IDENTIFYING OPPORTUNITIES FOR LOW CARBON EMISSION ZONES IN SOUTH AFRICA: A CASE STUDY OF DURBAN

by

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ABSTRACT

There is increasing attention on emissions reduction strategies that also deliver developmental co-benefits (i.e. low carbon development), especially in developing cities, thus research on the links between emissions, spatial planning, and urban development are emerging. The majority of studies on emissions inventories lack integration with strategic spatial planning, which is critical for place-based mitigation strategies. In response to this gap, a bottom-up methodological framework for the spatial representation of emissions was developed, based on the consumption perspective, to identify high emission zones and assess their urban development goals. The framework was applied to Durban (eThekwini Municipality), which aims to become a low carbon city and is also representative of a developing city.

The total emissions calculated for Durban in 2013, was 12 219 118 tCO_2e, of which the road transport sector contributed the most to total emissions (43%), followed by industry electricity consumption (30%) A high emissions zone was identified along the coast, from Durban south, through the central business district (CBD) and the north to Umhlanga. Specifically, the areas with the highest emissions activities are from energy-intensive manufacturing industries in south Durban, and road transport, specifically private passenger cars, in central and north Durban. Furthermore, the highest emitting area, Prospecton, (767 172 tCO_2e), emitted ~ 6.5 times more than the Durban ward average (118 632 tCO_2e). Furthermore, Prospecton is highlighted for further port, fuel, chemical and petrochemicals, transport equipment manufacturing, and logistics development. The lowest emissions were from the rural edges, where the neighbourhoods emitted ~11 times less than the Durban average, which are also the areas with the most developmental needs, therefore highlighting the spatial disparity in emissions contribution within the city.

A three-pronged approach of specific mitigation measures are recommended to simultaneously reduce emissions and achieve development: (i) manufacturing industries in south Durban must invest in carbon offset projects in the rural periphery to ensure that the development of those areas are not associated with increasing emissions, (ii) the implementation of car-free roads in central and north Durban to reduce distances travelled by private cars and to also ensure the widespread use of the Integrated Rapid Public Transport

Network and other eco-mobility options, (iii) limit industrial expansion in south Durban and commercial and residential developments in north Durban which do not have a low carbon plan. Thus, the spatially-resolved emissions inventory generated emissions profiles which identified suitable mitigation strategies to assist with the transition to a low carbon city.

PREFACE

This thesis was completed at the School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, Westville campus, between March 2014 and December 2015 under the supervision of Dr Tirusha Thambiran and Dr Michael Gebreslasie.

The work contained in this thesis is my own, and where the work of other authors has been used, it has been acknowledged accordingly. This dissertation has not been submitted in any form for any degree or diploma to any tertiary institution.

Meryl Jagarnath

DECLARATION 1 - PLAGIARISM

I, ***Meryl Jagarnath***, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.

2. This thesis has not been submitted for any degree or examination at any other university.

3. This thesis does not contain other persons’ data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.

4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
   a. Their words have been re-written but the general information attributed to them has been referenced
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Signed: ……Jagarnath…………………………… date………4 December 2015……………

Meryl Jagarnath

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LIST OF ABBREVIATIONS AND ACRONYMS

AD	activity data
AFOLU	Agriculture, Forestry and Other Land Use
AIDS	Acquired Immune Deficiency Syndrome
ASSAf	Academy of Science of South Africa
BOD	biological oxygen demand
CAIA	Chemical and Allied Industries Association
CBD	central business district
CCP	Cities for Climate Protection
CCS	carbon capture and storage
CDM	Clean Development Mechanism
CH_4	methane
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalents
COP	Congress of Parties
COPERT	Computer Programme to Calculate Emissions from Road Transport
DCCS	Durban Climate Change Strategy
DDOP	Durban Dig-Out Port
DEA	Department of Environmental Affairs
DEFRA	Department of Environment, Food, and Rural Affairs
DEROs	Desired Emission Reduction Outcomes
DMOSS	Durban Metropolitan Open Space System
DoE	Department of Energy
DoT	Department of Transport

