomposed at the end of year T-1

DDOCmdecomp(T) = total mass of DDOC decomposed in the year T

CH_4 generated (T) = CH_4 generated in year T

F = fraction of CH_4 by volume in generated landfill gas

16/12 = molecular weight ratio CH_4/C

R (T) = recovered CH_4 in year T

OX (T) = oxidation factor in year T

K = rate of reaction constant

M = month of reaction start

Base data for the amount of waste generated in the city is either available on a per capita basis or the disposal agency can provide aggregate data for the amount of solid waste collected from the city for disposal. The same agency also holds data for the distribution of waste type as organic, paper, textile or plastic waste.

Table 6-1 and **Table** 6-2 present the composition and characteristics of municipal waste in Dehradun.

Table 6-1: Composition of Municipal Solid Waste from Samples in the Dehradun (Source: Dehradun Nagar Nigam)

Constituent	Composition(%)
Organic Matter/ Bio-Mass	65
Paper	3.5
Rags/ Textiles	6
Plastics	7
Glass	1.5
Rubber/Leather	1.5
Metal	0.5
Stones	8
Sand/ Earth	7

Table 6-2: Characteristics of Municipal Solid Waste samples from Dehradun

Parameter	Sample -1	Sample -2	Sample – 3	Average
Moisture Content (%)	44	53	52	50
Total solids (%)	56	47	48	50
Volatile Matter (%)	47	36	36	40
Volatile Matter (% of Total Solids)	68	55	50	58
C/N	8	13	2	8
Gross Calorific Value Cals/gm (on a dry weight basis)	3280	3033	2742	3018

Currently, the 60% of waste collected is disposed off at a disposal site located at Dateda Lakhond on Sahashradhara Road and at a distance of about 7 km from the town. The site is 8.323 Ha and the waste is disposed of in trenches and covered with soil.

The calculation was done based on the IPCC recommended First Order Decay (FOD) methodology. The data for waste disposed in landfill was estimated as 60% of the waste generated in the city between the years 2007- 2011. Other data on factors was taken from the IPCC country specific estimates and is presented in **Table** 6**-**3.

Table 6-3: The Default IPCC recommended data used for MSW Emissions Calculation

Default IPCC values used for calculating based on Country Specific Data		
DOC	DOC	0.17
DOCf	DOCf	0.50
Methane generation rate constant	k	0.09
Half-life time (t1/2, years):	h = ln(2)/k	7.70
exp1	exp(-k)	0.91
Process start in deposition year. Month M	M	13.00
exp2	exp(-k*((13-M)/12))	1.00
Fraction to CH4	F	0.50

Equation 6-14 was used to calculate the emissions to a tier 1 level. The base data for amount of waste generated is based on the per capita estimate and population data from the years 2006-2011. While the amount of per capita waste generation estimate was collected from the municipal corporation of Dehradun, the population data is based on the Census of India.

Results

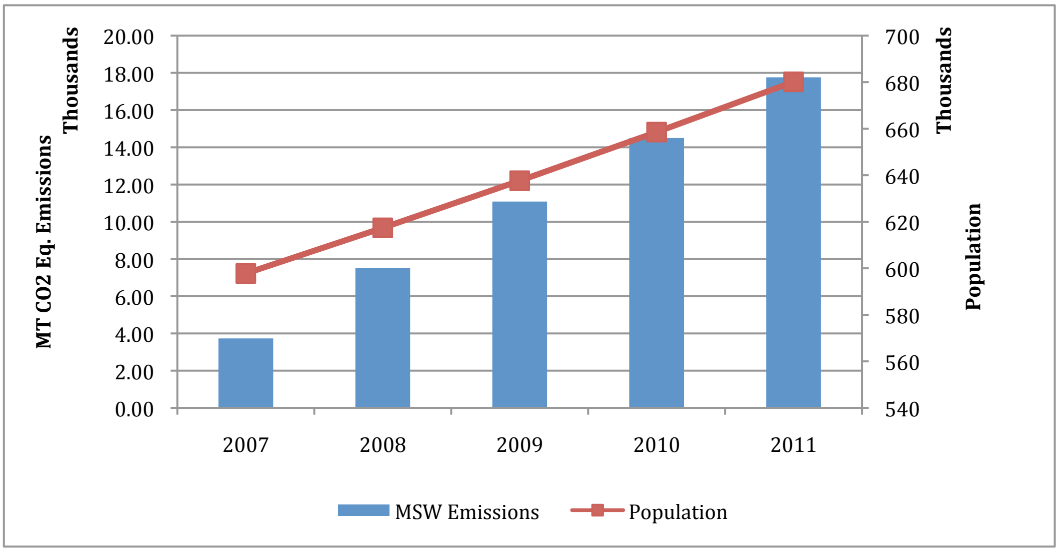


Figure 6-7: Total City CO2 Eq Emissions from Municipal Solid Waste

A steady increase in the CH4 emissions can be seen through the years, which is a result of the accumulating emissions from the FOD methodology. The Giga-grams CH4 emissions were converted to equivalent metric tons CO2 emissions by using the GWP of 21 as recommended by the IPCC. In 2011, 0.85 GG of CH4 was emitted from the Dehradun municipal solid waste disposal system, which is equivalent to 17,760.52 MT of CO2 eq [**Figure** 6-7].

The FOD methodology accounts for the multifold increase in emissions as 2006 is taken as the base year and hence emissions in 2007 are much lower and increase at a log scale through to 2011. The increase in emissions is also a result of increasing population pressure in the city.

6.1.4.2 Waste water

Waste water refers to the liquid waste discharge from domestic, commercial, industrial sources. Waste water is either collected by the city agency through a network of sewers, and disposed of untreated in rivers and lakes or after treatment, or where a city wide collection system is unavailable it is treated on site using septic tanks etc. or disposed without being treated to surface water sources. Anaerobic decomposition of this waste water can produce CH_4.

For collected waste water, closed sewers will not produce any CH_4, whereas, open sewers or untreated river discharge may become a source of CH_4. When treated, the waste water can go through two processes. In an aerobic treatment plant there is limited production of CH_4.

The most likely source of CH_4 is through anaerobic treatment. Where wastewater is not collected, septic tank onsite treatments are sources of CH_4 but the production is reduced by frequent solids removal.

IPCC identifies wastewater sector as one where data availability is limited. Hence, in the tier 1 methodology the calculations are based on default values for both the emission factor and the activity parameter.

The general equation used to estimate CH_4 emissions from domestic wastewater is –

CH_4 Emissions = $[\sum_{I,j} (U_i \times T_{i,j} \times EF_j)](TOW-S)-R$ **Equation 6-22**

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr
TOW = total organics in wastewater in inventory year, kg BOD/yr
S = organic component removed as sludge in inventory year, kg BOD/yr
U_i = fraction of population in income group i in inventory year
$Ti_{,j}$ = degree of utilisation of treatment/discharge pathway or system, j, for each income group fraction i in inventory year,
i = income group: rural, urban high income and urban low income
j = each treatment/discharge pathway or system
EFj = emission factor, kg CH_4 / kg BOD
R = amount of CH4 recovered in inventory year, kg CH_4/yr
BOD – Biochemical Oxygen Demand

IPCC provides estimates of Urbanization (U) and degree of utilization of treatment or discharge pathway by income group for various countries.

TOW or total organics in wastewater can be estimated by –

$$TOW = P \times BOD \times 0.001 \times I \times 365$$ **Equation 6-23**

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr
P = country population in inventory year, (person)
BOD = country-specific per capita BOD in inventory year, g/person/day
0.001 = conversion from grams BOD to kg BOD
I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00.)

Country specific per capita BOD values are available from the IPCC guideline. For India the range is 27-41 g/person/day or an average of 34 g/person/day.

And emission factors can be estimated from –

$$EF_j = B_o \times MCF_j$$ **Equation 6-24**

Where:

EF_j = emission factor, kg CH4/kg BOD
j = each treatment/discharge pathway or system
B_o = maximum CH4 producing capacity, kg CH4/kg BOD
MCF_j = methane correction factor (fraction)

MCF default factors are available based on the type of treatment and discharge system.

In view of the current status of the waste water collection and treatment facility in the city, the best approach was to use the tier 1 methodology recommended by the IPCC based on default factors and the population of the city. The population data was sourced from the census of India projections.

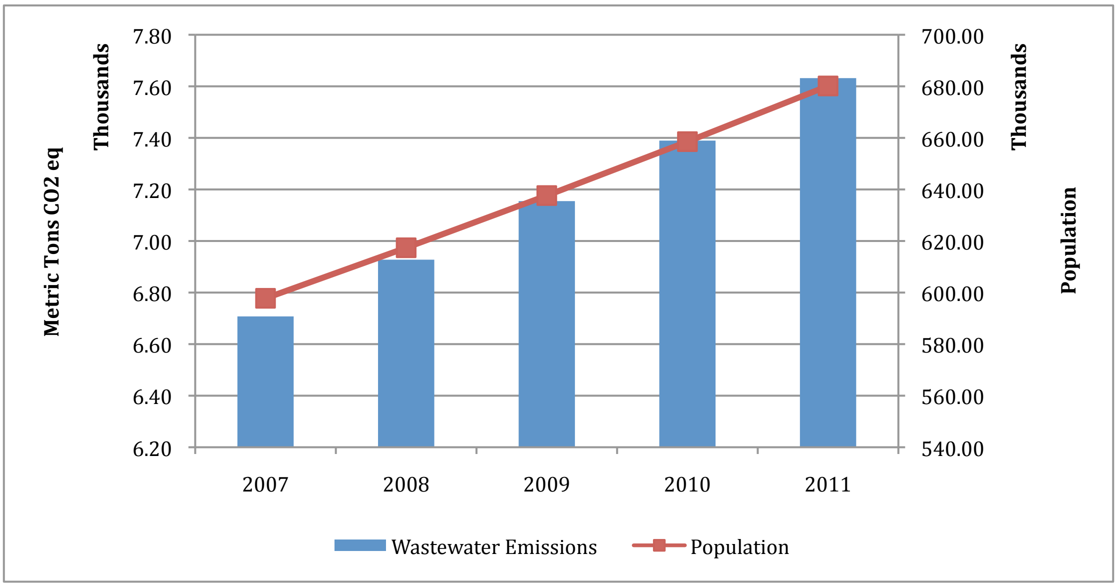


Figure 6-8: Total City CO2 Eq emissions from WasteWater

Emissions from wastewater account for 7632 MT of CO2 eq in the year 2011, up from 6707.5 MT CO2 eq in 2007. **Figure** 6-8 shows the annual total emissions from the category from 2007-2011. The emissions have steadily risen, with the rise in population in the city.

6.2 Discussion

6.2.1 Overall emissions from the city

In the 5-year period covered in this study, the overall emissions from the city increased by 52.6%. The top two sectors with the highest rate of increase were Waste (143%) and Transport (86%) followed by Fuel Use (54%) and Electricity Use (22%) in Buildings while the Agriculture sector registered a decrease in the five years (-53%).

Livestock data is only available for the years 2003 and 2007 where 2003 falls outside the time scale covered in the study. The data for 2007 is incorporated in the results. Since 2007 is the most comprehensive in terms of data available, it can be used as the base year for the inventory. It is evident from **Figure** 6-9 that the CO2 emissions in the city have grown at a more rapid pace than the population of the city. Hence, it can be inferred that population growth is not the only driving force behind the GHG emissions.

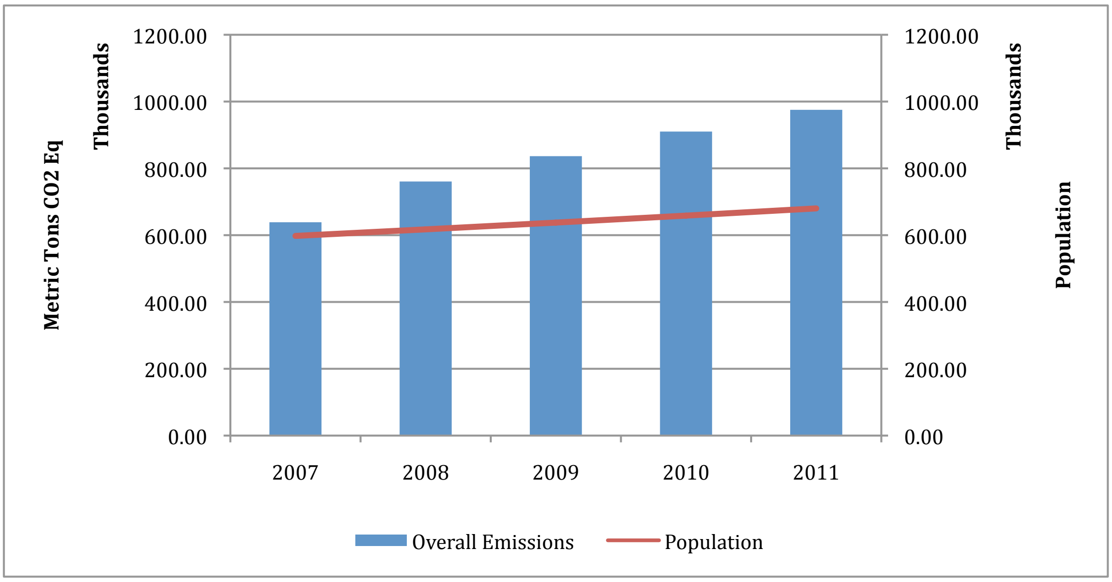


Figure 6-9: Aggregate MT CO2 Emissions from all sectors in the City

The per capita emissions increased from 1.07 MT to 1.43 MT in the period. **Table** 6-4 presents the results of all the sectoral calculation in a tabular form giving the total emissions results for the city over the years. The tabular format highlights the data gaps where data was not available.

Table 6-4: Total MT CO2 Eq. Emissions from the city

Year	Electricity	Fuel Use*	Transport	Agriculture	Livestock	Waste	Total
2001		(39777.18)					
2003					12763.39		
2007	275618.1	48438.87	288955.34	362.32	14879.56	10439.67	**638693.86**
2008	294667.16	64614.88	386710.49	239.43		14432.00	**760663.96**
2009	295290.35	58648.50	464158.4	202.85		18241.14	**836541.24**
2010	324787.43	64283.61	499015.37	207.98		21888.10	**910182.49**
2011	337378.25	74379.89 (55726.51)	537961.49	169.90		25392.30	**975281.83**

* For Fuel use emissions, the 2001 and 2011 results (in brackets) are only residential fuel use in the city based on Census data. The results for 2007-2011 are emissions from LPG and Kerosene used in the city in Residential and Commercial sector.

The results being an estimate of GHG emissions based on city level data are prone to uncertainty. Some uncertainty arises from the input parameters for example the data for fuel sold in black markets could not be collected; other sources of uncertainty are from the model. IPCC estimates uncertainty of 5-10% for CO2 emissions. However, it is safe to assume that the trends displayed through this analysis can be conceived reliable for informing policy measures. The following benchmark comparisons with other cities helps to validate the results and minimize the uncertainty associated with it.

6.2.2 Benchmark Comparison

Comparing the results from the case study to the benchmark data available from ICLEI, several inferences can be drawn. The overall emissions from the case study are below the average represented by the benchmark cities [**Figure** 6-10]. On a per capita basis, however, the city has a higher than average emissions rate at 1.07 MT per capita.

Among the various sectors, Residential, Commercial and Transport sectors in the city record higher than average emissions whereas, industry and waste have lower than average emissions [**Figure** 6-12 a, b, c, d, e] signifying that residents in the city use more electricity and fuel and travel more Vehicle Kms than people in many other Indian cities but produce less waste. This gives policy makers an indication of the potential for emissions reductions from the sectors accounting for higher than average emissions.

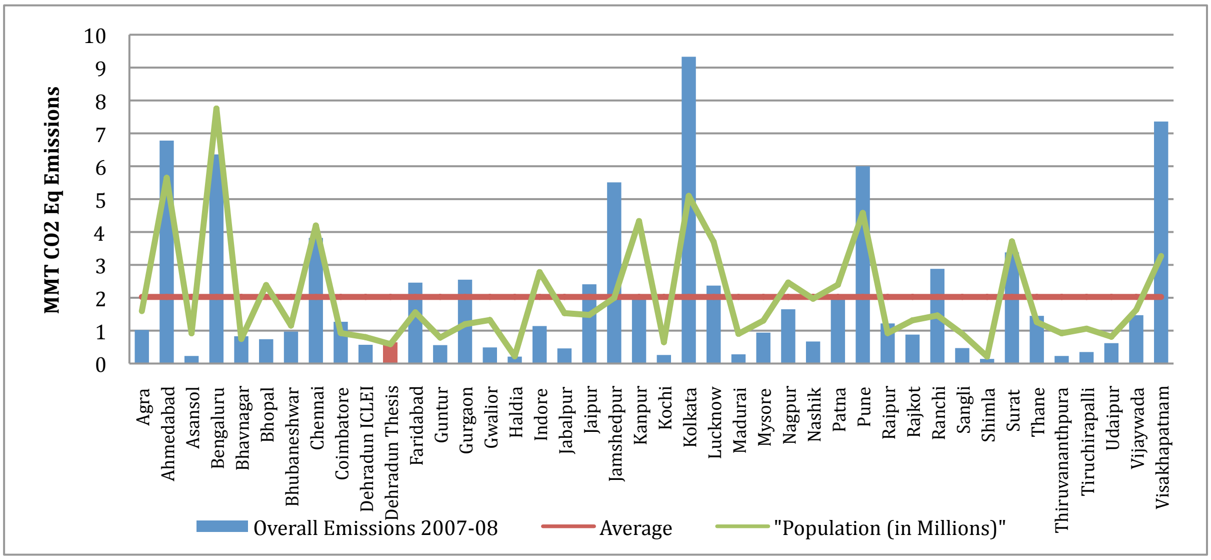


Figure 6-10: Total City CO2 Eq Emissions from Indian Cities

In most cities, the residential and transport emissions dominate the emissions profile [**Figure** 6-11]. But the highest emitting cities have a higher share of industrial emissions signifying industry as the main source of GHG. The emissions profile for the case study city is consistent with this trend with the residential and transport emission forming the major share of the emissions. Although there are exceptions, an emissions-population relationship in the benchmark data does shows a positive upward trend with an increase in city population signifying increased emissions [**Figure** 6-11].

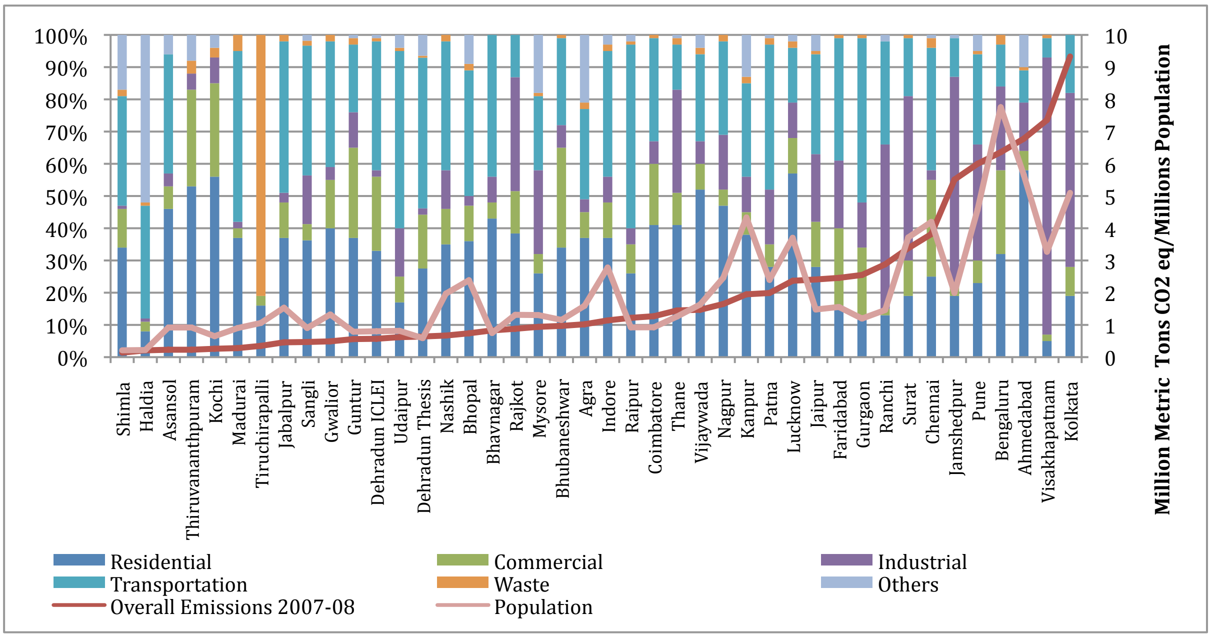
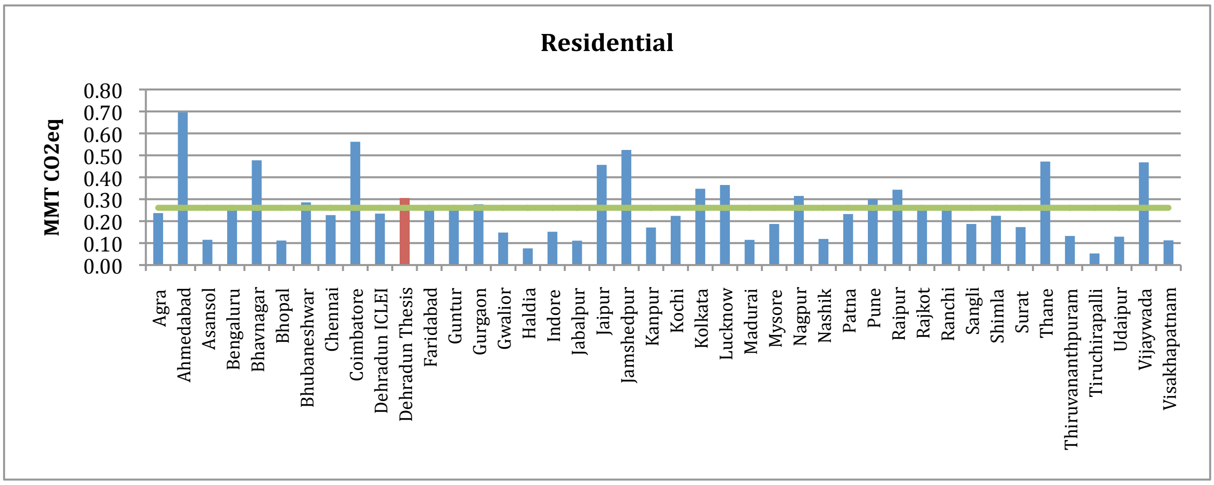
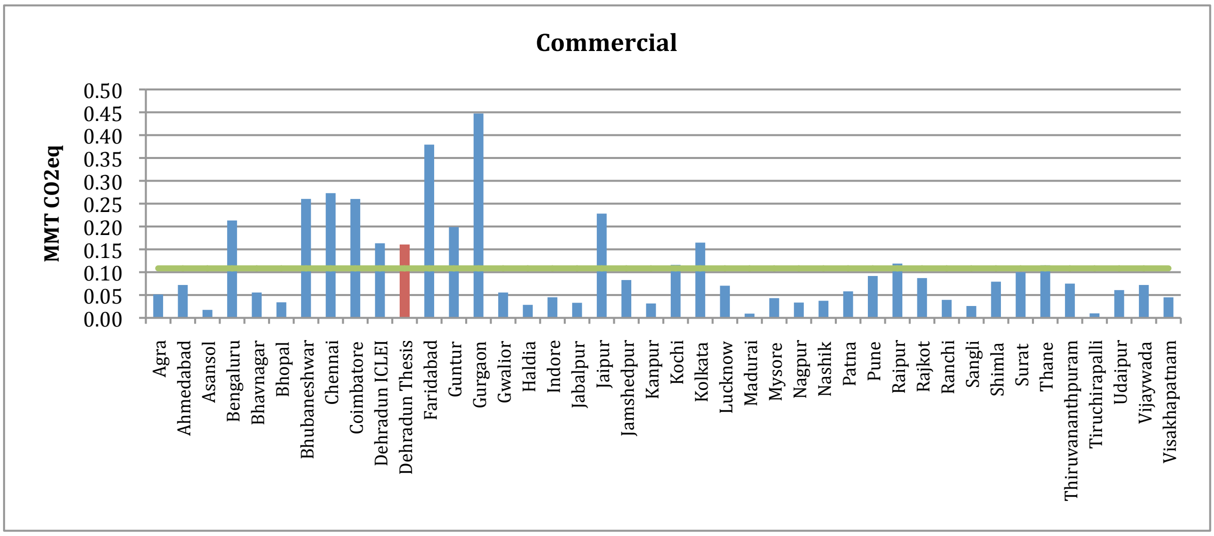


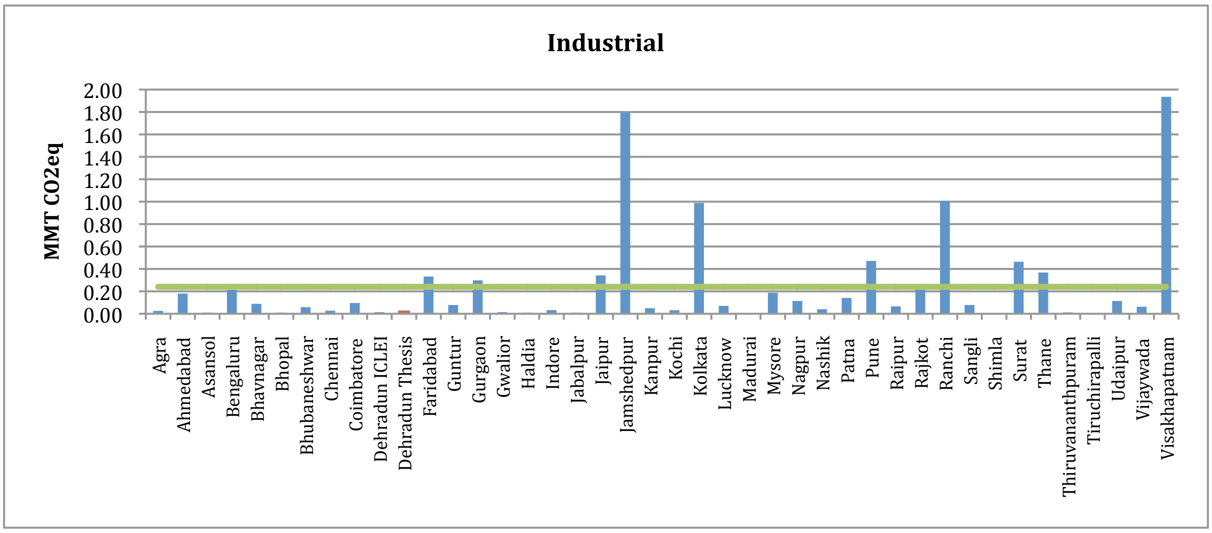
Figure 6-11: Sectoral emissions share, Total City emissions and Population for various Indian Cities

Comparing the emissions profile of Dehradun from the ICLEI study with the results from this study [**Figure** 6-13], gives several important insights into the methodological and data implications of GHG inventories. Although both the ICLEI study and the case study use 2007 as the base year for the inventory calculation, there are differences in the results owing to differences in the method and data used.

One of the key differences is the estimated population, the case study uses data from the JNNURM City Development Plan which estimates it at 0.59 million whereas the ICLEI study uses an estimate of 0.8 million in 2007. Considering that the 2011 Census data shows a population of 0.61 million within the municipal boundaries, the ICLEI data seems to be an overestimate.


Residential
MMT CO2eq
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Agra
Ahmedabad
Asansol
Bengaluru
Bhavnagar
Bhopal
Bhubaneshwar
Chennai
Coimbatore
Dehradun ICLEI
Dehradun Thesis
Faridabad
Guntur
Gurgaon
Gwalior
Haldia
Indore
Jabalpur
Jaipur
Jamshedpur
Kanpur
Kochi
Kolkata
Lucknow
Madurai
Mysore
Nagpur
Nashik
Patna
Pune
Raipur
Rajkot
Ranchi
Sangli
Shimla
Surat
Thane
Thiruvananthpuram
Tiruchirapalli
Udaipur
Vijaywada
Visakhapatnam


Commercial
MMT CO2eq
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Agra
Ahmedabad
Asansol
Bengaluru
Bhavnagar
Bhopal
Bhubaneshwar
Chennai
Coimbatore
Dehradun ICLEI
Dehradun Thesis
Faridabad
Guntur
Gurgaon
Gwalior
Haldia
Indore
Jabalpur
Jaipur
Jamshedpur
Kanpur
Kochi
Kolkata
Lucknow
Madurai
Mysore
Nagpur
Nashik
Patna
Pune
Raipur
Rajkot
Ranchi
Sangli
Shimla
Surat
Thane
Thiruvananthpuram
Tiruchirapalli
Udaipur
Vijaywada
Visakhapatnam


Industrial
MMT CO2eq
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Agra
Ahmedabad
Asansol
Bengaluru
Bhavnagar
Bhopal
Bhubaneshwar
Chennai
Coimbatore
Dehradun ICLEI
Dehradun Thesis
Faridabad
Guntur
Gurgaon
Gwalior
Haldia
Indore
Jabalpur
Jaipur
Jamshedpur
Kanpur
Kochi
Kolkata
Lucknow
Madurai
Mysore
Nagpur
Nashik
Patna
Pune
Raipur
Rajkot
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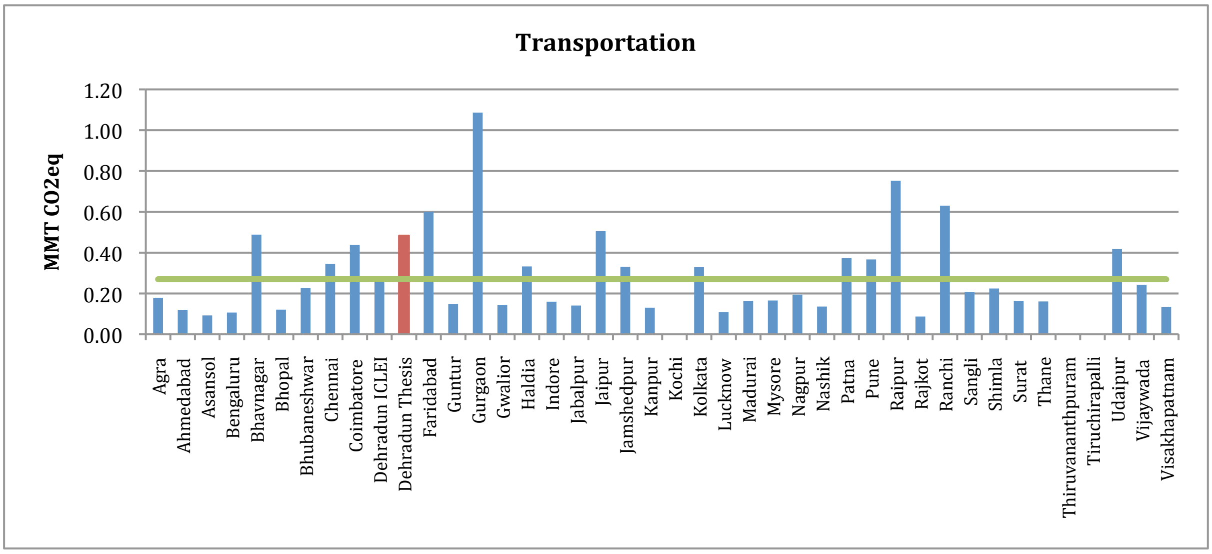


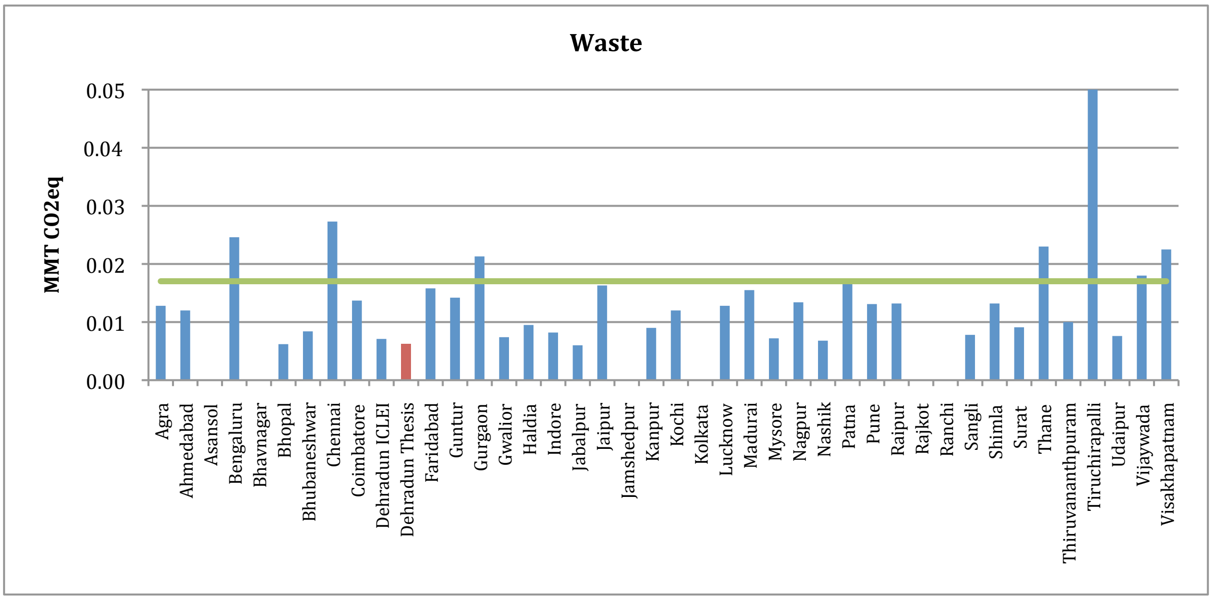


Figure 6-12: Sectoral per capita emissions benchmark comparison (a) Residential (b) Commercial (c) Industrial (d) Transportation (e) Waste

The digression in the transport emissions can be attributed to the difference in method. The ICLEI study uses the sales data for petrol and diesel to estimate the emissions whereas, in this study, the VKT methodology has been used to estimate the emissions. For the residential and commercial sectors, the ICLEI study does not include the LPG data for the Commercial sector, which is included in this study. Moreover, this study also includes emissions from Agriculture and Livestock whereas the ICLEI study also covers emissions from Fuel wood that is not addressed in this research.

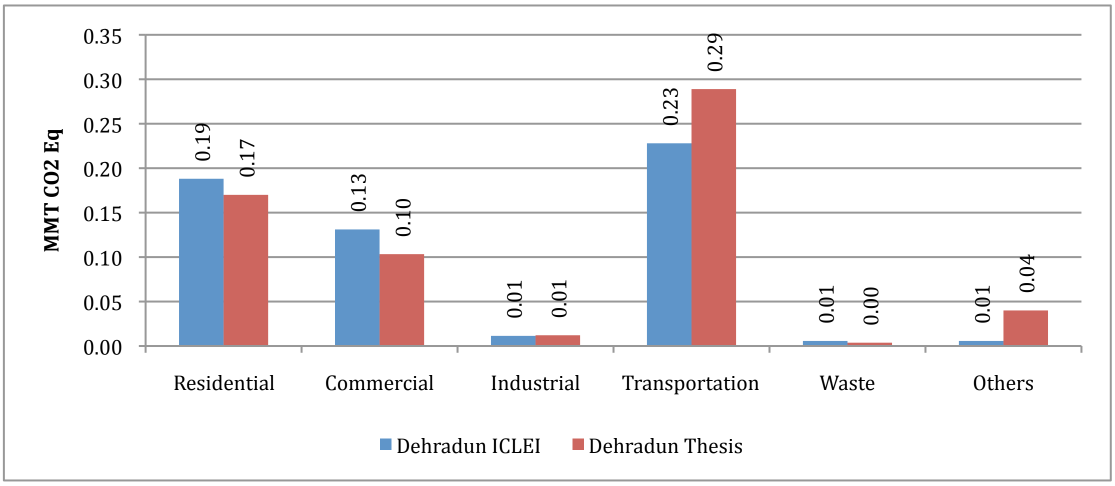


Figure 6-13: Comparison of ICLEI and Case Study results for Inventory base year 2007

6.3 Conclusion

This case study demonstrates that it is possible to conduct an inventory for a mid size Indian city from the existing data available with various agencies in the city with the exception of emissions from changes in land use category. A number of observations can be made with regards to the inventory method, its advantages and drawbacks. Being based on the IPCC method, the inventory results can be compared with other city inventories based on the same method but care must be taken to avoid confusion due to the flexible methodology.

With the available data from the city agencies, the inventory was calculated with tier 1 methods recommended by the IPCC. There is much scope for improvement in the methodology through more accurate data collection and using tier 2/3 methods. With the exception of land use changes, alternative methodology had to be used only for transport fuel use emissions, where the VKT method has been used to estimate the emissions. The lack of actual VKT data required the conversion of on road vehicles data to VKT through national mileage estimates. Also, the amount of fuel use data from number of household data from the census had to be estimated with the help of regional studies on amount of fuel used per household.

Some of the drawbacks in the inventory are the lack of proper disaggregation as in the electricity data where assumptions also had to be made with regards to the municipal boundary, the lack of comprehensive fuel use in buildings data, although the amount of fuel use in categories other than LPG and Kerosene is minimal. It can be concluded that whilst the existing data and methods allow for a base GHG inventory to be conducted, there is much scope for improvement in the quality and accuracy of data and the method used.

In terms of the results, the case study shows that emissions from the city have been on a steady rise over the past five years and the rate of increase of emissions is higher than the rate of population growth signifying the effect of other factors in the increasing emissions. Compared to the benchmarks, on a per capita basis the city ranks slightly higher than average among Indian cities.

The following chapter looks at the emissions scenario and drivers in more detail.

Chapter 7 Analysis

The previous chapter reported on the case study results over a five year time period and presented an analysis of trends, overall emissions profile of the city and its comparison to benchmarks to help validate the model. This Chapter has two aims – first, to look more closely at the subsectors and their emissions trend to have a better understanding of the emissions profile to effectively tailor policy and secondly, to explore from the case study and benchmark data what are the main emissions drivers for cities in India.

The first section of this Chapter, interpreting the results, aims to give more insight into the emissions scenario of the case study. Further disaggregation and subsectoral analysis is used to explore the underlying factors for emissions from various sectors. The second section, closing the loop, is aimed at reinterpreting and analyzing the results and benchmark data to provide an insight into the drivers behind Urban Carbon emissions.

7.1 Interpreting the Findings

Over the five years covered in this study, emissions in all sectors have risen. Looking at the growth, based on both the ICLEI sectors and the sectors used in this research provides two perspectives to analyse the results.

By ICLEI sectors [**Figure** 7-1] transport has the highest growth rate because of better economic status and more affordability for private vehicles. Emissions under the others category are high since the ICLEI method does not involve the AFOLU sector. The percentage growth for transport and residential sectors in the five-year period is 86 and 33 respectively.

The commercial and industrial sectors both show a growth rate of 27 percent, whereas other emissions grew by 4%. The 376 % rise in the MSW emissions is the result of the FOD method where emissions increase at a log scale and thus need to be considered with caution.

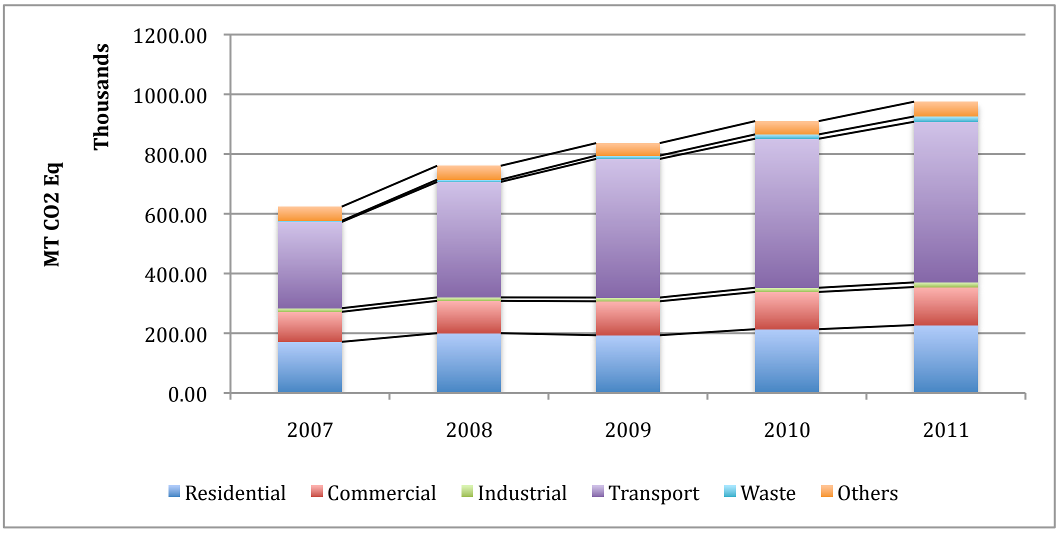


Figure 7-1: Sectoral emissions from the case study by ICLEI Sectors

As per the thesis sectoral disaggregation [**Figure** 7-2], the waste and transport sectors show the highest rate of increase in emissions. Fuel use in building sectors (54%) exhibits a considerably higher emissions growth rate than the electricity use in building sectors (22%). Agriculture including livestock emissions has a negative growth rate at -53%. It can be inferred that with increasing population pressure and improving economic growth in the city, the emissions are rising and would continue so in a business as usual scenario unless mitigation measures are applied to reduce emissions from the various sources in the city.

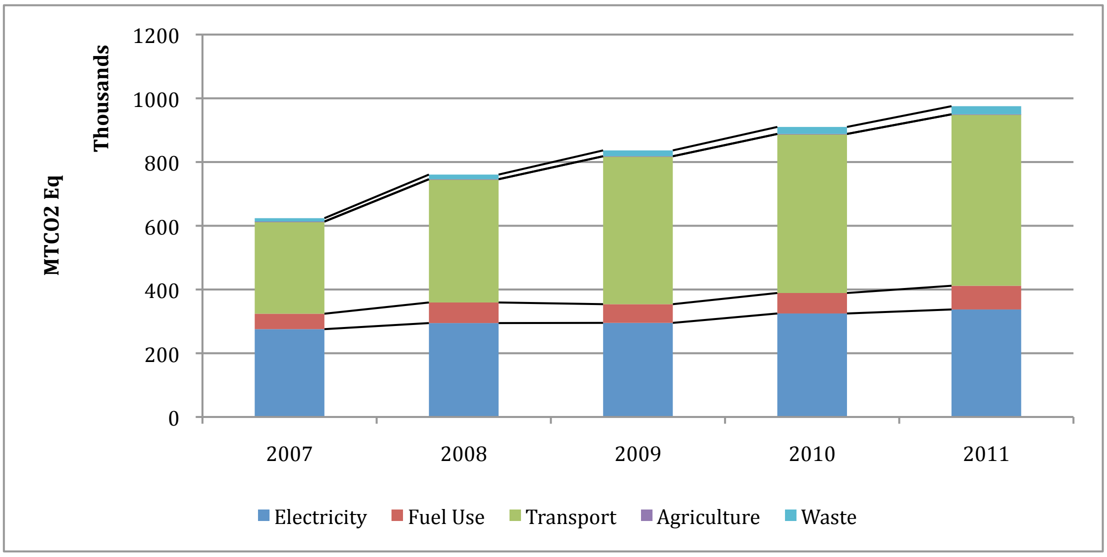


Figure 7-2: Sectoral Emissions from the case study by Thesis Sectors

Looking at the data in further detail (**Figure** 7-3), an interesting observation comes to the fore. Whilst overall the emissions are seen rising through the years, the rate of growth for emissions can be seen to be decreasing over the years during the study period. This trend is significant considering the future projections and policy directions as it gives new insight and raises further questions about the use of energy in cities in the developing countries. It emphasizes the need to track emissions profiles over the years rather than depend on a one-off study creating inventories for a point in time to inform policy.