EEA	European Environment Agency
EF	emission factor
EIA	Environmental Impact Assessment
EM	eThekwini Municipality
eNATIS	electronic National Traffic Information System
EPA	Environmental Protection Agency
EPCP	Environmental Planning and Climate Protection
ESRI	Environmental Systems Research Institute
FOD	first-order decay
GDP	gross domestic product
GHG	greenhouse gas
GIS	Geographic Information Systems
GVA	gross value added
GVM	gross vehicle mass
GWC	growth without constraints
GWP	global warming potential
HDI	Human Development Index
HFCs	hydrofluorocarbons
HIV	Human Immunodeficiency Virus
IA	integrated assessment
ICLEI	International Council for Local Environmental Initiatives
IDA	Infrastructure Development Act
IDP	Integrated Development Plan
IEA	International Energy Agency
ILS	Industrial Land Strategy
INDCs	Intended Nationally Determined Contributions
INK	Inanda, Ntuzuma, and KwaMashu
IPCC	Intergovernmental Panel on Climate

	Change
IPPU	Industrial Processes and Product Use
IRPTN	Integrated Rapid Public Transport Network
ISO	International Organization for Standardization
IUDF	Integrated Urban Development Framework
JI	Joint Implementation
kg	kilogram
km^2	kilometres square
kWh	kilowatt hours
KZN	Kwa-Zulu Natal
LCA	life cycle assessment
LEAP	Long Range Energy Alternative Planning
LEZ	Low Emission Zone
LFG	landfill gas
LTDF	Long Term Development Framework
LTMS	Long Term Mitigation Scenarios
m	metre
M&E	Monitoring and Evaluation
MARKEL	Market Allocation Model
MCCP	Municipal Climate Protection Programme
MGHG-INT	modified greenhouse gas intensity
MMSCF	million standard cubic feet
MPA	Mitigation Potential Analysis
Mt	Mega tonnes
MW	megawatt
MWh	megawatt hours
N_2O	nitrous oxide
NAEIS	National Atmospheric Emissions

	Inventory System
NCCRP	National Climate Change Response Policy
NDP	National Development Plan
NF_3	nitrogen trifluoride
NGO	non-governmental organizations
NO_x	nitrous oxide
PFCs	perfluorocarbons
PICC	Presidential Infrastructure Coordinating Commission
PM	particulate matter
ppm	parts per million
RBS	required by science
RTMC	Road Traffic Management Corporation
SA	South Africa
SAPREF	South African Petroleum Refinery
SDB	South Durban Basin
SDB-MPP	South Durban Basin Multi-Point Plan
SDCEA	South Durban Community Environmental Alliance
SDF	Spatial Development Framework
SDIB	South Durban Industrial Basin
SDP	Spatial Development Plan
SEA	Strategic Environmental Assessment
SF_6	sulphur hexafluoride
SIP	Strategic Integrated Project
SO_2	sulphur dioxide
SPLUMA	Spatial Planning and Land Use Management Act
StatsSA	Statistics South Africa
tCO_2e	tons per CO_2 equivalents
UDL	Urban Development Line

UK	United Kingdom
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
VKT	vehicle kilometres travelled
W/m^2	watts per square metre
WMO	World Meteorological Society
WRI	World Resources Institute
WWTP	wastewater treatment plants

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CHAPTER 1: INTRODUCTION

1.1 Background

Climate change, attributed to the release of greenhouse gases (GHGs) caused by human activities, has emerged as one of the most challenging issues that humanity faces, as it manifests itself at both the local and global scale. Thus, feasible strategies and policies to address climate change require the synchronization of various institutions and frameworks for the international, local and sectoral levels (Biesbroek *et al.*, 2009). According to the Intergovernmental Panel on Climate Change (IPCC, 2013), the impacts associated with climate change are direct, such as global temperature increase and exposure to extreme weather events, and indirect, as climate change will exacerbate already existing challenges such as poverty, disease outbreaks, food insecurity and water scarcity (Revi *et al.*, 2014). Therefore it is vital to not only adapt to the impacts of climate change but also limit the cause that is anthropogenic sources of GHG emissions.