The declining trend can be seen in almost all sectors. The emissions grew at the highest rate between 2007 and 2008; the growth rate dropped considerably between 2008 and 2009 and has been gradually decreasing thereafter. The plausible reasons behind this declining trend in growth rate could be rising fuel prices, improved efficiencies in the product markets, growing awareness of energy issues among consumers or policy effects in terms of fuel prices or taxes etc. However, there is a need for further in-depth research to isolate the reasons. There also arises the need for more case studies looking at the trends of emissions growth in cities to ascertain whether this is the case with other cities in the country as well or a unique case.

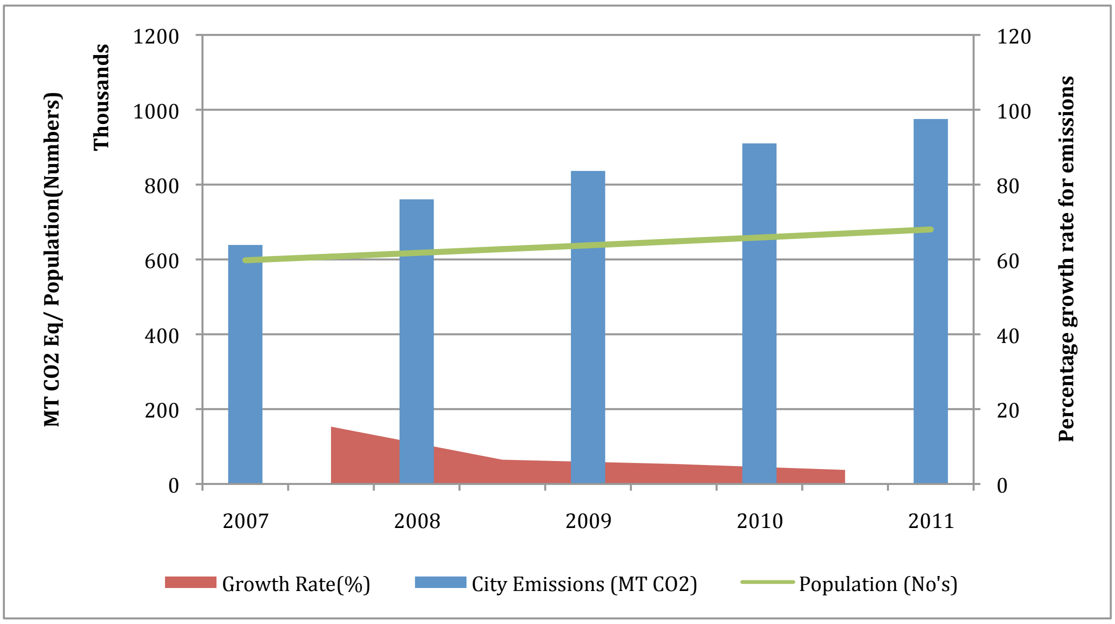


Figure 7-3: City Emissions profile, population growth and Annual Growth Rate of emissions

The steep decline in the growth rate for emissions in 2008 could be explained by the global recession as one of the factors. The Bureau of Energy Efficiency (BEE) introduced the Energy Star Rating for household electrical appliances in the year 2006. Although it became mandatory only in 2010, most leading manufacturers had adopted it in the voluntary phase. This improvement in efficiency can also be a possible factor.

Looking at the different sectors in further detail (**Figure** 7-4), plausible explanations for the decline in emissions growth rates can be explored but these will need further study to establish their impact on the growth rate. In the Electricity Sector, the city witnessed a reduction in AT&C losses (from 27.5% to 23%); also, 2008-09 had the highest percentage of hydro supply (62%), 2009-10 had the lowest (56%), whereas nuclear supply, though not as significant, saw a rise in 2010-11(1.56%, up from 0.44%). The effect of a less carbon intensive fuel supply and a reduction in losses are factors that contributed to the decline of emissions growth rate in this sector.

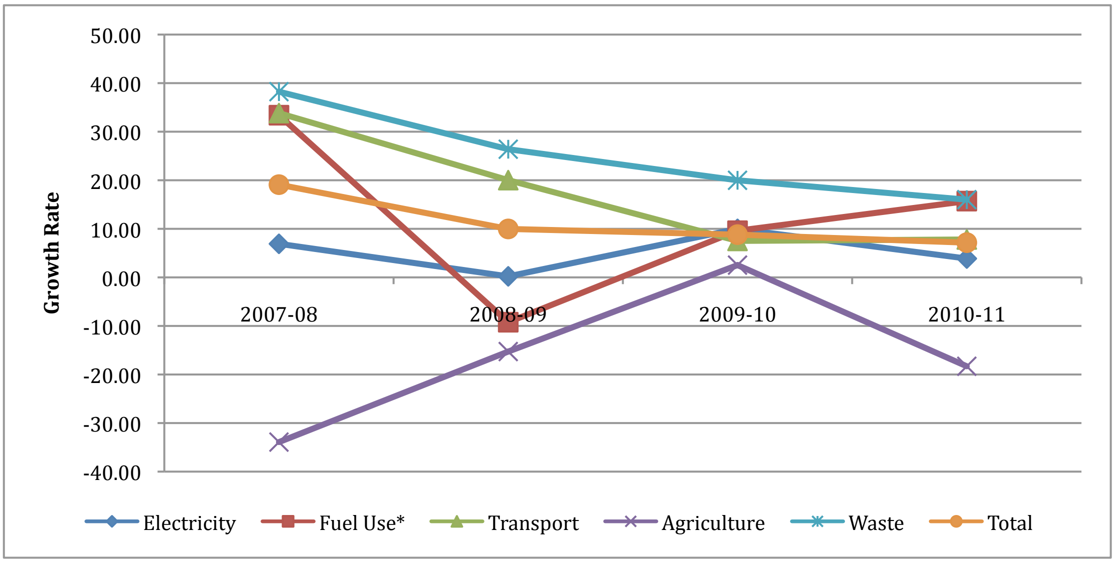


Figure 7-4: Annual Emissions Growth rates for different City Sectors

In the Fuel Use Sector, the key factor seems to be a rise in LPG prices, 2008-09 saw a high variability in LPG pricing, when costs went up to Rs. 346 per cylinder from Rs 281per cylinder in 2008 and then back to Rs. 281 in 2009; The LPG costs have risen again through 2010 to Rs. 304 and later to Rs. 312 per cylinder. LPG being the main source of cooking fuel, these pricing policies have a direct impact on the amount of fuel used. Moreover, the subsidy on kerosene has been reduced over the years, where it was available at subsidised prices to families with a single LPG connection earlier, now its only available to families that have no LPG.

In the transport sector there has been a steady increase in fuel prices for both petrol and diesel; there was a rise in bus transport in 2007-08 following a JNNURM scheme but this declined steeply thereafter.

These factors are plausible explanations for the declining growth rate that needs to be further examined to assess their effect. Further in-depth research in the area is required to validate these possibilities and to ascertain any other reasons behind the trend.

7.1.1 By Sector

In the next four sections, each sector has been focused on separately to analyse the results of the calculations based on various criteria to provide a better understanding of the reasons behind the emissions and the trends displayed. The analysis will help tailor the mitigation policies better, so as to improve the likelihood of the interventions' success.

7.1.1.1 Buildings

Electricity Use

Based on the data subsectors available from the electricity company, an analysis of the emissions trend over the past five years shows increasing emissions from most sectors [**Figure** 7-5]. Leading emitters of CO2 from electricity usage are the residential sector and the commercial and institutional sector [**Figure** 7-6]. The residential sector has a share of 46% of CO2 Eq emissions in 2011 (45% in the base year 2007) and accounts for 0.15 MMT. Over the last five years, the growth rate for the rise of residential CO2 emissions was 5.08% PA whereas population growth rate in the last 10 year period was recorded at 1.56% PA based on the census data from 2001 and 2011.

The commercial and institutional sector exhibited a slightly higher growth rate of 5.17% PA and makes up 37% of the 2011 electricity based emissions. The share of industrial emissions from the city rose with a growth rate of 5.5% PA. The only subsectors that have a negative rate of change are the UPCL offices and

Public Lamps with an emission reduction of 38.15 and 19.82% respectively, over the five-year period. Electricity used for agricultural processes has a negligible share of 0.1% of the city's electricity based emissions.

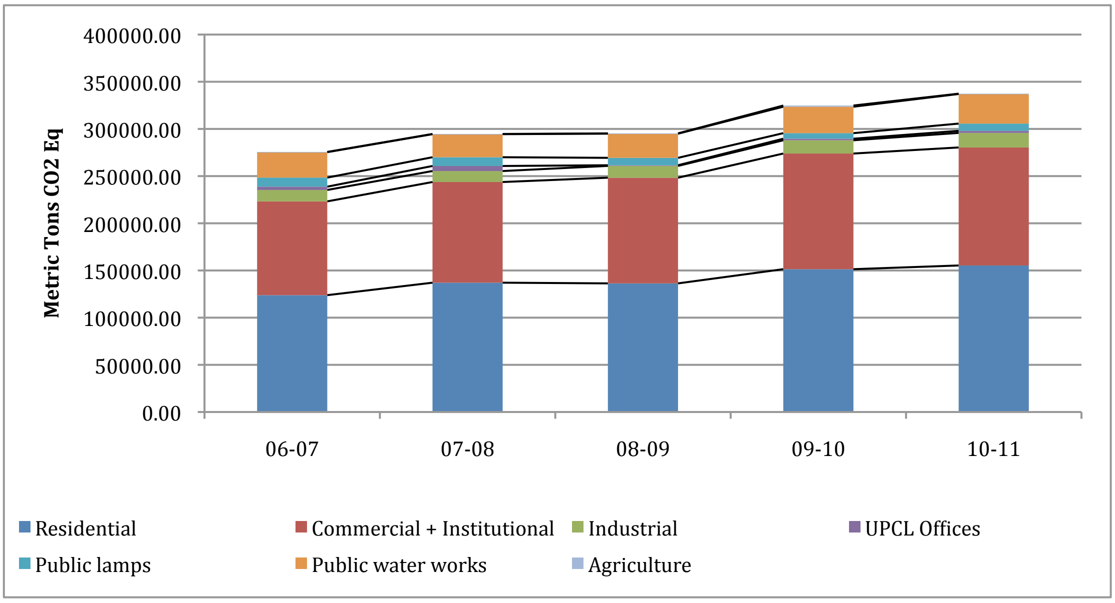


Figure 7-5: Subsectoral analysis of electricity based emissions

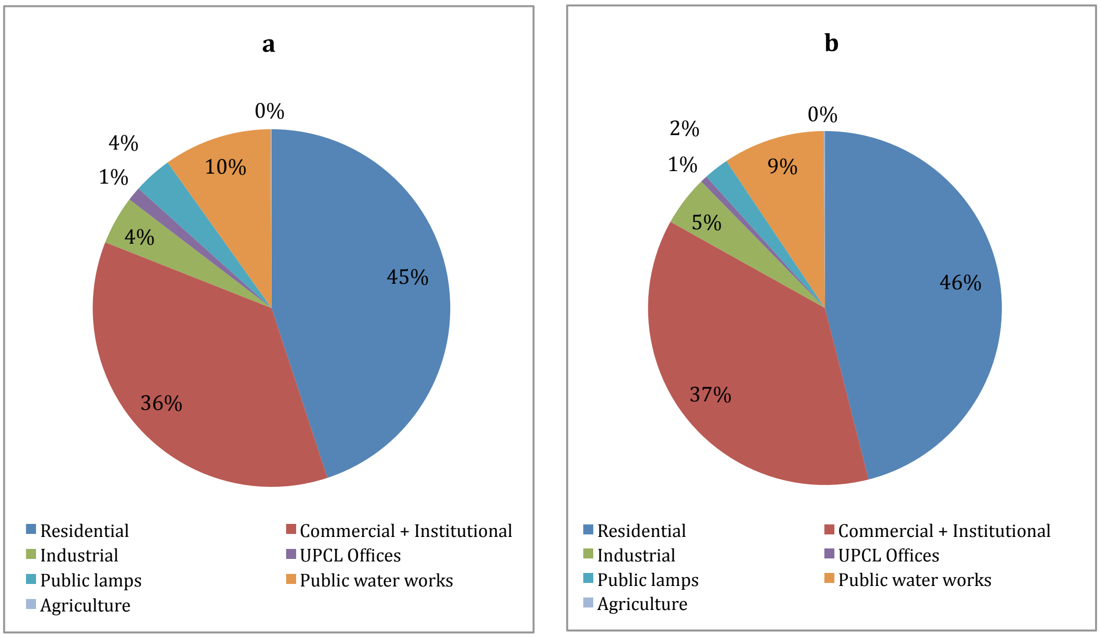


Figure 7-6: Share of electricity based emissions from subsectors in 2007 and 2011

The rise in Residential, Commercial and Institutional electricity emissions is expected with a rise in the population. However, the much higher growth rate for electricity based residential emissions points to an increased use of electrical appliances among the city households. This may be attributed to economic growth in the city (GDP) recorded at an average of 22%. A more prosperous economy leads to a better lifestyle among the city residents often translating to a higher use of appliances. The growth in Industrial emissions is the result of government policy to promote industry in the region since the establishment of the city as the capital of the state in 2001. The reduction in emissions from UPCL Offices and Public lamps however, shows a conscientious effort by the electricity company to reduce its emissions, with the introduction of solar street lamps as part of the solar cities project.

The electricity supply mix in Dehradun has a reasonably high percentage of renewable sources as seen in **Figure** 7-7. Still, thermal, cogeneration and other (sourced from other states- supply mix unknown) sources account for 40% of the supply mix.

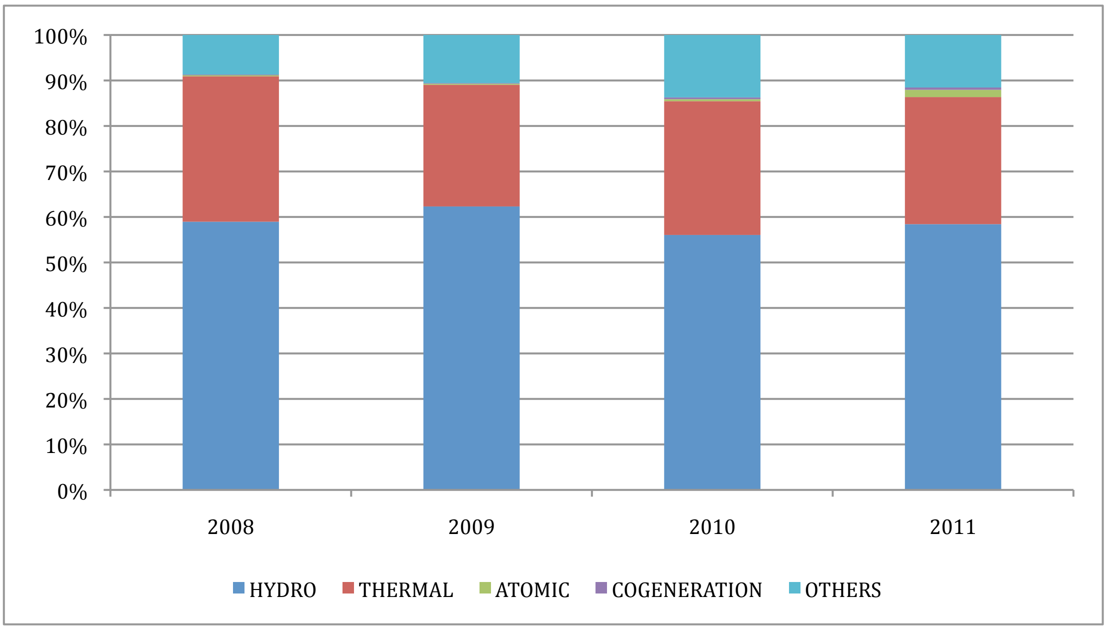


Figure 7-7: Share of electricity supply mix by mode of generation

Fuel use

Based on the census data from 2001 and 2011, it can be seen from **Figure** 7-8 that the share of LPG as the choice for cooking fuel in households is the highest. The overall emissions from residential cooking fuel have risen by 40% in the ten-year period where the number of households has increased by 42% exhibits an emissions growth synonymous with the growth in the population or number of households. The share of LPG has seen a growth rate of 61%.

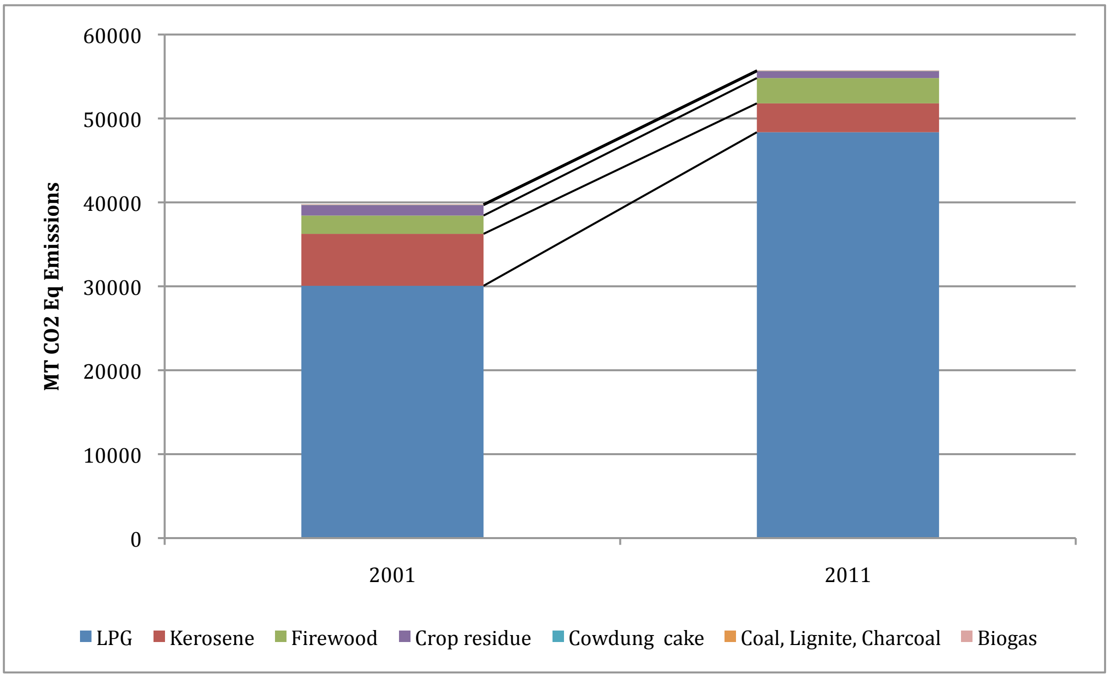
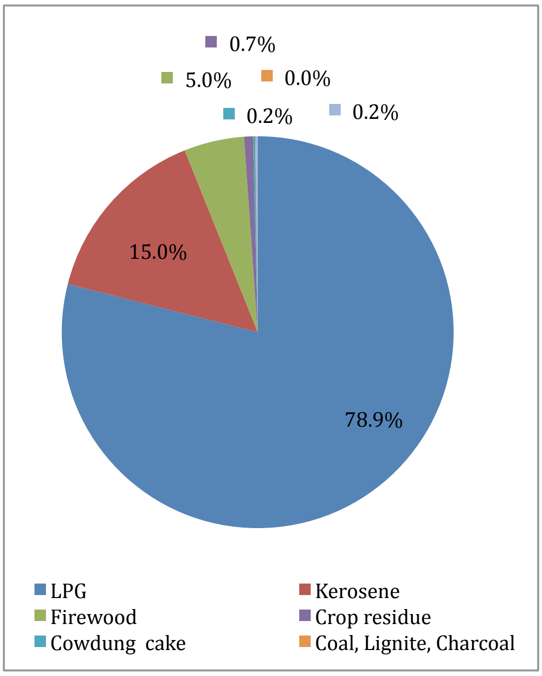


Figure 7-8: Subsectoral analysis for Residential cooking fuel use

Figure 7-9 shows the share of cooking fuel use by fuel types in Dehradun in 2001 and the equivalent CO2 emissions from the different fuels. LPG has a 79% share in the choice of fuel and accounts for 76% of the emissions. Crop residue on the other hand is only used by 1% of the households but accounts for 3% of the emissions.

The share of cow dung, coal and biogas is minimal with only 312, 62 and 286 houses using it respectively. It also shows the choice of fuel type by number of households and the resulting emissions for the census year 2011. While LPG use now commands 89% of the households, Kerosene is used in 6% down from 15% 10 years ago.

The share of LPG has gone up while the share of Kerosene has reduced in the 10-year period. Kerosene emissions have a 99% share of CO2 emissions and 1% CO2 eq. from CH4 whereas the share of CO2 eq. emissions from CH4 for Firewood, Crop residue, Cow dung cake, Coal and Biogas is 6%, 11%, 10%, 6% and 1% respectively and negligible for LPG. Crop residue and Cow dung cake are the most polluting in terms of air pollution and also have high emissions of CH4 that has a higher GWP.



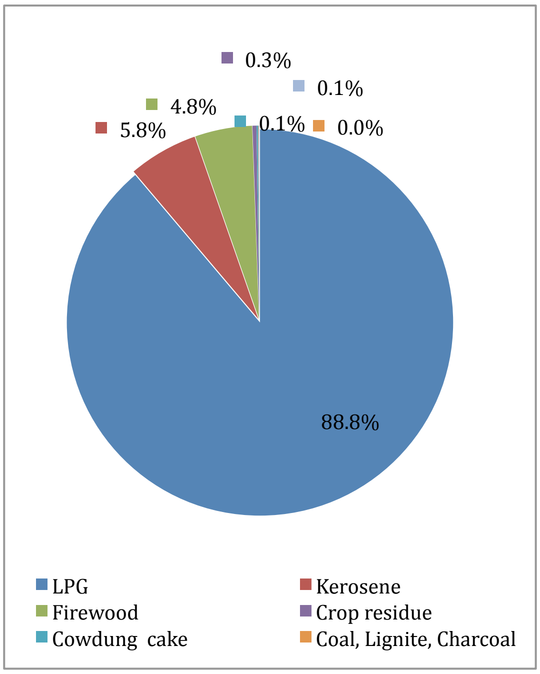


Figure 7-9: Share of fuel choice for residential cooking in 2001 and 2011

The figure from the census data illustrates that the top two fuels (LPG and Kerosene) together command a fuel choice of 93.7% in 2001 and 94.6% in 2011. Hence, even with a lack of data on other fuel sources, emissions calculations based on the LPG and Kerosene use in the city can give a reasonable estimate of the scenario of emissions from fuel use in building.

Looking at the emissions trend from LPG and Kerosene use in the residential and commercial sectors [**Figure** 7-10], the rise in emissions is evident.

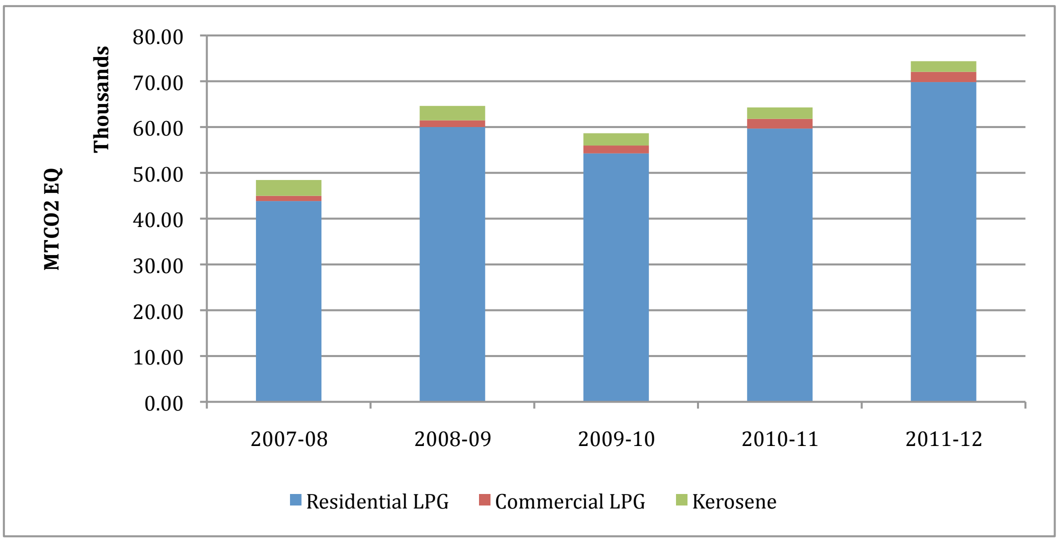
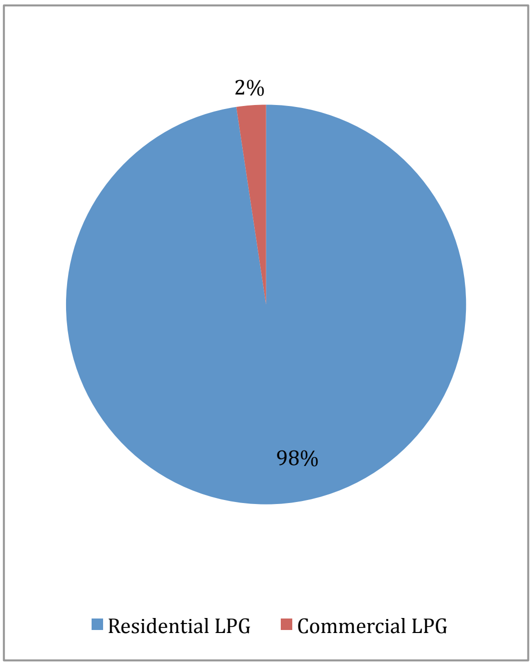


Figure 7-10: Subsectoral analysis for LPG and Kerosene use in Residential and Commercial sectors

Compared to the census-based calculations, the emissions from LPG based on the DSO data are higher whereas those from kerosene are lower. It must be noted that the share of commercial LPG is much lower compared to the residential sector [**Figure** 7-11]. This is true not only for the case study city but also for other Indian cities as seen from the ICLEI data.

While the residential population is one reason behind this, another factor is that many commercial establishments in Indian cities use residential LPG connections since the residential LPG is subsidized by the government under the Essential Commodity act and is available at a much lower rate.

As for the kerosene emissions the DSO provided data of the government allocation of kerosene at a subsidized price for the BPL population. Kerosene, however, is also available on the open market, data for which is unavailable. This explains the lower estimates for kerosene as compared to the census data, which only records the number of households using kerosene irrespective of the source they get it from.



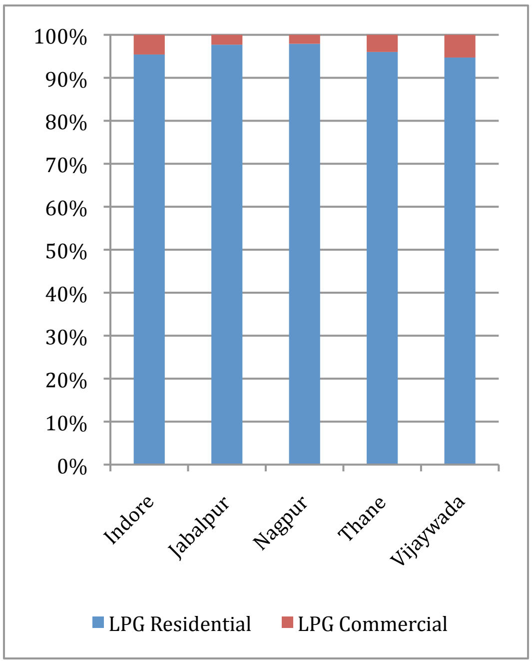


Figure 7-11: Share of Commercial and Residential LPG in Dehradun and other ICLEI study cities

7.1.1.2 Transport

Fuel Use

The overall growth rate for transport based emissions from the city in the five-year period studied has been 86%, where, 2007-2008 and 2008-2009 exhibited a steeper growth rate of 34 and 20%, the rate thereafter had been much lower between 7-8% in the next two years [**Figure** 7-12].

The per capita emissions have risen from 0.48 MT CO2 eq/cap to 0.79 MT CO2 eq/cap in five years. The major share of emissions comes from buses and cars. The percentage share of both buses (27-34) and cars (32-34) has increased from 2007 to 2011. The share of taxis (10-5) and three-wheelers (8-6) has significantly reduced in the five years.

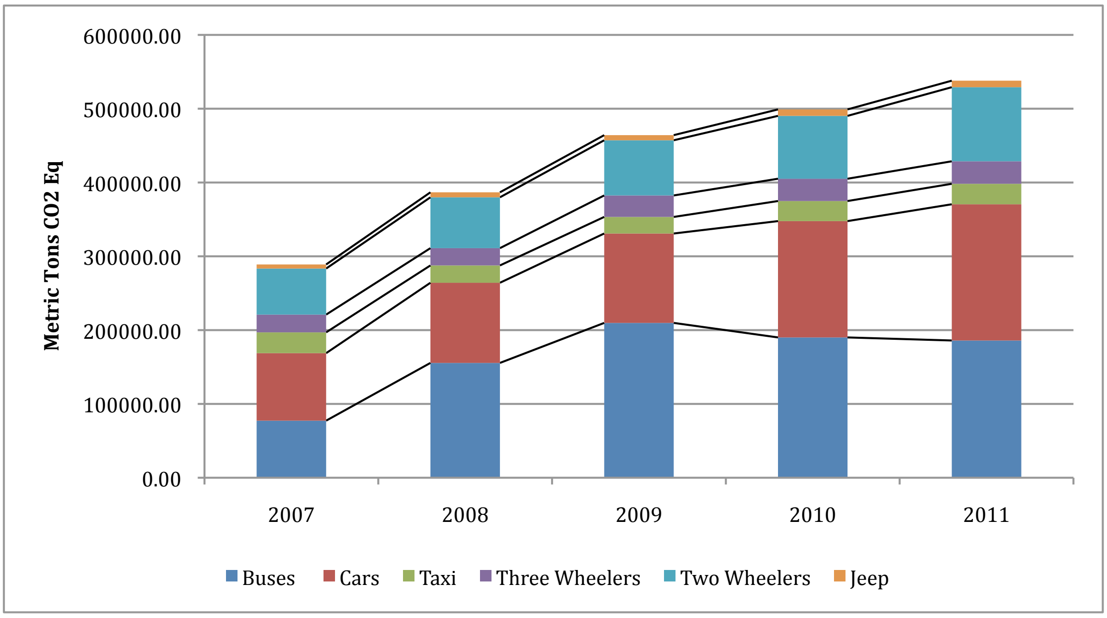


Figure 7-12: Subsectoral analysis for emissions from Transport fuel use

Looking at the trends of emissions from all vehicle types [**Figure** 7-13], public transport modes show a variable trend over the years, the private transport modes show a steady increase. Buses have the most variable trend, peaking in 2008 and then reducing slightly, whilst taxis and three wheelers exhibit a steadier pattern. The peak in the bus emissions can be explained by the implementation of the JNNURM transport policy.

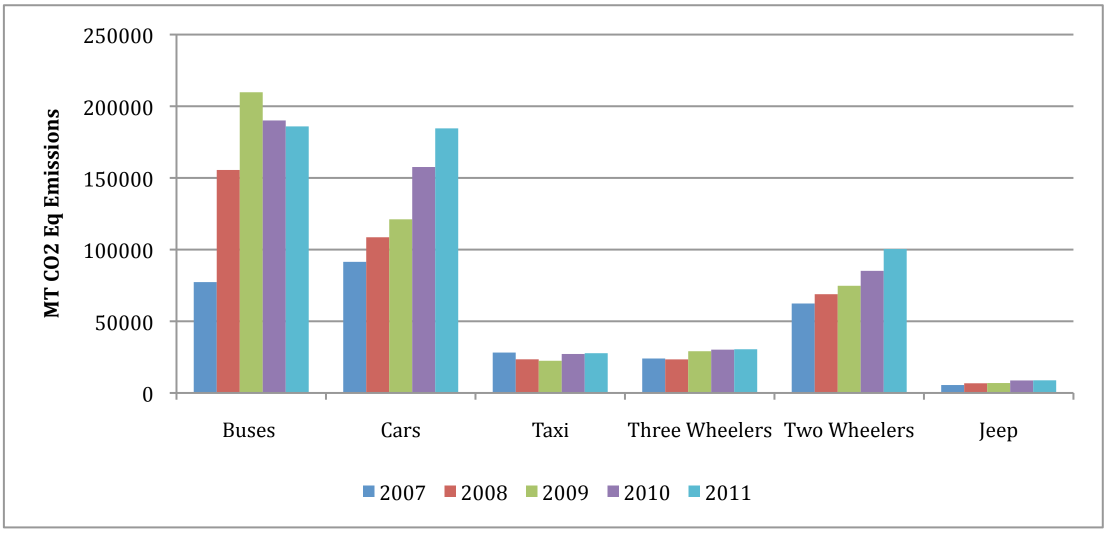


Figure 7-13: Trends in emissions from Transport subsectors

The modal share of vehicular trips in the city is illustrated in **Figure** 7-14. The share of public transport vehicles as a trip mode is significantly lower than that of privately owned vehicles, indicating the lack of good public transport facilities in the city. Two wheelers dominate the modal share for trips, followed by cars.

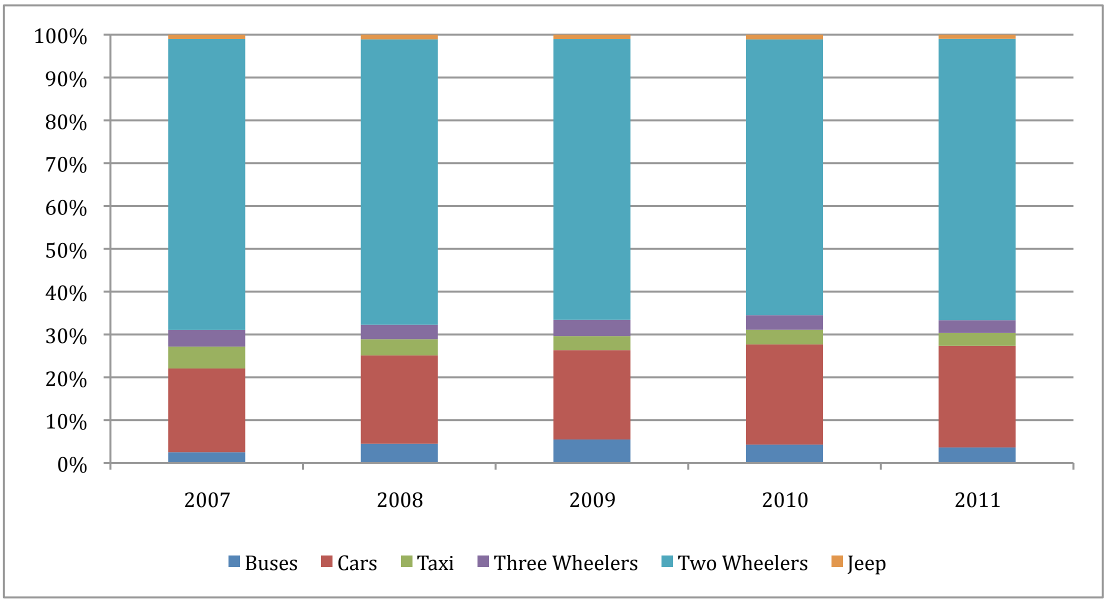


Figure 7-14: Share of Annual VKT'S by Vehicle type in the city

Where the share of VKT travelled per capita by public transport has been below 1000 kms, the kms travelled by private vehicles has risen from 5250 to 7840 from 2007 to 2011 [**Figure** 7-15]. From 2009 to 2011, the VKT from privately owned vehicles has seen a steeper rise at 14% PA.

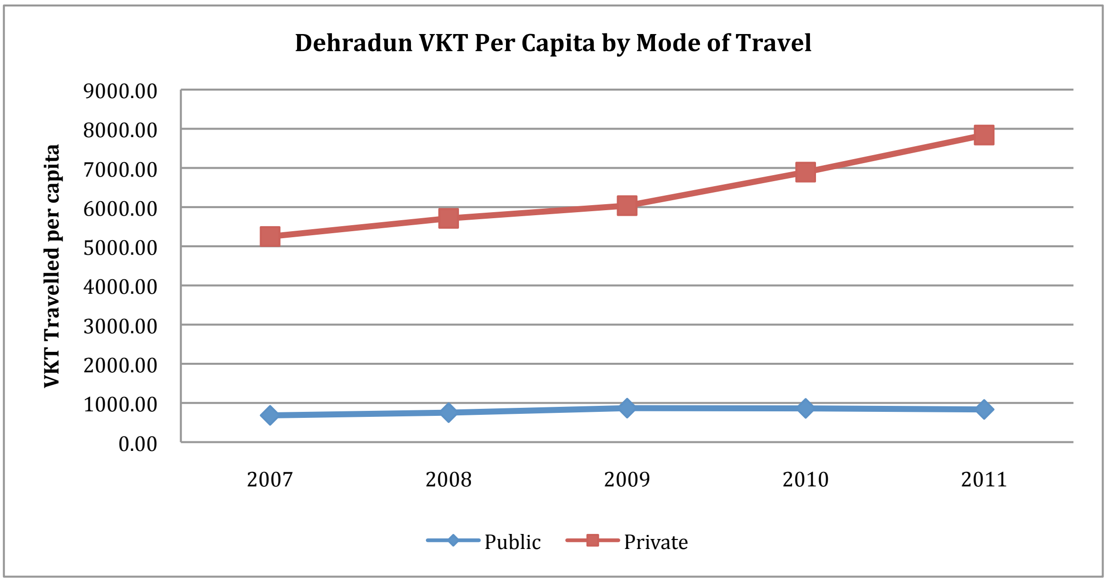


Figure 7-15: VKT per capita by mode of travel (Private vs. Public)

A look at the share of emissions from public and private modes of transportation [**Figure** 7-16] reveals that in the past five years, emissions from privately owned vehicles have steadily risen and overtaken those from the public transport system in 2010-2011.

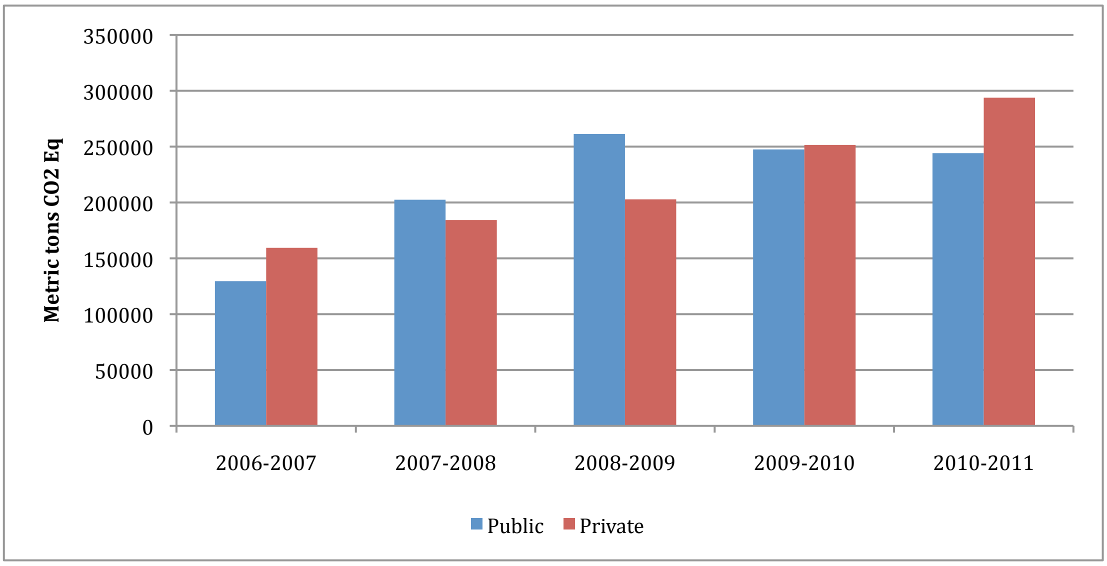


Figure 7-16: Emissions by mode of travel (Public vs. Private)

A similar comparison by fuel type [**Figure** 7-17] also shows that while diesel vehicles accounted for the larger share of emissions until 2010, the trend has reversed in 2011. This can be accounted for by an increase in private ownership of vehicles, most of which are run on gasoline.

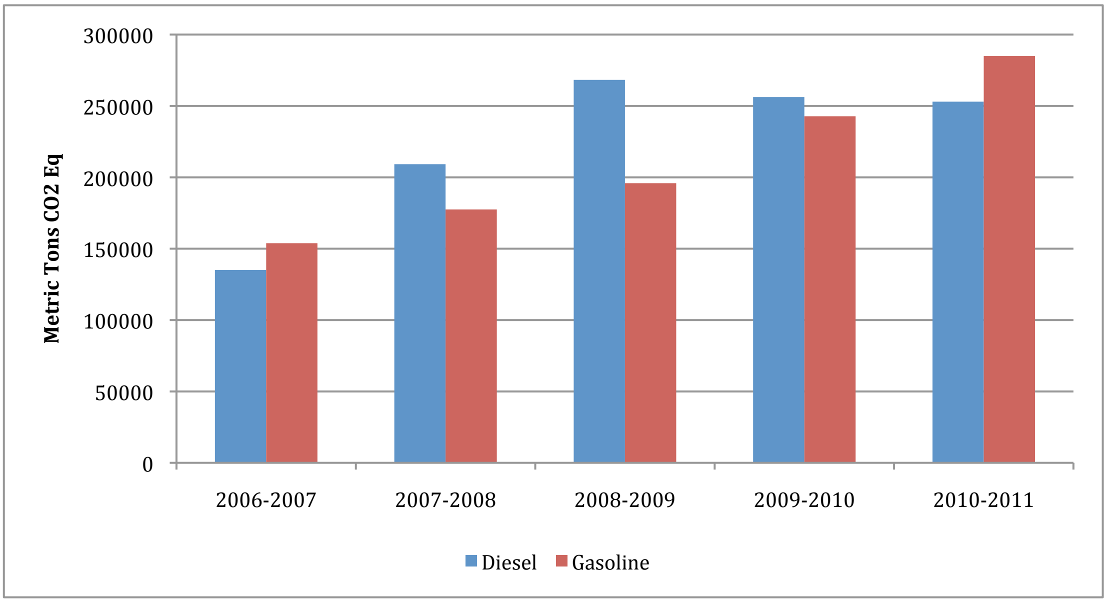


Figure 7-17: Emissions by fuel type (Diesel vs. Gasoline)

The rising share of private vehicles is the major source of increasing emissions from the transport sector. Better affordability with more competitive vehicle costs and easily available loans have driven up the private vehicle ownership. Moreover, the social status that is associated with owning a vehicle as well as the lack of a proper public transport facility drive the higher rates of private ownership.