The majority of climate change studies are on impacts and future emissions forecast (Bastianoni *et al.*, 2004; Ezcurra, 2007; Hamin and Gurran, 2009). There is a growing move towards the development of low carbon, resilient cities but there are few studies on the spatial distribution of carbon dioxide (CO_2) and other GHG emissions even though it is vital for developing, implementing and assessing policies (Bulkeley, 2006; Ezcurra, 2007; VandeWeghe and Kennedy, 2007; Dulal *et al.*, 2011; Williams, 2012; Zhang *et al.*, 2013; Jones and Kammen, 2014; Konstantinaviciute and Bobinaite, 2015). Furthermore, studies on CO_2 emissions are important in climate change negotiations on emissions attribution, as protocols that are perceived as unequitable will not be ratified (Beg *et al.*, 2002; Ezcurra, 2007; Huang and Meng, 2013; Lu, 2014).

The concentration of population, economic activities, and built environments in cities[1] are responsible for the high rates of GHG emissions from resource consumption and waste production (Bulkeley and Betsill, 2005; Hallegatte *et al.*, 2011), and also increases risk to vulnerabilities, such as flooding and heat waves, which will increase in intensity (Wilbanks *et*

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[1] City, urban, local government, local scale, municipality, and metropolitan are considered similar and used interchangeably.

al., 2003; Satterthwaite, 2010; Romero-Lankao and Dodman, 2011). Thus, there is a consensus (Sperling and Cannon, 2006; Dhakal, 2010; Satterthwaite, 2010; Hoornweg *et al.*, 2011; Seto *et al.*, 2014; Jabareen, 2015) that the long-term solution for climate change requires the complete transformation and planning of cities from "hotbeds of GHG emissions and vulnerability to seedbeds of sustainability and resilience" (Romero-Lankao and Dodman, 2011; p. 113), which can be achieved through innovative mitigation and adaptation strategies (Satterthwaite, 2010). The low carbon city concept is prevalent amongst urban planners and city governments (Lehmann, 2013), to reduce emissions from production and consumption, whilst securing a high quality of life for all citizens (Ho and Fong, 2007; Dhar *et al.*, 2013; Yang and Yanan, 2013).

Responses to global warming and climate change focus on international, regional and national scale (IPCC, 2013; Seto *et al.*, 2014). However, in the last decade, research and policy have placed importance on urban GHGs (Betts, 2007; Dhakal, 2010; Satterthwaite, 2014; Seto *et al.*, 2014). Expert reports, such as Stern (2008), called for urgent carbon emission reductions from cities, and the IPCC Fifth Assessment Report (IPCC, 2013) highlighted the need for more coverage on issues of urban carbon mitigation. Currently, more than half of the world's population live in urban areas and this number is expected to grow, by the United Nations (UN, 2014), to more than 66% of the global population residing in cities by 2050.

The urban transition (change from being predominantly rural to increasingly urbanized nations) has now switched from Europe, North and South America to Africa and Asia, where the middle to low income nations are located (Romero-Lankao and Dodman, 2011; UN, 2014). Thus, the share of emissions from developing cities is expected to increase (Cai and Zhang, 2014). The priorities of developing cities are economic growth and service delivery (Dhakal, 2010; Dulal and Akbar, 2013; Garibaldi *et al.*, 2014; Jabareen, 2015), with pro-poor and environmental strategies receiving less attention, thus causing conflicts (Hannan and Sutherland, 2014).

Due to uncertainties associated with the future, the developmental decisions that are made now have the potential to cause maladaptation's, where activities result in increased GHG emissions, risk, and vulnerability (Barnett and O'Neill, 2010). However, most of the development in emerging economies are occurring or yet to occur so the resilience of cities can be enhanced through adaptation and mitigation initiatives, achieved by effective urban planning, thereby delivering additional benefits, or co-benefits (Beg *et al.*, 2002; Campbell, 2006; Dhakal, 2010; Dulal and Akbar, 2013; Cai and Zhang, 2014). This is demonstrated by many cities, even developing nation cities, where urban climate change mitigation actions have been led by the local government municipals and related city networks (Dhakal, 2010; Romero-Lankao and Dodman, 2011).