7.1.1.3 Land use

Agriculture

Agriculture emissions from the city form a small share of the total emissions and come from rice cultivation, which is a major source of CH_4 emissions and Fertilizer use. The Dehradun district is a major producer of basmati rice in the country and emissions from the cultivation of rice in the city can be seen in **Figure 7-**18.

Over the five-year period the emissions from rice cultivation show a steadily decreasing trend owing to less land being cultivated within the city boundaries.

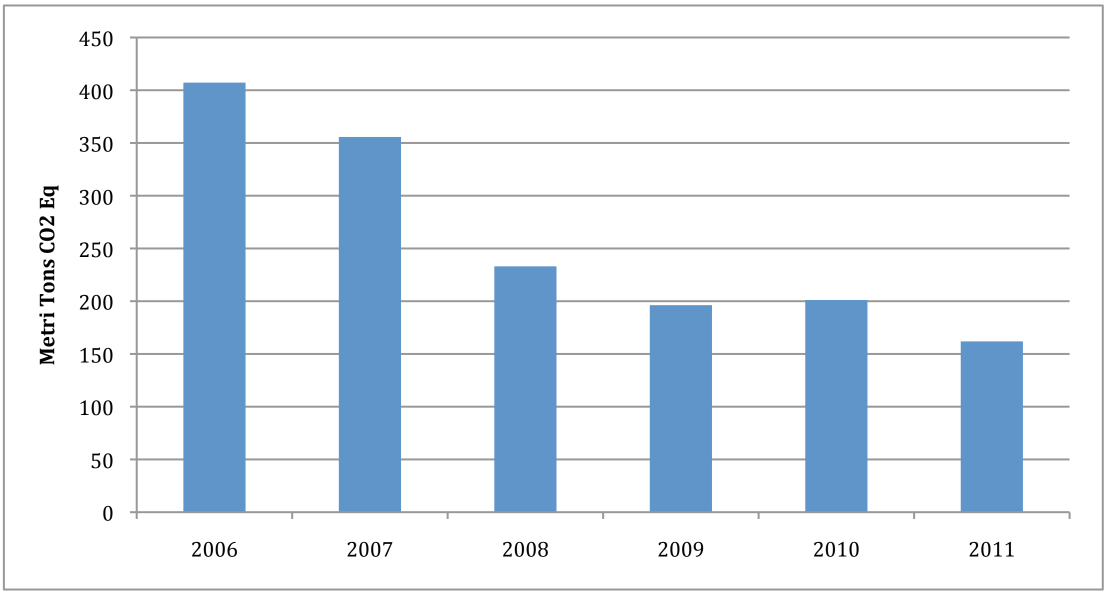


Figure 7-18: Emissions from Rice Cultivation

Emissions from fertilizer use [**Figure** 7-19] are negligible compared to those from rice cultivation but show a rising trend over the years from 5.5 MT in 2007 to 8 MT in 2011.

This is significant in that even though the land area under cultivation is decreasing, the use of urea is rising to increase productivity. This trend might have potential health risks due to adverse impacts of fertilizer concentrations in food.

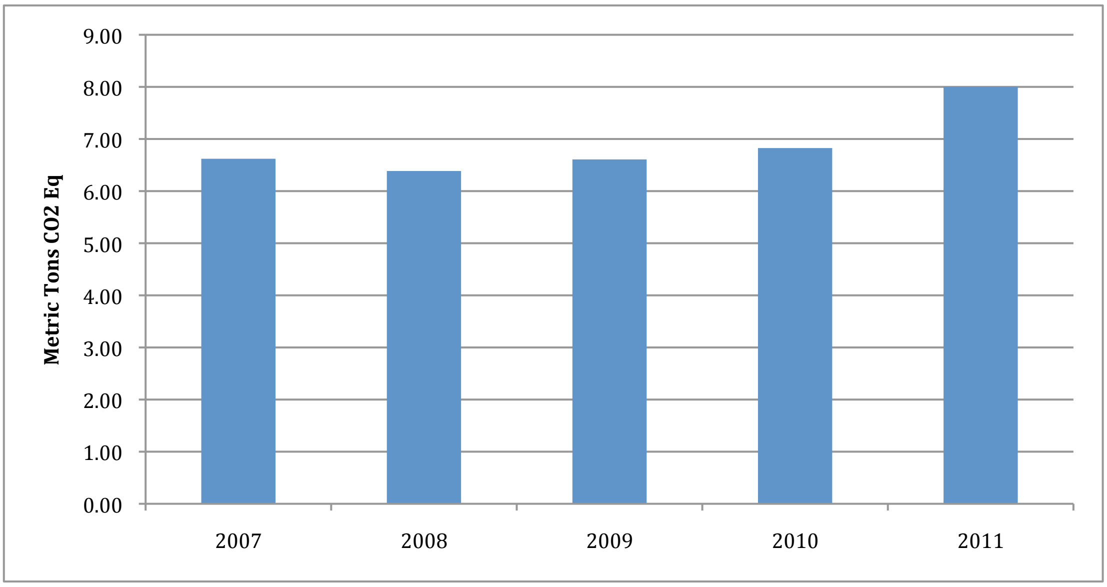


Figure 7-19: Emissions from Fertilizer Use

Livestock

A disaggregation of the emissions by cattle type for the years 2003 and 2007 is shown in **Figure** 7-20 and **Figure** 7-21. Only three types of cattle stand out by the amount of emissions through enteric fermentation as well as manure management – dairy cows, other cattle and buffaloes. The number of dairy cows and cattle has increased in the time period while that of buffaloes and swine has reduced.

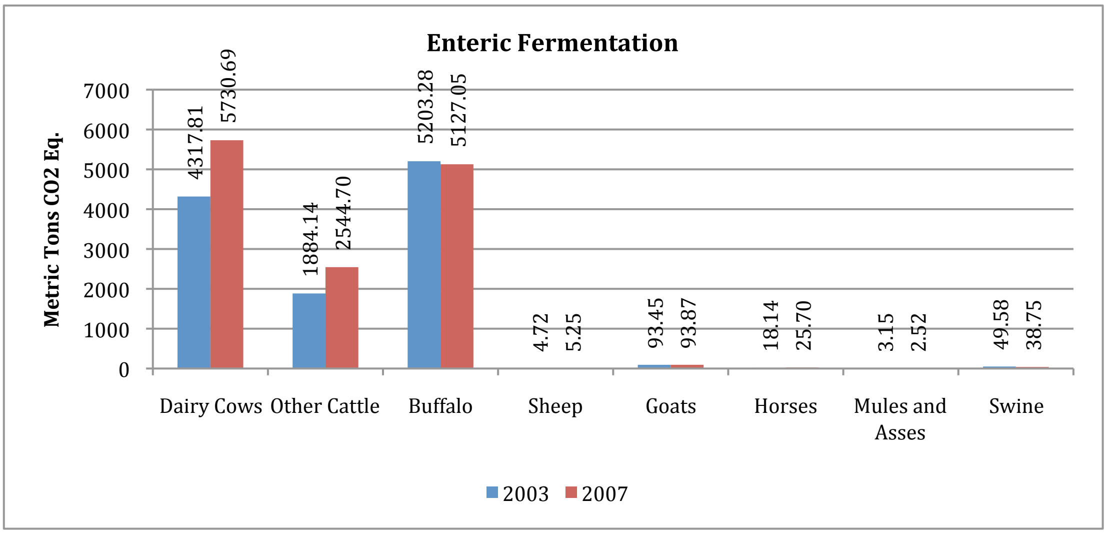


Figure 7-20: Subsectoral analysis for emissions from Enteric Fermentation

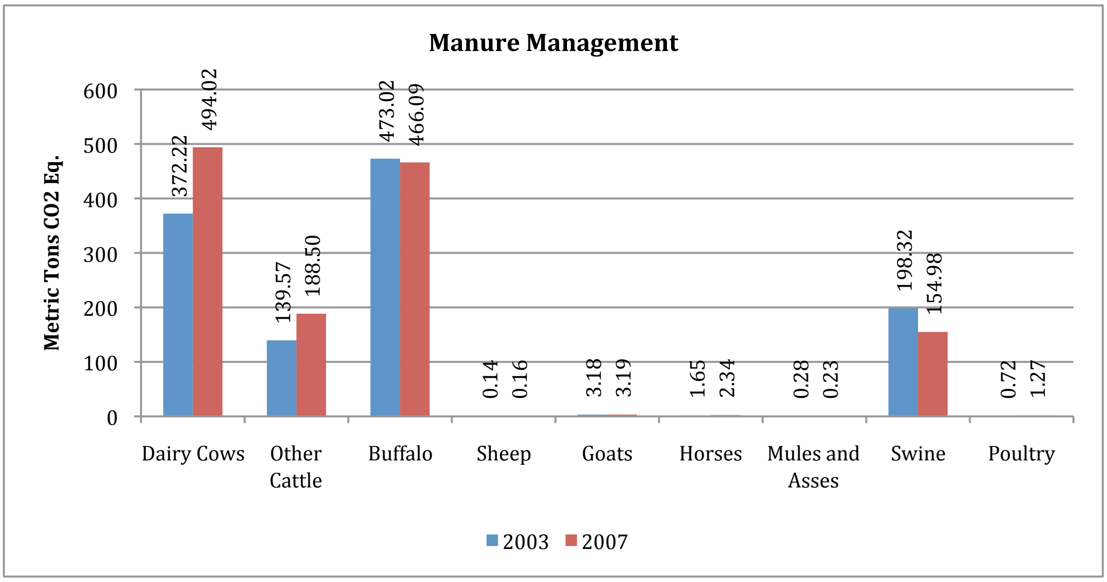


Figure 7-21: Subsectoral analysis for emissions from Manure Management

7.1.1.4 Infrastructure

Municipal Solid Waste

Based on the First Order Decay (FOD) method, the emissions from landfill of the municipal solid waste have been illustrated in **Figure** 7-22. The steep and steady rise in emissions can be attributed to the FOD method that uses a logarithmic emission profiling from landfills to account for the MSW emissions. The per capita waste generation in Dehradun is 0.43 kg/day, which is higher than the average of 0.35 kg/day from the ICLEI study cases. **Figure** 7-23 shows that the ratio of recyclables in the waste generated in the city is about 20%, which can be separated before the waste is land filled.

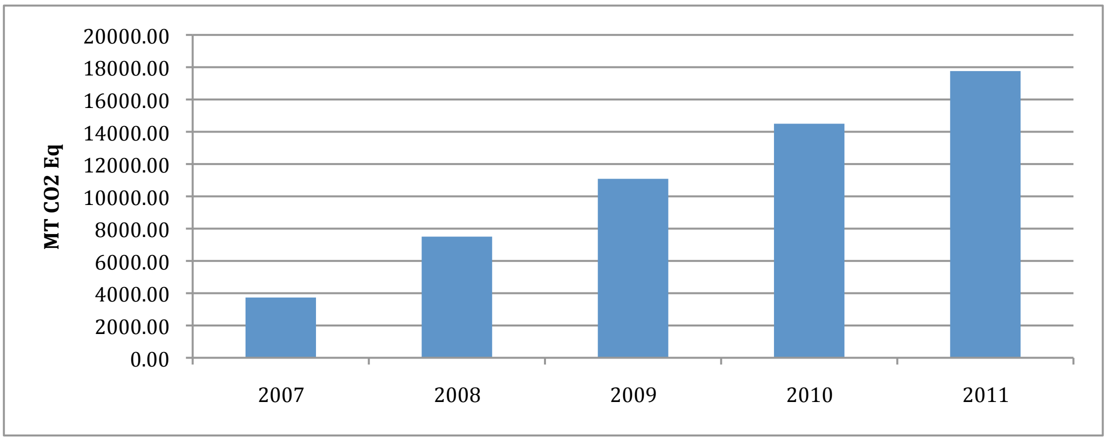


Figure 7-22: Emissions from Municipal Solid Waste Landfill

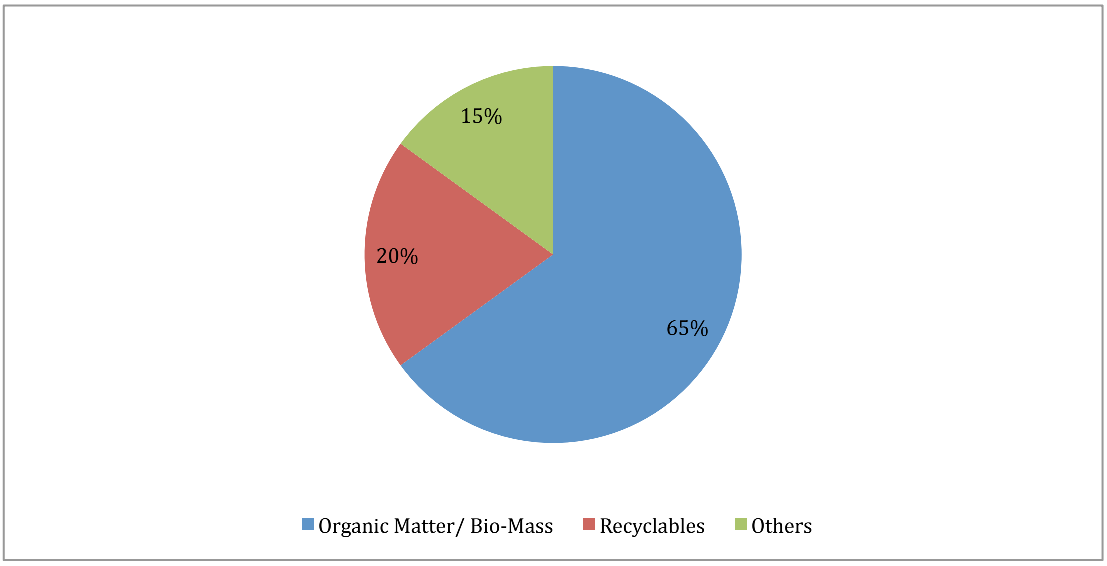


Figure 7-23: Ratio of recyclables

Waste water

The trends of emission scenario by different treatment pathways and income groups have been presented in **Figure** 7-24. The trend is mostly upwards, and in the absence of a proper sewerage network and treatment plants, the first priority should be to upgrade the system and start treating the waste before it is let into the rivers.

Most emissions come from the urban low-income group that is estimated to be the highest population in the city. 71% of the emissions are attributed to just untreated and septic tank emissions from the low-income group. These estimates are entirely based on the IPCC defaults and as such there is a need to improve the data availability in this area for more accurate estimates. However, it is known that the city lacks a proper sewerage network and treatment facilities.

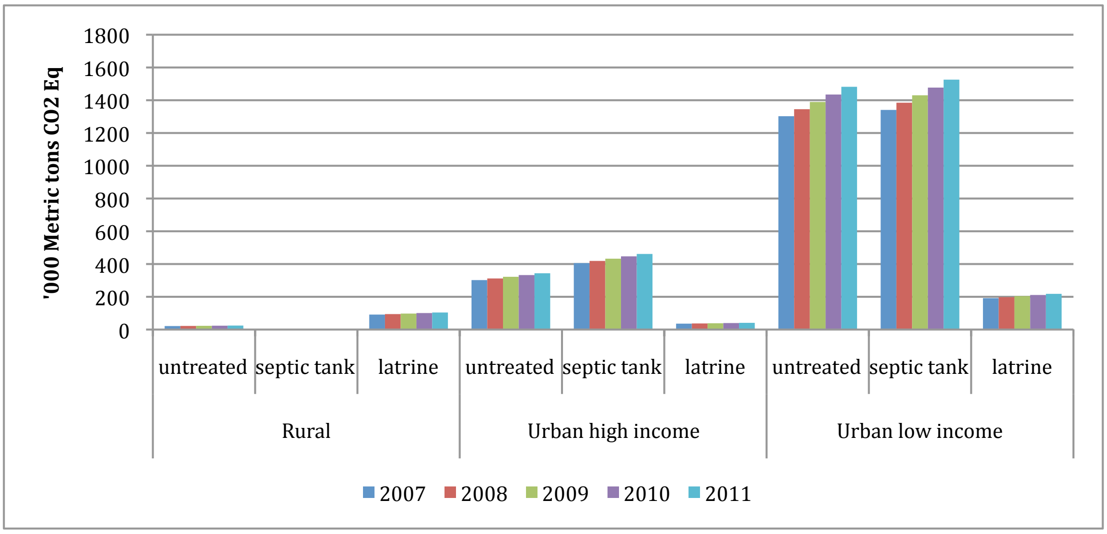


Figure 7-24: Subsectoral analysis of trend of emissions from wastewater

7.2 Dehradun's emissions' drivers

There are a number of factors that influence the energy use and emissions profiles in cities. Shobhakar Dhakal (Dhakal, 2008b) summarizes some of the major drivers of carbon emissions in cities under the following heads –

1. Urban demography
2. Economic development
3. Infrastructure and Technology

4. Urban Form and Function
5. Behavioural and Societal factors
6. Globalization
7. Institutional and political factors
8. Natural Factors

This section presents a discussion on the emissions drivers with a focus on the case study.

7.2.1 Urban Demographics

Urban demographic is defined by the size, growth, composition and distribution of population. The affect of each of these individually on the emissions profiles of cities needs further research although population size can be positively correlated with emissions. A simple scatter analysis of the data available for Indian cities confirms the positive correlation between emissions and population.

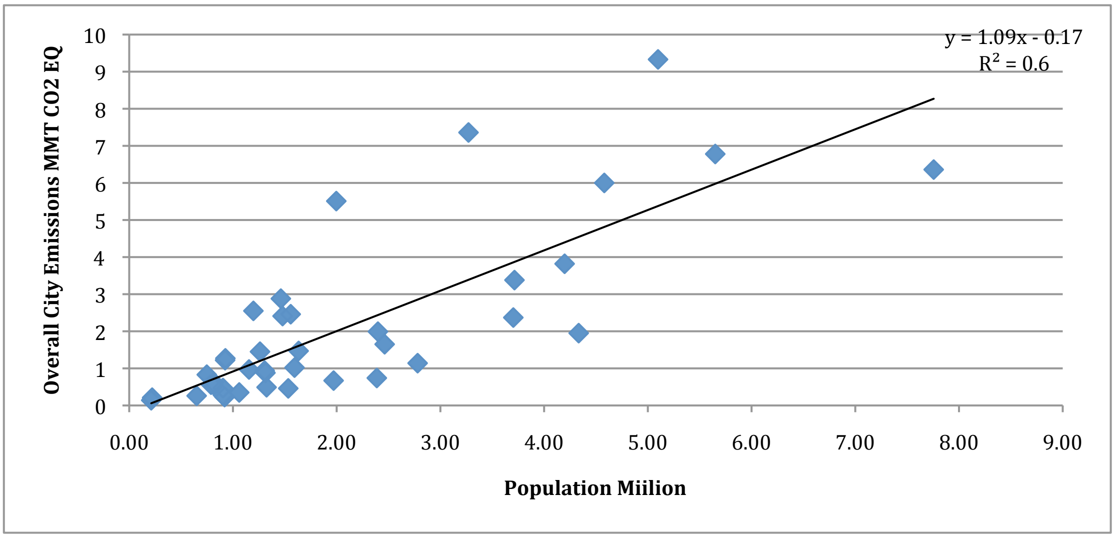


Figure 7-25: City Emissions VS. Population for Indian cities (Source: ICLEI Study)

Dhakal suggests that household size is an important factor in the energy consumption profile with smaller households accounting for more energy use per capita as well as more waste generation.

For Dehradun, the per capita residential energy use is slightly higher than average benchmark data and the average household size is between 4-6 people per household. However, data from only one case is insufficient to establish the relationship between per capita energy use and household size.

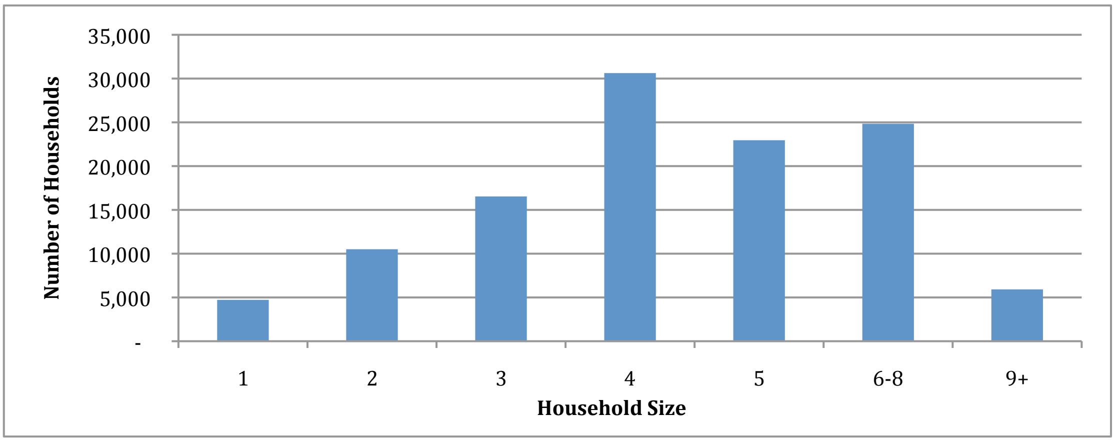


Figure 7-26: Household size frequency for Dehradun (Source: Census 2011)

Dehradun, being a rather recent capital of the state, is a magnet for immigrant population in the area. This increased population pressure is leading to many problems from basic services access and also increased emissions.

7.2.2 Economic Development

It has also already been established that economic growth correlates positively with carbon emissions. As the city grows economically, there is a lifestyle shift in the population with an introduction of more appliance use, increase in car ownership etc. all contributing to increase in emissions. With an average GDP growth rate of 22.4% PA in Dehradun over the last five years, the positive impact of this economic boom can be witnessed in the increase in vehicle ownership and increased used of appliances like air conditioning units in the summer over the years.

The effect of economic growth of a city on its emissions is also dependent on the economic activity. For an industrial city, there will be more direct emissions while a commercial/services oriented city will be responsible for more indirect emissions. This can be corroborated with data from the ICLEI study where the highest emitting cities had a higher share of industrial emissions.

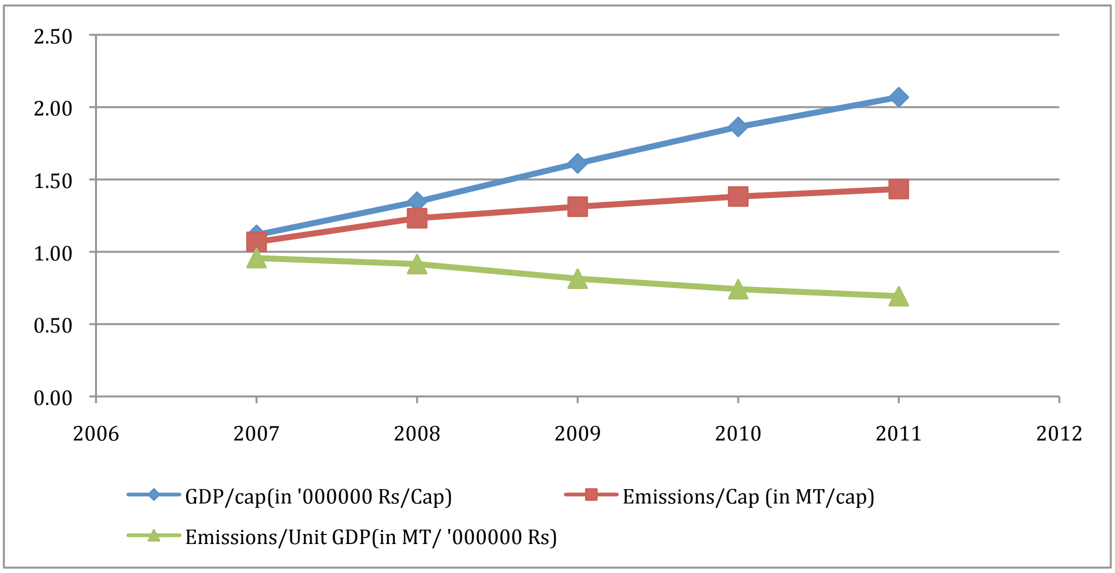


Figure 7-27: Dehradun City Emissions/cap and GDP growth/cap and emissions/unit GDP

Dehradun is an administrative and educational town with a high number of institutions. The high-energy use in the commercial/institutional sector supports this, and thus implies institutional buildings are a major driver in energy use along with residential buildings.

One of the key results from this research was the finding that over the five-year study period, there appears to be a diverging trend between the GDP growth and the emissions profile. While GDP/cap and Emissions/cap have increased during the study period, the Emissions/unit GDP has seen a declining trend [**Figure** 7-27]. A similar trend was observed in Chinese cities (Wang et al., 2012) though the reasons are yet to be explored. This is very significant since one of the key policy areas includes measures to decouple the economic growth from incremental emissions. The reasons behind this decoupling trend need to be further analysed. The plausible reasons for a decreasing rate of growth in emissions were discussed in Section 7.1.

The relationship between the GDP growth and Carbon Emissions has always been of interest to researchers. Although the data from this research might be insufficient to establish a relationship [**Figure** 7-28], it does raise the question of how the GDP-CO2 relationship will develop over time? In the figure, the data points for the five years fit to a logarithmic curve. Will it follow a linear progression or is there a possibility of an Environmental Kuznets Curve (EKC)?

The EKC theory proposes that at the initial levels of development, there is more pollution and as the per capita income increases, there is a tipping point beyond which further economic development leads to a better environment.

This theory has held true for many pollutants like sulphur di oxide and other local pollutants but is highly debatable in the case of CO2, some studies supporting it while others reject it. Most of these studies have been on a country scale both in a cross-sectional analysis and a time-series analysis. These questions need to be explored to understand the link between economic growth and emissions at the city scale.

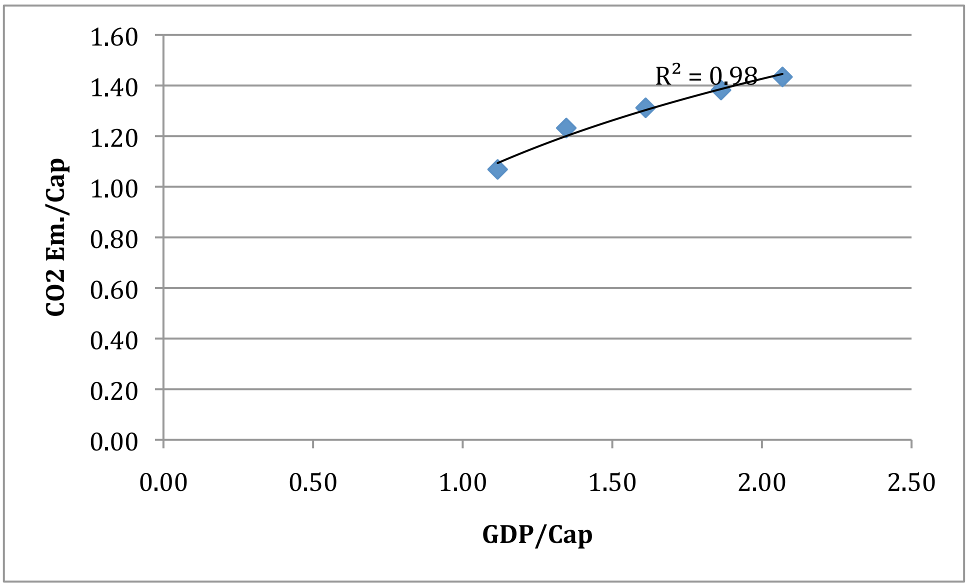


Figure 7-28: Emissions/cap and GDP/cap

7.2.3 Infrastructures and Technology

This driver covers most of the sectors and the policy pathways related to them. The role of infrastructure and technology in the emissions profiles of cities can be the difference in high and low emissions. Two regions with the same electricity consumption can have varying emissions profiles depending on the supply pathways and delivery efficiency. Similarly, the choice and efficiency of the modes of mobility in different regions can be the difference in emissions profiles.

Whilst for the electricity sector Dehradun has a higher supply mix of low carbon intensive sources, in the transport sector lack of good public transportation has led to higher emissions from private vehicle use. There is however, much potential for improvement in the reduction of AT&C losses from electricity distribution in the city.

Efficiency also comes in to play at the smaller level of buildings operations and appliance use. There are no standards in place in Dehradun to check building efficiency and the awareness for the efficiency of electrical appliances is also low.

7.2.4 Urban Form and Function

A city's size, density, shape and distribution of functions have an impact on its emissions profile. It has been documented that denser cities with mixed use developments and efficient public transport systems have considerably lower emissions than sprawled suburban developments with higher reliance on private transport. The role of density on transport emissions has received a relatively larger focus in studies.

Dehradun has a linear form, with the city centre being the major commercial hub and spreading to the northeast along the Rajpur road in a ribbon development. The eastern part of the city is mostly residential whilst the institutions are spread over the city outside the central core, many in the western part with the IMA and FRI. The newer developments are mostly in the south-eastern region of the city around the newly developed ISBT area. The city does not have a very high density of population. One of the reasons for a higher VKT can be the linear city form requiring longer travel distances.

7.2.5 Behavioural and Societal Factors

Cultural and social contexts shape the lifestyle of people and hence affect their energy use. While people in developed nations use more per-capita energy owing to their lifestyle choices of more travel and lesser focus on conscientious energy use, those in developing nations have different energy use profiles.

For an average middle-income family in a developing nation like India, the amount of travel will be far less than their counterparts in developed countries. They might, however, cook more often at home but have a tendency to save electricity by switching off when not in use. There is still not much awareness when it comes to choosing energy efficient appliances. And though the car ownership per 1000 people is much less in India, a car is a symbol of social class and lifestyle status and thus the number is rapidly on a rise.

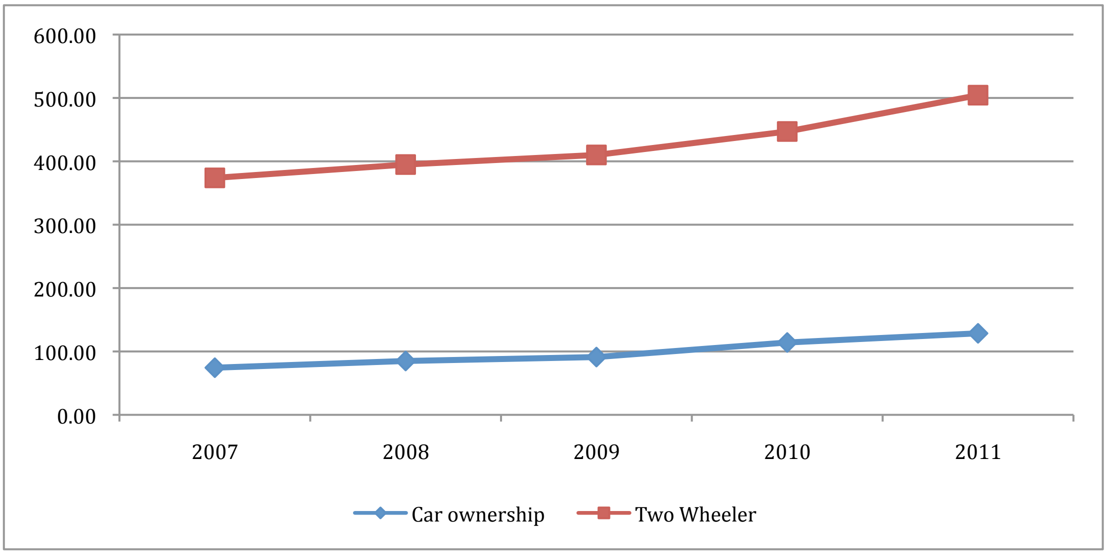


Figure 7-29: Dehradun Private vehicle ownership per 1000

7.2.6 Globalization

As an example for the role of globalization in the emissions profile of cities, two Indian cities can be used. Gurgaon and Bengaluru have seen a phenomenal rise in FDI in the past decade. As a result, both cities have witnessed rapid population, infrastructure and economic growth in the period resulting in the cities having some of the highest emissions in the country. Closer looks at the impacts of globalization show that the architectural typology has drastically changed from the vernacular to blindly emulate the west. This disregards the local climatic conditions and has led to a jump in the need for cooling and hence associated emissions.

Dehradun can potentially be a victim to the same fate owing to its location and climatic factors. Being only 6 hours drive from New Delhi and 4 hours from Chandigarh, which might reduce further with better road infrastructure, as well as being a valley with a moderate climate, it has the potential to attract a lot of Foreign Direct Investment (FDI) if the right infrastructure is in place. Whilst this will mean more economic growth for the city, it might also pose challenges that the city managers should be wary of.

7.2.7 Institutional and Political factors

The role of governance and institutional/political responsibility can be a key driver in the increase or decrease of emissions. A more aware and responsive government will make informed choices to decouple the economic growth from the emissions and be proactive in the mitigation and adaptation measures. In contrast, an ill-informed and resource deficient government can lead to cities making the same mistakes that have been made in the past.

A successful intervention can only happen when the government engages in the policies at all levels and ensures that the decisions are properly implemented. Local Governments in developing nations should engage with those in developed nations to learn from their experiences in managing growth and reducing emissions.

The issue of governance problems in Dehradun was raised in the process chapter. The devolved structure, lack of awareness and capacity as well as unclear definitions of roles and responsibility among the city agencies, present hurdles in the implementation of policy.

7.2.8 Natural Factors

Finally, the role of natural factors on the emissions profiles cannot be overlooked and although there is not much that can be done in terms of interventions in this area, it is crucial to consider this especially when comparing emissions inventories to understand the drivers of emissions. A city in a cold region cannot be expected to have the same emissions as that in a moderate climate.

Dehradun usually has a moderate climate but has been experiencing a rise in summertime temperatures over the past decades. This has led to an increased use of cooling in the city with more air conditioning being used where there was not even the need for ceiling fans some decades ago.

7.3 Conclusions

The analysis shows that 55% of the city's 2011 emissions comes from transport making it the highest emitting sector. 42% can be attributed to energy use in the buildings' sectors whereas waste and agriculture contribute 3% and 0.0002% respectively of the emissions. All sectors except agriculture show a trend of increasing emissions over the five-year study period.

The subsectoral analysis gives more insight into the emission sources, helping identify and target the key emitters. Some important insights as part of this process were the identification of the increasing private vehicle ownership as the key driver of transport emissions and the dominance of the commercial and institutional sectors in the electricity use in buildings. The transport sector also displayed a shift from higher emissions from diesel vehicles to those from gasoline vehicles due to an increase in the private vehicle ownership over the five years.

Another key finding was that even though the emissions are seen as rising over the years, the annual growth rate for emissions is decreasing, which presents a positive trend for a low carbon future. A divergent trend between the economic growth and emissions is also seen wherein the economic growth is considerably faster than the emissions growth.

The major drivers for emissions from the city are economic growth and urban demographics as well as the behavioural and societal factors. The major difference between the emissions profile of an Indian city as compared to cities in developing nations comes from the Behavioural and Societal factors. Having faced an energy deficit in the form of power cuts, consumers in India are more conscientious in terms of energy use. The idea of savings whether monetary or energy related is also a part of the cultural differentiation. On the other hand, the Indian population also adheres to the belief of vehicle ownership being a symbol of one's status in the society.

At its present stage of development, Dehradun city is still grappling with its new identity as the administrative capital of Uttarakhand state. While this status has meant a lot of focus on the development of the city's infrastructure, the involvement of too many agencies and the clash of interest between them has also led to confusion in the process. Compared to cities in developed nations where the focus is usually on improving the infrastructure or making it more efficient, Dehradun is still in the process of providing the population with the basic infrastructure needed. It is important to address this distinction when planning policy for mitigation, as the city is likely to see an increase in emissions from added infrastructure as the local government strives to fulfil the basic service needs for its entire population. This may seem to offset any reduction targets and should be taken into account when setting the reduction targets. In the future, globalization may become a major driver for changing the emissions' profile in the city. The role of institutional and political factors is also identified as a key focus area for the success of policy interventions to mitigate climate change.

Chapter 8 Applications

In this chapter, the utility of a GHG inventory as a policy tool has been explored. The issues discussed include the benefits of using a GHG inventory tool at the municipal level for Carbon reduction policies, the strengths and weaknesses of the local governance scenario, and the potential policy pathways that can be explored. The first section in the chapter presents a business case for the use of an emissions inventory by local governments reiterating its need and listing its potential benefits. This is followed by an overall review of the inferences from the previous chapter with a focus on identifying the key drivers of emissions in the city.

Following this, a discussion on policy pathways for each sector and the various drivers as discussed in Chapter 7 with a focus on local priorities is presented. The policy options are evaluated for their impact and ease of implementation and probable success rates, drawing where possible from other case studies. Where available, recent policy developments relating to the field in the city have been discussed. Each of these sectors also includes a section relating to governance issues that will be faced for each policy measure. Some sectors are also supported with examples of policy scenarios to exhibit the potential savings in carbon. The chapter ends with an overall discussion of the key outcomes/recommendations of the study and the opportunities and barriers in the conclusion to the chapter.

8.1 Business case for using a GHG inventory

The objectives and aims of this thesis have been set out to include a three-part system analysis approach where a process has been evaluated and an inventory has been calculated. The purpose of these two exercises is redundant if the third step of using the information gleaned to create a policy framework for municipal governments to reduce their emissions is not met. As an academic objective, it may be sufficient to recommend policy measures based on the study, but from the standpoint of a local government, it is essential to put forward a business case for the use of a GHG inventory as a policy tool. This step will also support the aim of this thesis by evaluating the usefulness of the inventory tool in the current format.

Climate Change and Carbon management policies can work in one of two ways – the first involves mitigation measures and the latter adaptation. In the real world, to cope with the challenges of climate change, both these approaches must be applied. Mitigation strategies will involve policies to reduce the emissions in order to check the 2˚C rise in temperature whereas adaptation strategies will involve policies to accommodate the changes in climate or climate induced changes in lifestyles. There has to be a concerted effort by the world community to reduce emissions in order to contain the 2 degrees rise in temperature and this has to be followed by measures by local governments to prepare their regions for any eventualities. As by 2030, 73% of the energy will be used in cities, which will also have the most population, cities need to lead the movement in both the mitigation and adaptation measures.

So far, most research on energy consumption in cities is focused on megacities. However, considering that by 2015, 358 cities in the world will have a population of over 1 million of which 153 will be in Asia (Dhakal, 2004) and by 2030 India alone will have 68 cities with more than a million population, 13 cities with more than 4 million and 6 megacities with more than 10 million (Sankhe et al., 2010); there is a looming opportunity to introduce sustainability measures in the tier 3 and 4 cities. It must also be noted here that while the tier 1 cities require an investment of more than $200/cap/year between 2010-2030, smaller cities have historically shown robust growth with low municipal expenditure.

Between 1999-2006, municipal spending in tier 1 cities averaged $130/cap/yr with a growth rate of 8.3% compared to tier 2 cities which spent $38/cap/yr with a growth rate of 8.4% whereas tier 3 and 4 cities spent only $12/cap/yr to achieve a growth rate of 7.5 % (Sankhe et al., 2010). Hence, it can be concluded that the benefits of applying emissions reduction policies in tier 3 and 4 cities will be multifold; firstly, because the number of cities in the group is large and rapidly growing meaning the emission savings can be tremendous; secondly, the investment requirements to maintain the growth rate is low, so there is an opportunity to use funds to promote sustainability measures.

A recent development at the Cancun COP16 decisions (UNFCCC, 2011) (FCCC/KP/CMP/2010/12/Add.2) with regards to the Clean Development Mechanism (CDM), requests the Executive Board to reassess its regulations with a possibility to include City-Wide programmes that will provide major opportunities for cities to generate Certified Emissions Reductions (CER). The city-wide projects will help reduce the transaction costs associated with individual projects and encourage local governments to implement city-wide climate change agendas.

8.2 Policy making for reducing emissions

In such a background, the usefulness of an inventory tool is also strengthened by the policy making process and the local governance model. Policymaking and implementation usually work with establishing the current scenario, making policies, implementing the policy recommendation and eventually monitoring the results to provide feedback to the policy process. The difference between a successful policy and a failure can often be the lack of this feedback loop. It is essential for policymakers to assess the effects of their policy to make an informed decision regarding future interventions.

A GHG inventory not only provides the policymakers with a measured quantity of the current scenario but can also be used to predict effects of various policy pathways and most importantly, can be a monitoring tool to assess and feed back into the policy process to ensure the success of carbon mitigation interventions in the city.

In the previous chapters, references have been made to the weaknesses of the current local governance structure in Indian cities. In a devolved model of governance like that in the city, although there are difficulties in the initial process of setting up an inventory process, an inventory can also be adapted to suit the model. Once a base inventory has been drawn up, each government agency involved in the process can be assigned the part of the inventory that directly relates to them and be responsible for its maintenance and implementation of related policies. The maintenance of the inventory can be set up as an online database that is managed and updated by each agency. A cell in the development authority can be responsible for the overall management with stakeholders from each government agency who will form the decision making body.

The success of policies also depends on the approach being holistic. A regulatory measure by the government to introduce energy labelling in electronic products will not be successful unless there is also a drive to educate the consumers about the initiative and its benefits. Likewise, any subsidies/tax rebates for adopting renewable generation/green technologies have to be promoted and the stakeholders in the process need to be educated.

8.2.1 Policy pathways and Scenario modelling

There are two policy pathways with regards to GHG emissions reduction and Climate Change policy – the first is Mitigation, which requires cities to reduce their emissions to minimize the damage caused by Climate Change and the second is Adaptation, which requires them to prepare for eventual Climate Change Scenarios of extreme weather conditions and associated risks. The use of a GHG inventory is a key step in the mitigation policy formation.