1.2 Motivation

Atmospheric carbon dioxide (CO_2) concentrations greatly exceed the natural range of 180-300 parts per million (ppm) (Dulal *et al.*, 2011), with the current (2015) concentration at 400 ppm (Huisingh *et al.*, 2015). Therefore, it is essential to explore all possible strategies to reduce GHG emissions. The combustion of fossil fuels for energy and transport, and the generation of waste are the main contributors to GHG emissions (IPCC, 2013). Furthermore, the activities which emit GHG are distributed disproportionately in space.

Globally, developed countries, which contain 20% of the world's population, are responsible for 46.4% of GHG emissions and developing countries are home to 80% of the world's population and contribute 53.6% of GHG emissions (Dodman, 2009a). It is estimated that up to 80% of global GHG emissions are attributed to cities, thus highlighting the disparate contribution of cities to global emissions when compared to their extent (Hoornweg *et al.*, 2011). There are also spatial differences in GHG emissions within countries and cities, due to variable industrial, development, social, economic, and natural conditions, and this motivates for tailoring mitigation efforts to those differences (VandeWeghe and Kennedy, 2007; Dodman, 2009a; Dhakal, 2010; Knuth, 2010; Chuai *et al.*, 2012; Yu *et al.*, 2012; Dulal and Akbar, 2013; Garibaldi *et al.*, 2014; Jones and Kammen, 2014; Seto *et al.*, 2014; Winkler, 2014; Zhang *et al.*, 2014). Additionally, the impacts, effects, resources, and responses of countries and cities to climate change are disparately distributed in space (Aylett, 2010; Stone *et al.*, 2012).

The United Kingdom (UK) Department of Environment, Food, and Rural Affairs (DEFRA, 2010) emphasized identifying the spatial location of emissions to determine low emission zones (LEZs). LEZs are the geographic areas where the low emission strategy is applied

(DEFRA, 2010). A low emission strategy is a broad package of measures to mitigate the impacts of development and complement other mitigation options such as planning and infrastructure (DEFRA, 2010). Therefore, the quantity of GHG emissions and associated spatial distribution of emissions from the various sectors are identified through the compilation of an emissions inventory (VandeWeghe and Kennedy, 2007; Knuth, 2010; Qin and Xie, 2011; Hillmer-Pegram *et al.*, 2012; Yu *et al.*, 2012; Jones and Kammen, 2014), as is the case for air pollution (Hsu *et al.*, 2013). This information assists policy makers and city planners to make informed decisions about mitigation strategies and action; to focus on reducing large emitters and develop place-based mitigation strategies and infrastructure improvements for urban development (Knuth, 2010; Jones and Kammen, 2014; Baur *et al.*, 2015), and thus facilitate low carbon city planning.

Overall, research on GHG emissions calculations are in its early development and requires further and urgent research so that approaches can be improved (Chuai *et al.*, 2012; Lesiv *et al.*, 2014). The majority of studies undertaken on GHG emissions are focused on the national scale with few studies on the local scale, of which the majority are for cities in developed countries (Kates *et al.*, 1998; Grazi and van den Bergh, 2008; Carney and Shackley, 2009; Chuai *et al.*, 2012; Jones and Kammen, 2014; Seto *et al.*, 2014; Baur *et al.*, 2015; Feng *et al.*, 2015). Furthermore, Simon and Leck (2015) noted that climate change research for African cities were disjointed, lacked consideration of the links between urban, rural, and peri-urban, and often addressed a single topic focused on a specific location or community within a city. In addition, some view that cities are not doing their fair share of the work to achieve the binding mitigation targets and, with increasing emissions, they are hindering progress by making the target less achievable (VandeWeghe and Kennedy, 2007). Although cities have increasingly unsustainable resource usage rates they can become centres of low GHG emissions with high standards of living with the correct guidelines, policy and implementation.