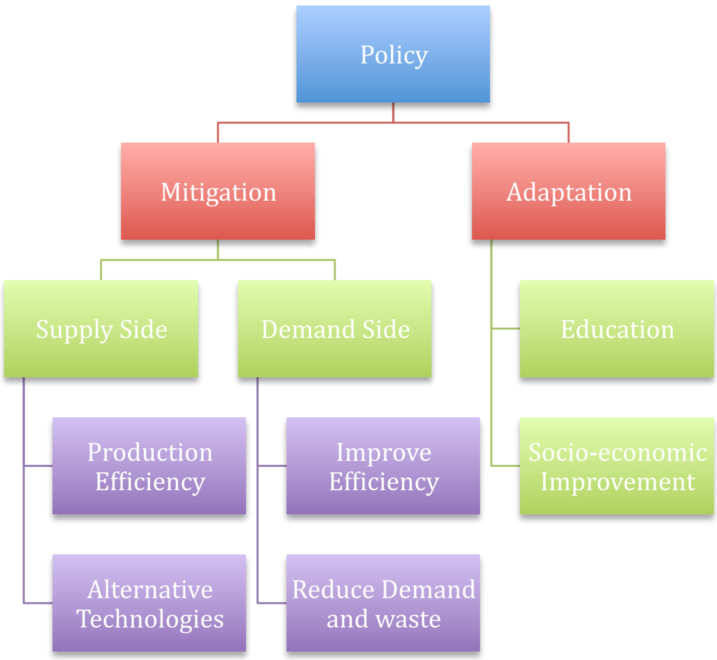


Figure 8-1 - Policy Pathways for Carbon Management

In terms of the policy tools available to local governments to reduce emissions, there can be four approaches: Technology, Regulatory, Education/ Awareness and Financial frameworks. Technological policy tools will include improvements in service efficiency or the introduction of renewable non-emission technology alternatives. Regulatory tools may have many options ranging from targeting building and products' efficiency through energy labelling regulations to mandatory assessment regulations or planning regulations.

Education and Awareness policies are mainly concerned with influencing the lifestyle choices of citizens, whereby increased awareness of the issues and ways of reducing emissions, can significantly help citizens voluntarily reduce their emissions. Finally, a key tool is the financial means, where tax exemptions or feed in tariffs for local renewable energy generation can encourage renewable energy usage or congestion charges for vehicles in cities to reduce private vehicle use.

The use of any of these policy tools and pathways is dependent on the potentials for carbon reduction from various policy measures. Scenario modelling offers policymakers an insight into the possible savings from different policy measures that may be applied in the city. Through scenario modelling of future emissions' scenarios and a comparison of savings potential from different policy measures, policy makers can make better-informed choices on the policies that will provide the best results with the least trouble.

8.2.2 Local Priorities

Among the local priorities for the Dehradun municipal corporation, the extension and upgrading of infrastructure rate the highest. Most of the city's finances and resources are currently invested in the expansion and upgrade of service provisions like water supply, sewage treatment and MSW management. In recent years, Dehradun has also witnessed which would appear to be impacts of Climate Change in the changing weather patterns in the regions. May 8, 2012 witnessed a record high air temperature of 41.4 deg C, the highest in 8 years. The Dehradun valley experienced pleasant summers until 20 yrs ago when there was no need for ceiling fans and is now seeing an exponential rise in the use of air-conditioning due to changing weather and non-climate responsive design of buildings in the city.

The poorer sections of the population, who are most affected by the increased heat waves and related diseases, feel the impacts of such climatic changes.

8.2.3 Recent Policy developments

The city has a number of ongoing development programmes in relation to services delivery. Under the JNNURM mission, projects include the Sewage Collection and Disposal programme, Water Supply reorganization scheme, Integrated Solid Waste Management, and Improvement of 30 intersections of Dehradun city. As noted earlier, if cities in this phase of development start looking not just at quantity but also at the impacts of the projects, successful measures may be taken to minimize the potential emissions from these service projects.

For instance, Carbon Capture from Integrated solid waste management is one of the most successful CDM opportunities, which could be integrated at this stage itself. Also, the sewage treatment facility could incorporate CH_4 capture and flaring or other reduction measures like using the CH_4 to generate electricity, reducing the cost of introducing such measures at a later date.

The city is also part of the Solar Cities Initiatives to promote renewable energy generation. The program aims for a 10% reduction in the projected energy demand at the end of five years. 5% of the reduction will come from the introduction of renewable sources. The program also proposes establishing off-grid solar power plants in the city.

The e-governance program in the city aims at digitizing the records and creating an integrated portal for financial management within the municipal government. The aim of the e-governance project is to provide electronic service delivery gateways, state data centres, common service centres and state-wide networks for IT facilitation to improve service delivery and increase transparency.

Among other smaller initiatives within the city that relate to the areas of Climate Change and Energy use, the Forest Research Institute (FRI) which is one of the dominant institutions in the city has introduced a department for research and development in the area of Climate Change and is also undertaking an inventory of the institute's carbon emissions.

8.2.4 Opportunities and Barriers

Several barriers and opportunities can be identified with regards to the introduction of Climate Change mitigation policies. A lack of awareness among the stakeholders is one of the key obstacles. In the absence of regulatory legislation, being another barrier, the focus on Climate Change policy is voluntary by concerned authorities. As such, there needs to be more awareness of the impacts of climate change and the benefits of mitigation and adaptation policies.

The current institutional arrangement in the city is identified, in this research, as a major hurdle to the introduction and implementation of a GHG inventory and mitigation policies. There are two ways to address this issue – one being reforming the whole system to introduce a more integrated municipal governance structure with clear definitions of roles and responsibilities whilst the other is to adapt to the existing structure and try and work with it. Reforming the structure will have multiple benefits but is very difficult to achieve due to the resistance from existing structure whereas adapting to the existing system may present some problems in roles and responsibility identification.

The opportunities that Climate Change mitigation and adaptation policies present is firstly, better preparedness by the local authority to tackle any adverse impacts of climate change in the longer term and in the shorter term, financial opportunity to generate Certified Emissions' Reductions (CER's) through voluntary reduction measures.

8.3 Intervention Opportunities

There are a number of policy pathways that can be adopted to reduce emissions from cities. In terms of the intervention pathways, there are two options. The first – management pathways aim at reduction of energy use and waste generation and thus associated emissions. The second – technology pathway aims at providing cleaner forms of energy and improving energy efficiency.

To implement these policy pathways, there can be a number of intervention tools (Dhakal, 2004). Economic tools may include incentives or taxation policies like increased taxation on polluting vehicles/fuels or fiscal incentives for adapting local renewable technologies. Regulatory frameworks may include policies where new laws require more efficient building performance or minimum standards of efficiency in products. A voluntary mechanism includes CDM opportunities where projects are undertaken voluntarily to reduce emissions and institutional arrangements to empower the local authorities to take the necessary decisions to mitigate emissions.

In the sections that follow, challenges for each sector have been identified based on the inventory and its analysis, then intervention pathways are explored along with a focus on related socioeconomic sustainability benefits from such interventions. Finally, a proposal is presented for each sector/driver area. The process section is introduced to address the issues identified in the inventory compilation and governance along with the inventory sectors.

8.3.1 Process

The study of the process of conducting a GHG inventory for the city was a major part of this research and helped identify a number of policy relevant issues that must be addressed. Institutional and political factors were identified as a roadblock in the successful adaptation and more importantly implementation of a GHG inventory as a policy tool.

Challenges – Many issues were identified through this research. A lack of metadata in the various agencies made it difficult to locate the right data. Lack of regular data collection mandates for some sectors like land use and livestock meant these sectors could not be accounted for in the inventory. A lack of awareness about the issue among municipal employees was also identified as a roadblock since this ignorance meant no action was taken. The devolved structure of the governance system led to two problems – one concerning the data collection and the other concerning the ownership and responsibility of the GHG inventory and its policy implementation.

Policy Pathways – In the shorter term, the problem can be addressed through the e-governance system, mandating the different government agencies to regularly collect requisite data and update it. Also, the creation of a Climate change cell within the municipal body, which has the powers to formulate, and implement policy across various sectors/ agencies will create accountability for the policy process. In the longer term however, there is a need for a reformed governance structure (**Figure** 8-2) with a clear hierarchy and a holistic approach that does away with the complete segregation of various agencies that is present at the moment.

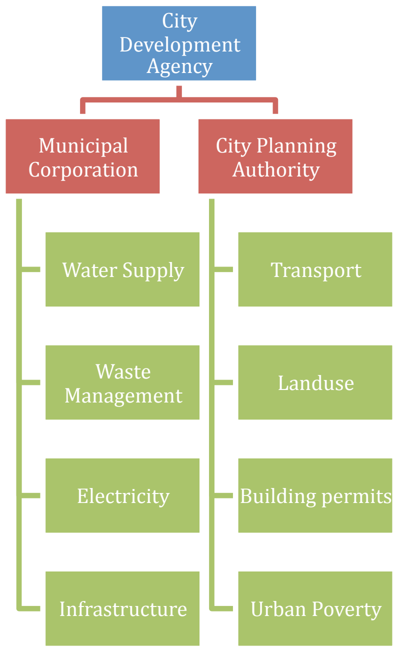


Figure 8-2: Proposed structure for the Local Authority

Socio-economic Impact – The transparency that will be introduced through the e-governance system will improve citizen experience with the authority and also help increase awareness among the citizens and improve public participation.

Proposal – (a) Create a Climate Change cell in the local authority and initiate a process to integrate the various government agencies acting in the city leveraging on the e-governance policy that is being implemented.

The first steps in the reform process will be to assign accountability and use the e-governance platform to collate and refine data management practices in the local authority. Follow this by policy and monitoring to showcase the benefits of GHG management and increasing awareness and knowledge among government employees as well as consumers and eventually create an integrated city management system. The plan also recommends creation of a climate change fund, capacity building through CDM potentials and eventually making GHG mitigation a key component of the municipal functions that is also financially self sufficient.

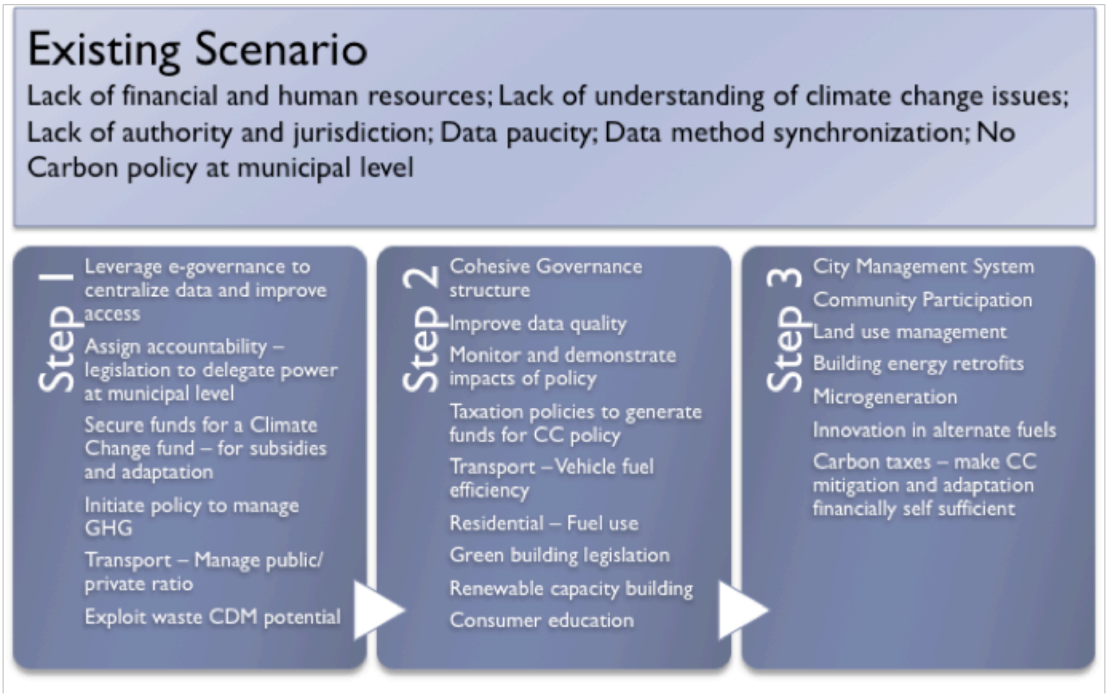


Figure 8-3: Recommended steps to governance reform and improved inventory process and carbon management

This recommended three step process aims to help make the transition from the current structure with governance issues to an integrated governance structure with a city management plan and clear roles and responsibilities. In the light of the current lack of resources and identifying that this is a major change, the steps use already ongoing reform measure to initiate the transition. In the first step, the problems of data collection and lack of knowledge are the main targets for the reform whilst the transport sector is identified as the first policy area that must be addressed by the policymakers. Leveraging the e-governance plan, the data from the agencies can be centralized and made more accessible and also provide a platform for the agencies to regularly update the data.

As a first step, the municipality must also have accountability to manage emissions and thus also associated powers to make and implement policy. Thus, legislation to empower the municipality is needed. To start things, the city authorities will need to secure a Climate Change fund – for policies relating to mitigation and adaptation of climate change. Policies to manage the public private vehicle ratio, like improving public transport and discouraging private vehicle ownership through financial disincentives can be explored. The CDM potential from waste management is also a key policy area that can be immediately acted upon.

In the second step, the issue of data quality improvement can be tackled at the level of various departmental stakeholders. A shift to a cohesive governance hierarchy as illustrated in **Figure** 8-2 can be initiated at this stage. On the policy side, once the monitoring results from previous policy measures have been assessed, stronger policy measures can be initiated including taxations, efficiency improvements and capacity building for renewable technologies.

Consumer awareness of energy and climate change issues must also be addressed at this stage to encourage demand side management. In the final step, the eventual shift to a city management system that is IT enabled with a centralized database and a transparent government hierarchy is sought [**Figure** 8-4]. More policies for adaptation and micro generation, building energy retrofits etc. that require more resources and knowledge can be started now. The introduction of carbon taxes can move the climate change adaptation and policy programmes towards financial self-sufficiency.

(b) Fill the data gap identified in the land use sector and; improve data disaggregation. Use the e-governance platform to collate and manage data and integrate the GHG inventory as a module of the platform.

The recommendation aims to leverage the ongoing e-governance reform to not only set up data management practices for the departmental accounting systems but also as a portal for government and consumers to access data. For the government portal, the platform will enable financial, facilities and knowledge management as well as data analysis modules including the GHG inventory tool to assist in the policy process. The knowledge management system will be a database for effective carbon management, disaster management, traffic management etc. The consumer portal on the other hand, will provide the consumers with easy access online payment systems for taxes and bills as well as access to information about their energy uses and best practice guidelines to manage their consumption. In the later stages, it could also be used to collect consumption data from households to facilitate a completely bottom up approach to GHG inventory.

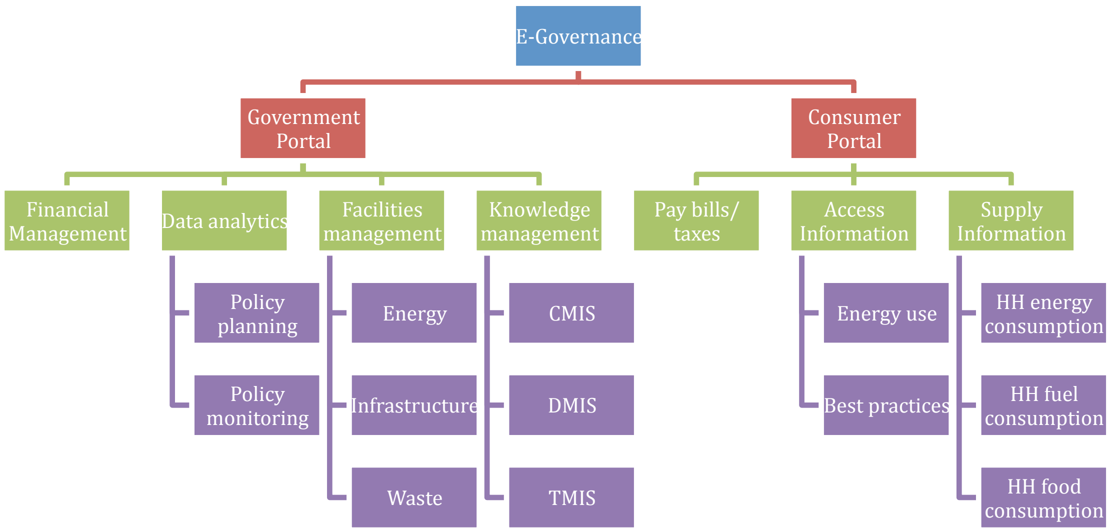


Figure 8-4: The E-Governance Platform to serve as a data management tool

8.3.2 Buildings

The building sector in Dehradun emitted 411758 MT CO2 eq in 2011 and has risen by a rate of 54% for fuel use and 22% for electricity use over the five-year study period. The major drivers identified for the rising trend in the sector include – urban demographics (increasing population pressure) and behavioural factors (increased appliance use). In the future there is a high potential for the city attracting FDI developments. This must receive careful consideration by policymakers to avoid the unfettered growth seen in cities like Gurgaon and Bangalore that increased their emissions multifold.

A number of policies can be applied to reduce these emissions as well as manage the growth to ensure a low carbon development. A two-step approach is needed to reduce the emissions from this sector. The first step is to reduce the emissions. This will involve lifestyle changes and policies may include education and awareness, economic incentives, and regulatory/voluntary frameworks to make buildings more energy efficient. The second step is then to supply the demand by less carbon intensive pathways and a more efficient distribution network and promote local renewable generation. It is easier to intervene in the second step with complete government control than the first, which may face resistance from the population unwilling to make lifestyle changes and the construction industry for efficiency improvements in the building stock. Regulatory measures for new FDI developments in the future must be introduced that require them to follow stringent energy efficiency measures as well as address the local socio-economic issues.

Challenges – The analysis of emissions from the buildings' sector in the city shows that it is the second biggest emitter after transport. Further subsectoral analysis revealed that residential and commercial and institutional sectors were the most energy intensive in terms of electricity use. In the five-year study period there has been continuous growth in the emissions from buildings in the city with only the electrical company registering some reduction in its offices and public lamps subsector. Some problems were also identified in the data available with Mussourie being included in the electricity network boundary and the disaggregation combining the commercial and institutional subsectors. The residential sector was identified as the key sector for fuel use in buildings with LPG being the major fuel. With increasing summer time temperature over the years, the use of air-conditioning in the city is rising. A policy for building energy efficient buildings in the city can go a long way in the reduction of emissions due to the need for cooling or heating especially in the wake of globalization and its adverse impact on the architectural vocabulary.

Policy Pathways – As the analysis points, this is a major sector for policy intervention. Based on the subsectoral analysis, the policies should be aimed at the residential and commercial and institutional sectors. Dehradun being a primarily administrative and institutional town, it will be beneficial to segregate the institutional sector in the electricity subsectors to better assess the emissions profile. Both management and technology pathways can be used to reduce emissions from building energy use. Building and equipment energy efficiency legislation to promote reduction in energy use, raising public awareness of energy use and its climatic impacts to affect lifestyle choices are the management options that can reduce energy use.

Among the technological options, promoting local renewable and improving the existing transmission and distribution network to reduce AT&C losses can be used to reduce emissions. For electricity related emissions, Dehradun already has a supply mix with a larger share than average of less carbon intensive fuels. However, the distribution system can be upgraded to use much more efficient technology to reduce the AT&C losses from 24% to 12-13% which is typical in developed nations. Alternative low energy fuel options can also be explored for fuel use in buildings.

Socio-economic Impact – The reduced electricity use will mean a reduced shortage of energy supply as well as reduced energy cost for the public. Local renewable adoption will also bring positive economic benefits for the people by reducing energy bills and also by selling excess energy to the grid.

Proposal – Based on the analysis and observations, the following recommendations can be made with regards to policy in the buildings sector.

a) Refine the disaggregation of the energy use data to include a separate institutions subsector in order to better understand the city’s emissions profile.

b) Use the ongoing GIS mapping of all electricity consumers as a tool to increase awareness among city residents. The project aims to map every consumer in the city. The recommendation is to use this platform to include an electricity use and emissions module, which can be added to the GIS. This can then be used to provide customers with information on their electricity use and associated emissions along with a benchmark for ideal use in their usage profile category along with their bills. This will raise awareness among the customers about the amount of energy they use and will encourage conscientious use of energy.

c) Further reduce the AT&C losses – the electricity company has been trying to cut down its AT&C losses in the past few years. However, there is still potential to reduce these losses and thus, this comes as a key recommendation. The present scenario shows AT&C losses at 23% whereas the international standard is close to 12-13%.

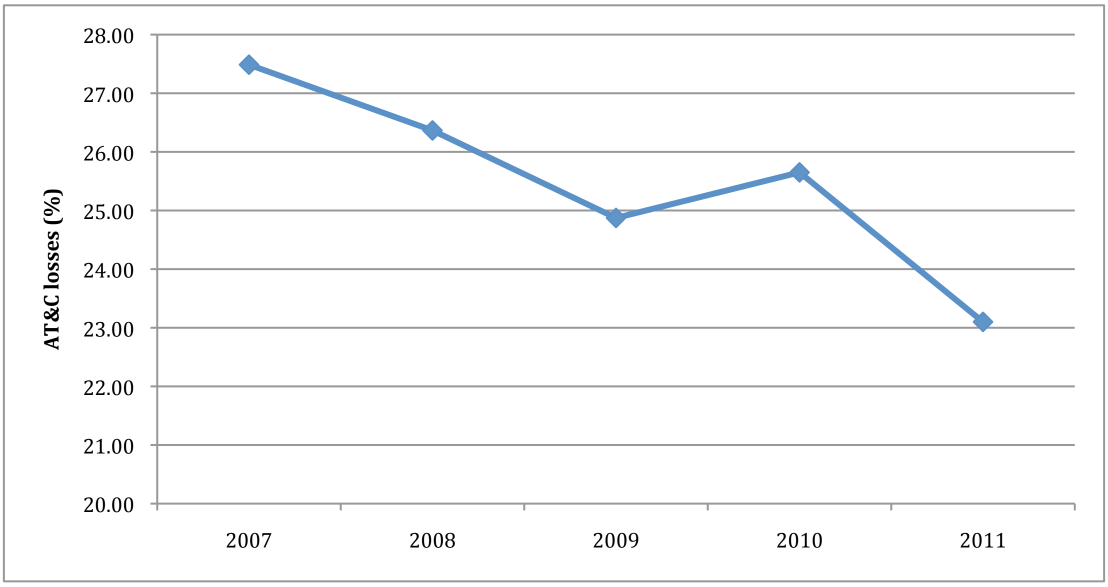


Figure 8-5: AT&C losses in the electricity distribution system in Dehradun

d) Promote local renewable generation – Dehradun has a high potential for solar renewable energy, thus making this an important policy recommendation to reduce emissions from the city. The use of solar water heating and solar PVs must be encouraged on a building/ community level. Institutions form an ideal sector to introduce renewable deployment as they have the concentrated demand as well as ample area to be used for renewable technologies.

The table gives the average solar insolation figures in KWh/m2/day for a solar panel oriented at a 60º angle facing south in Dehradun city, showing the potential of solar-based generation.

Table 8-1: Average monthly Solar Insolation potential in Dehradun

Jan	Feb	Mar	Apr	May	Jun
5.37	5.84	6.39	6.71	6.74	5.92
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
4.86	4.62	5.55	6.89	6.42	5.62

8.3.3 Transport

Transport is another key sector in the city's emissions with a share of 44% of the total city emissions rising at an alarming rate of 86% in the study period. The major drivers identified were a lack of an efficient public transport system and increasing private vehicle ownership with increasing income per capita and vehicle affordability with an easy finance mechanism.

Policy options for a reduction of transport emissions may include economic incentives to use more efficient technologies, regulatory frameworks to reduce car dependence eg. Congestion charges and promotion of a more efficient public transport system. The choice of fuel can also make a significant reduction in emissions.

Challenges – Transport is the highest CO2 emitting sector in the city and should be the priority in policy formation. Subsectoral analysis of the sector points to increasing use of privately owned vehicles in the city. The lack of footpaths and safe cycling pathways make safe alternative non-motorized transportation difficult in the current scenario. The social status attached to vehicle ownership is a major hurdle in changing public perception.

Policy Pathways – Improving public transport, using alternative low emissions fuels, vehicle efficiency improvements and promoting non-motorized transport options are some of the key policy interventions in this sector. In Dehradun, the key intervention area must be the public transport network. The current public transportation network is below par in its capacity and efficiency, thus, encouraging people to use private vehicle. An improved network will encourage people to use the public transport system. Use of CNG can be promoted especially for public transport to reduce emissions.

Socio-economic Impacts – Better public transport with an alternative low emitting fuel will ensure lower air pollution improving public health. More people using public transport will also mean less congestion and also improved road safety. The job generation associated with the introduction of an expanded public transport network will reap economic benefits. Creating more walkable neighbourhoods will improve neighbourhood safety and improve health.

Proposal –

The key recommendations for the transport sector –

a) Introduce a Bus Rapid Transport System (BRTS) in the city to improve the public transport network with dedicated lanes and improved frequency.

b) Promote the use of CNG as the fuel for the BRTS system to reduce emissions from the more polluting diesel alternative. Based on the current vehicle kms travelled in the city by buses and autos, the estimated emissions reduction by adopting Euro II CNG buses with three way catalytic converters and CNG autos will be around 16% for the buses and 67% for the autos.

c) As an urban design intervention, create more walkable neighbourhoods and introduce footpaths and cycle lanes to promote safe non-motorized transport options.

8.3.4 Agriculture and Livestock

Agriculture emissions within the city's boundaries are minimal and decreasing due to a decrease in agriculture land. Thus, this sector does not rate high in the policy intervention list. The lack of information for the land use sector is a major drawback and must be addressed as a priority since the loss of carbon sinks in the city and the lack of green spaces is evident but needs to be accounted for. Drivers for this sector include natural factors like increasing average temperature, the urban heat island effect. The lack of data is attributed to the institutional and political factors. Indians on average consume more dairy products and hence, the population of livestock is higher.

Challenges – Although emissions and sinks from the land use category could not be calculated due to the lack of data and emissions from agriculture and livestock are low, this sector does not rank high in the intervention priority. Yet the lack of green spaces in the city is evident especially in the core and the eastern part of the city. Whilst the Forest Research Institute (FRI) has a large green zone that is a carbon sink for the city, there is need for more green areas. Urban expansion, especially road widening around the city has meant a lot of deforestation and loss of sinks around the city.

Policy Pathways – Introduction of more green spaces in the city to improve carbon sequestration can be used as a policy intervention.

Socio-economic Impact – The introduction of green spaces in the city fabric will also have social and health benefits for the community providing safe open spaces for children and improving air quality.

Proposal – (a) The first recommendation is to improve the data availability for the sector so that changes in land use can be accounted for in the emissions inventory.

(b) The other proposition for this sector will be to include more open spaces in the masterplan to act as carbon sinks for the city especially in the more dense urban fabric. The introduction of green spaces will lead to carbon capture by biomass and also improve the local air quality.

8.3.5 Infrastructure

Infrastructure is the third area of concern for policymakers. Immediate concerns in infrastructure relate to the provision of basic services to all the population. Policymakers must consider that fulfilling the need for infrastructure services provision for 100% of the urban population will lead to increased emissions that may be minimized with good planning but cannot be eliminated. While this is underway, several steps can also be taken to ensure proper treatment and disposal of the effluents. As part of this, policymakers could promote waste recycling to reduce the tons per day generation and with well-designed treatment pathways, much of the CH4 emitted can be captured and used or flared to reduce emissions.

Challenges – The research shows there is a lack of access to basic services in the city. The waste sector lacks a proper collection, treatment and disposal facility. Only 60% of the solid waste is collected and is landfilled with no options for emissions capture whereas in the case of wastewater, the collection scenario is even worse and there is no treatment facility available at present. Garbage is illegally dumped in the city and creates unhealthy conditions.

Policy Pathways – Even though the waste sector does not contribute much to the overall city emissions, it is an important policy area since it presents a good CDM potential. Policy interventions will include improved collection, proper treatments and disposal including flaring from landfills for energy generation from waste. Also, promoting more recycling by standardizing the recycling industry, which works like a cottage industry at present.

Socio-economic Impact – Apart from the health benefits from improved collection and reduction in illegal dumping, the CDM potential will be an added economic benefit for the city. Generating energy from waste will help reduce the energy deficit and reduce the water pollution caused by direct dumping of wastewater in the rivers. Standardizing the recycling industry will create jobs and improve livelihoods of the people involved in the collection of recyclable waste.

Proposal –

a) Introduce energy from waste project by burning CH4 for electricity generation from solid waste.

b) Waste water treatment plant - The work on building wastewater treatment plant for the city is already underway. It presents an opportunity for the local government to integrate a waste to energy plant with it to reduce emissions as well as effectively using the waste to generate energy to supplement the city supply.

8.4 Conclusion

The use of inventory results for carbon mitigation policy making in the city has been explored in this chapter. The existing Institutional arrangement was identified as a key barrier to the inventory and policy process in the city. Although the process can be adapted to work in the existing scenario, it is highly recommended that the governance structure be reformed to enable clearer differentiation of roles and responsibilities and holistic planning in the city. It is also important to raise awareness of the issues of climate change and associated threats.

The key policies identified based on the analysis include an improvement in the public transport network, increasing awareness of energy use among the population, improving efficiency and using the CDM opportunities to generate financial benefits while reducing emissions. The subsectoral analysis provided a deeper understanding of the emissions profile and thus helped target the policies. These policies can be adopted alongside the infrastructure development programmes currently ongoing in the city. The policymakers should also acknowledge the expected rise in emissions from the expanding infrastructure, as the basic service needs for the whole population are fulfilled.

The study also suggests that the emissions reduction policies in each sector also have associated economic and/or social sustainability impacts, which can be seen as a positive spin-off of the policy to spearhead the sustainability movement in cities. The use of the inventory as a policy tool will be more effective if it also serves as a monitoring and feedback loop for the policy process. As such the annual data collection and inventory calculation must be maintained.

Chapter 9 Conclusions

This thesis used an empirical case study research method to investigate the process, method and potential of a GHG inventory tool in a mid size Indian city within its existing local structures of governance and data availability and the global context of Climate Change and Urban Sustainability requirements.

This final Chapter of concluding remarks includes the research summary highlighting the main findings of the research, the inferences drawn, limitations and recommendations based on the study. The Chapter also identifies areas of further research that emerge in relation to this study area.

9.1 Concluding Discussion

Even though India boasts a low per capita emissions profile, its large population base has already made it the 5th largest GHG emitting nation. In the absence of any action to limit or reduce emissions, the continued economic and population growth in the country will propel India to even higher emissions.

Owing to its large section of population below poverty level, India is also among the top nations to bear the brunt of Climate Change. The aim is to innovate strategies to decouple economic growth from high-energy use. For cities in developing countries like India, sustainability is usually a secondary issue, but they must use it as a process and not a goal. The disaggregated deterministic ideal of urban planning needs to shift towards holistic planning embracing chaos.

The Aim of this thesis was to identify the opportunities and barriers to the use of GHG inventory as a strategic policy tool at the municipal level in a tier III city (Dehradun) India. Although it is possible to conduct a GHG inventory within the existing data and governance scenario in mid scale Indian cities, with the exception of land use changes, a number of lessons, inferences and issues have emerged as part of this study. In this chapter the major conclusions of this work are outlined.

The overall trend of rising emissions from 1.07 tons per capita to 1.43 tons per capita was as expected. However, a key finding was the decline in annual growth rate for emissions over the five year study period, which is a potentially positive incidence. The finding triggers a need for further research, one, to establish if a similar trend is seen in other Indian cities and two, to isolate the reasons or drivers behind this trend. There are several possibilities that need to be explored including the rising fuel prices, more energy efficient products, increased awareness or impacts of policies. The trend displays that the emissions growth in the city does not have an exponentially rising growth rate as might be expected in cities in developing countries.

From the five-year emissions profile calculation for the city, it was established that compared to cities in developed countries the emissions from the city are very low. However, compared to cities in India, the emissions fall close to average for the base year (2007) rising rapidly thereafter. It can thus be stated that the challenge for the city is not so much to reduce its emissions as to manage them efficiently to decouple them from socioeconomic development. The low per capita averages in the city point to several observations –

Whilst cities in developed nations are focusing on improving infrastructure or making it more efficient, cities like Dehradun are still struggling to provide basic services to the population. This distinction needs to be addressed when assessing emissions profiles from these cities, as they are likely to see an increase in emissions from added infrastructure, which cannot be done away with. As the local governments strive to fulfil the basic services needs for its entire population, low carbon pathways may be initiated, for example, by CH_4 flaring from wastewater treatment; yet some leeway must be provided to account for these indispensable emissions

The significant gap in emissions profiles between developed and developing nations cannot just be attributed to the differences in city infrastructure. Characteristics of Indian cities and the Indian consumer in the way energy is used are also key factors in the emissions profiles of the city and must be given more research consideration. The per capita electricity energy consumption in the city was found to be 800 kWh excluding AT&C losses. Per capita energy consumptions for cities in developed nations range higher than 5000 kWh (Dickinson and Tenorio, 2011). The mixed-use development that characterizes

Indian cities, along with bigger household sizes and lower concentration of vehicle ownership (though on a steep rise) have been identified as positive factors in the low emissions profile. These socioeconomic and urban design characteristics need more focus to promote such low carbon indigenous measures.

The GHG per capita over the five-year study period rose at a considerably faster rate than the population growth. However, compared to the GDP growth, emissions show a diverging trend. This points to a positive trend of emissions decoupling from economic growth. Yet other socioeconomic factors can be said to contribute to the higher rate of emissions increase as compared to population.

A key trend can be seen through the transport emissions – Transport has the highest growth rate of all sectors with a phenomenal increase in private vehicle ownership. Rise in per capita income and the increasing competitiveness of the vehicle finance industry might explain this rise in private vehicle ownership as more people can afford it. Moreover, a lack of good public transportation acts as key stimulus for people to look for private transport.

Emissions management policies are demonstrated to have associated socio-economic benefits driving the city towards a more sustainable growth path. For instance, a higher collection efficiency for waste as well as proper disposal, will also mean cleaner neighbourhoods, fewer instances of vector borne diseases, less land, air and water pollution and thus, an overall better quality of life.

Whilst numerous cities in developed countries are adopting GHG inventories as strategic policy tools, the same is not true for cities in developing countries. The thesis also aimed at finding the barriers to the successful use of GHG inventories as policy tools in Indian cities by investigating the process of collecting data, performing an inventory and assessing policy implications of the analysis. The following discussion presents in brief the major barriers identified throughout the process including methodological and institutional hurdles as well as knowledge barriers.

The conclusions in this section have been discussed as per the study sections of process, inventory, and applications.

Most urban GHG studies focus on the methodology of conducting an inventory or discuss its results and policy implications. Although, they recognize the local contextual problem of data availability, few have attempted to document the process of collection. A detailed documentation of the process, though case specific, lays the foundations for streamlining it.

The process study pointed to two major issues – Lack of Knowledge, and Governance issues.

During the data collection process, a lot of delegation of task and lack of interest in the reason for data collection was noticed. Whilst employees were aware of the concepts of carbon footprints and efficient use of energy, it did not feature in their priorities. The only answer for anything in the general area of study was met with a reference to the solar cities initiative.

It can be seen from cities in the developed countries using the tool that the key to its success is an aware government that takes up a stand. Hence, this apathy among government employees is one of the biggest hurdles to be identified, pointing to a need for a knowledge update among the employees and to make them more aware of the importance of Climate Change initiatives at the local government level.

A key observation was that most of the reliable data sources were linked to revenue. For electricity, it was the sales data; similarly for fuel use, the kerosene allocation and LPG sales, for transport the number of on road vehicles comes from the vehicle tax records whereas for agriculture it was the cultivation area and urea sales. In the waste and land use sector, there are no such revenue systems linked to waste generation or changes in land use. Although property tax does exist, it is insufficient to estimate the change in land use type. The land use survey is typically conducted only when preparing the master plan and no system is in place to monitor annual land use changes.

The presence of a number of parastatal agencies presented a perplexing environment with no clear boundaries of the roles and responsibilities allocation. As such, there were problems with locating the right agencies for the data collection. It will be noteworthy here to state that this situation with the presence of parastatal bodies taking over the jurisdiction of the municipal corporation is more pronounced in Dehradun owing to it being a new state capital. The contested grounds of roles and responsibilities among municipal corporations and agencies like city development authorities are often present in Indian cities. So whilst in this case the problem may be present to a higher degree, its presence in other cities cannot be disregarded. Once the right agencies were established, the collection itself required multiple visits and follow ups at most agencies to finally get access to the data. Thus, though the current governance structure is not prohibitive in the creation of an inventory, a governance reform is much called for.

A clear structure to the governance of a local authority would have multiple benefits –

1. The roles and responsibilities of each level will be well defined to increase accountability of the various agencies.
2. The data collection time and the data quality will both benefit from a well-structured local government.
3. Executive decision making powers can be allocated to appropriate agencies for planning and implementing carbon mitigation policies.
4. The financial status of the local authority can be improved.

The lack of metadata and interest from the employees both point to problems with the governance of local authorities. The first is caused by organizational inefficiency; and the second indicated a lack of awareness. The lack of coordination between the various agencies is an issue. Since the creation and maintenance of the inventory requires inputs from many agencies, coordination between them is important.

Inventory – On the methodological front, it has been demonstrated by this case study that a carbon inventory in the existing scenario although not as comprehensive as may be desired, is nevertheless possible. Even where recommended IPCC data is unavailable there are alternative methodologies using different data sets that can be employed to fill the gap. With the exception of land use changes, the data was mostly found and was in a format that could be used for the calculations. Only with the transport emissions and cooking fuel use, an alternative methodology had to be followed to convert available data in to a usable format. For the buildings fuel use sector the census data of fuel choice by household was converted to estimated activity data using average fuel demand per household from regional studies whilst for the transport sector too, the vehicle Kms travelled were estimated using regional studies and the number of on-road vehicles in the City.

The quality of data though, leaves much to be improved. The use of defaults Emissions Factors or tier 1 calculations can be improved to tier 2/3 levels. The disaggregation of data with the sectors can be improved. For example, in the case of electricity use data, the institutional category has not been disaggregated. Especially concerning the case study city, which is a hub of educational and administrative institutions, this category is important and must be addressed separately.

The geographical boundaries too must be commonly recognized and followed by all agencies. In the current case the inclusion of Mussourie in the electricity sale data, tends to reduce the quality and reliability of the data. Hence, it is desirable to define the municipal boundary as a standard among all the agencies.

Application – The application of a GHG inventory as a strategic policy tool in cities in developing countries can have multiple benefits. Although the analysis shows that the city does not have very high emissions, it also identifies a rapid increasing trend in the emissions. This reinforces the need to monitor the emissions and their growth trends to timely introduce policies in order to manage the emissions profile from the city. This will save the city from additional costs of employing sustainability practices at a later stage.

For instance, the transport sector which is the major contributor of emissions in the city, has been showing a rapid growth in five years. Further analysis points to a rapid increase in private vehicle ownership. If the trend is left to continue, the vehicle population in the city will present much greater problems in the future to manage both in terms of emissions as well as traffic congestion, air pollution, accidents and related problems. However, if suitable measures are taken now, to improve public transportation and employ policies that discourage vehicle ownership, the city can grow in a more sustainable manner, with better accessibility, lower pollution and many such socio-economic benefits.

A lack of clear roles of the governance structure makes it difficult to assign the responsibility of the inventory. Moreover, it needs to be maintained by people/organization, which has powers to formulate and implement policies for it to be actually useful. This presents a barrier in the successful application of the tool for policy.

9.1.1 Recommendations

The major recommendations from this research can be summarized as follows –

The benefits of using a GHG inventory as a policy tool are multifold as showcased in the applications chapter. As such, the city government must maintain the inventory with regular updates and use it to inform policy and monitor impacts.

The local governance system must be reformed to improve the governance and resolve the problems associated with decision-making and roles and responsibilities as well as improve data collection and quality.

Measures should be taken to increase awareness among the stakeholders of the impacts of climate change and what can be done to mitigate and adapt.

Transport and energy use in buildings are the key sectors to introduce emissions reduction policies. The role of institutional buildings in the city is very important and their emissions profile must be further investigated and targeted through policy.

The CDM potential of reducing emissions from waste must be explored.

9.1.2 Limitations

As with any research, there are limitations to this work. One of the limitations is that the work is based on a single case study and hence has a much-limited scope. It is hard to conclude the potential of its applicability in other cities.

Emissions from land use changes could not be calculated. Moreover, the scope of the research was also limited in terms of the sectors used and gases considered for the emissions profiling. Although reasonable arguments are presented for these choices, a thorough inventory would include the exclusions.

The case of embodied energy and related emissions was also recognized as an important issue but the time and data availability constraints made it prohibitive to include it in the scope of this thesis.

9.2 Research Significance

The intent of this research was to increase awareness among Indian local authorities of carbon reduction in urban management. Inferences from this research aim to demonstrate the usability of GHG inventories within the existing scenario of constraints and its potential benefits to the Local Authorities to focus on and enforce CO2 mitigation measures to spearhead sustainability.

The use of the inventory as a policy tool will also aid authorities to measure and monitor carbon reduction and use the Clean Development Mechanism (CDM) potential to raise revenue making it financially attractive to Local Authorities that are usually working on deficient budgets. It will help Local Authorities contribute towards achieving the 20-25% reduction target set by India for 2020.

A better understanding and early awareness of climate change and its impacts will allow the authorities to plan the adaptation measures and be well prepared for any eventualities.

Many carbon reduction policies will also have positive socioeconomic benefits for the city. For example, creating more carbon sinks within the city by introducing green spaces will create more vibrant and healthy communities; introducing and promoting local renewable generation will promote energy self sufficiency and reduce energy poverty whilst also providing the citizens with an opportunity to sell the excess energy to the grid, or by planning walkable neighbourhoods, apart from reducing transport dependence and associated emissions, the health and safety within the community will also be positively affected.

Thus, well-designed carbon reduction policies can be used to spearhead sustainable development in local authorities.

The research adds to the existing body of literature in the field by focusing on the process analysis and adding detail to the understanding of the role of governance structure on policymaking and the adaptation of policy tools. The research identifies that global benchmarking should perhaps not be considered as a key goal in designing inventories, since the wide deviation in inventory results among developed and developing nations only serves to discourage local authorities from taking action. Rather, focusing on the local issues and highlighting the associated socioeconomic benefits will encourage more authorities to adopt the process.

The diverging relationship between GDP growth and Emissions growth found in the research is a key finding that opens further areas of research to understand the dynamics of emissions in cities.

9.3 Further Research

There is a need for more case studies to streamline the process. More case studies will also test the replicability of the methodology. Two key research areas identified were to test the declining emissions growth rate finding in other cities and also explore the reasons behind this trend. There also needs to be more research focus on the underlying drivers of emissions in cities to target policies to decouple growth from emissions.

The relationship between GDP/cap and Emissons/cap also warrants further research with a larger data set to test the Environmental Kuznets Curve (EKC) hypothesis in the case of emissions from cities. The role of embodied energy as part of the city emissions has also been identified in this study as an important area that has not received enough research focus. Another research direction will be to document the usefulness of an inventory as a policy tool and the success of policy measures.

As a final concluding remark, it can be said that with respect to the initial aims of the thesis, this work has demonstrated that it is viable to inventory GHG emissions from small – mid size Indian cities within the existing data and governance framework and without the recourse to large resource use. And that achievable policy targets can be formulated based on information from the inventory to bring significant benefits to cities in terms of improving their sustainability and contributing towards mitigating Climate Change.

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