South Africa (SA) is the 13th highest CO_2 emitter in the world and the largest CO_2 emitter in Africa. SA's CO_2 emission per capita is between 9.22-9.9 tons of CO_2 equivalents (tCO_2e) (Winkler, 2009; DEA, 2011c) and much greater than the world average of 4.9 tCO_2e per capita (Singer *et al.*, 2014). SA's high carbon emissions are due to the energy-intensive economy reliant on fossil fuels (Raubenheimer, 2011). Additionally, the vast majority of SA's electricity supply is generated from coal, synthetic petroleum, and diesel with renewable energy generation nominal (Eskom, 2014). This must be noted in the context that many South African households do not have access to electricity and other basic services.

In SA, GHGs have been recently declared as priority air pollutants by the Department of Environmental Affairs (DEA) and activities that produce an excess of 0.1 Mega tonnes (Mt) of emissions annually will have to produce an air pollution prevention plan (DEA, 2014a). Areas with high air pollution emissions are considered priority areas and therefore areas of high GHG emissions and emitting activities should also be considered as such. Cities have a pivotal role in mitigating climate change, through the role of local government strategies and policies, in reducing polluting activities and implementing GHG reduction policies and programmes (Lazarus *et al.*, 2013). Thus, South African cities will need to play a key role in achieving the legally binding GHG emission reduction targets of 34% by 2020 and 42% by 2025 as well as deliver development, redress Apartheid inequalities, and promote socio-economic growth whilst maintaining a healthy and safe environment (DEA, 2011b; DEA, 2014b; Winkler, 2014). Therefore there is a need for detailed information to target emissions reduction effectively (Ramachandra *et al.*, 2015) that will deliver additional benefits to South African local development goals and improve quality of life.

Durban[2] endeavours to become a low carbon city and is considered a leader in South Africa with climate change mitigation efforts (Roberts, 2008; Aylett, 2011; Roberts, 2013; Roberts and Donoghue, 2013; Walsh *et al.*, 2013). Durban has produced GHG emissions inventories on an annual basis since 2010 (EM Energy Office, 2012), however, these emissions are not spatially allocated and do not inform development planning and mitigation actions in the city. Thus, given the importance of aligning mitigation strategies with development (Dulal and Akbar, 2013; Garibaldi *et al.*, 2014; Winkler, 2014), this study focuses on the compilation of an emissions inventory with a spatial focus to identify the sources and sectors that contribute the most to emissions, and the implications for low carbon development.

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[2] Durban and the eThekwini Municipality (EM) share the same geographic and administrative boundary, and are used interchangeably. Durban is the city name and eThekwini is used in official documents (Sutherland *et al.*, 2013).

1.3 Aims and Objectives

The aim of this study is to identify the spatial distribution of anthropogenic GHG emissions in Durban, thus providing an indication of high carbon emission zones, thereby planning and development of low emissions zones can be spatially focused in order to achieve the goal of a low carbon city.

Research Question

- What are the opportunities for using emission inventories to inform low carbon spatial planning at a local scale in South Africa?

The specific objectives are:

(i) Develop a conceptual framework for the attribution of GHG emissions.
(ii) Create GHG emissions inventories for the energy, transport and waste sectors for Durban.
(iii) Explore the spatial distribution of emissions using Geographic Information Systems (GIS).
(iv) Identify high emission areas in Durban and, in conjunction with city development priorities, assess the opportunities for mitigation.
(v) Provide recommendations to reduce emissions in order to facilitate the planning of a low carbon city.

1.4 Thesis Structure

Chapter 2 comprises the literature review of the linkages between GHG emissions inventory and spatial planning, and also highlights the relevant policy in South Africa. Chapter 3 details the research design including the conceptual framework developed for this study, focusing on the key sectors underlined in the literature review and the methodological approach which discusses the scope of this study, data sources, and analysis applied. The results and discussion are provided in Chapter 4. Chapter 5 provides an overview of the key findings of the study within the context of the aim and objectives, and presents recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Climate change is a cross cutting issue, particularly relevant in the developing city context, that has the potential to present benefits and challenges to policy-makers. This review focuses on the linkages between GHG emissions inventory and spatial planning from a mitigation perspective. Specifically, the major international mitigation agreements are highlighted, as well as the significance of the local scale as the appropriate scale to formulate and implement mitigation actions. The various concepts, methods and challenges associated with compiling an emissions inventory and spatial planning at the local scale are reviewed. In order to compare emissions from different methods, cities, and sectors, emissions indicators are required. The most commonly used emission indicators are discussed. Thereafter, South African policies on emissions mitigation, specifically emissions inventory and spatial planning are reviewed.

2.2 Climate Change Mitigation

Over the past century, the global average temperature has increased by 0.84°C, with a range of 0.65°C to 1.02°C (IPCC, 2013). The earth's climate is influenced by various factors, such as solar radiation, the reflectivity of earth's surface, clouds, fine particles, and GHG concentrations in the atmosphere. GHGs are the natural and anthropogenic gaseous components of the atmosphere that absorb and emit radiation at specific wavelengths within the thermal infrared radiation spectrum emitted by the Earth's surface, atmosphere, and clouds, thus causing the greenhouse effect.

The greenhouse effect warms the earth to a habitable temperature for all life forms, however the increasing concentration of GHGs, due to anthropogenic activities, have modified the natural effect. The GHGs that contribute the most to global warming are CO_2, methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), and halons, such as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs), which are known as the Kyoto gases. Furthermore, in 2013, nitrogen trifluoride (NF_3) was designated a major GHG due to the observed high atmospheric concentrations, which were previously thought to be minimal (GHG Protocol, 2013). GHGs are measured in global warming potential (GWP), which is the contribution of a mass of GHG to global warming, compared to the same mass of CO_2 over 100 years. CO_2e emissions refer to the amount of CO_2 emissions that would cause the same amount of radiative forcing. Radiative forcing is the change in net vertical irradiance, in watts per square metre (W/m^2) between the boundaries of the troposphere and stratosphere (IPCC, 2013). There is considerable variability in GHG lifetimes, their contribution to warming, and their sources (Table 2.1; p. 9). CO_2 has received crucial attention because fossil fuel combustion directly adds CO_2 into the atmosphere and has a larger greenhouse effect than other GHGs. SF_6 and halons are synthetic GHGs, known as 'super GHGs' due to their long lifetimes and strong radiative forcing, produced by the chemical industry since 1930 (Ramathan and Feng, 2009).

There is consensus in the literature that both mitigation and adaptation measures are needed to combat climate change and ensure resilient communities (Haman and Garran, 2009; Puppis de Oliveira, 2009; IPCC, 2013). Mitigation involves the reduction of GHG emissions and adaptation entails the reduction of climate change impacts (Biesbroek *et al.*, 2009). Most of the focus is on mitigation, as emissions are quantified, thus producing measurable targets and monitoring when compared to adaptation (Biesbroek *et al.*, 2009; Puppim de Oliveira, 2009; Ho *et al.*, 2013). However, mitigation strategies are long-term whereas adaptation strategies can be implemented in the short and medium-term (Hamin and Gurran, 2009). Successful mitigation requires the co-ordination with other disciplines, sectors, and scales (Biesbroek *et al.*, 2009), but is considered an international and national issue, due to the global and stock nature of GHG emissions, and the effects of local mitigation actions are difficult to conceptualise (Wilbanks *et al.*, 2003; Moriarty and Honnery, 2015). Furthermore, even if a country or city achieves their emissions reduction targets, it will be futile if others do not do the same, thus decreasing the motivation for mitigation policies and actions (Moriarty and Honnery, 2015). Therefore, to ensure the wide-scale undertaking of mitigation actions, Garibaldi *et al.* (2014) motivated for mitigation actions to be linked with developmental objectives.

Table 2.1 The major GHGs and their sources, lifetime, and GWP. Adapted from Ramanathan and Feng (2009) and IPCC (2013).

GHG	*Main anthropogenic source*	*Lifetime (years)*	*Radiative Forcing (W/m^2)*	*GWP (100 years)*
CO_2	Fossil fuel combustion, deforestation, cement and lime manufacture	Unspecified	1.68	1
CH_4	Agriculture, landfills, biomass burning	12	0.97	28
N_2O	Fertilizer use, fossil fuel combustion	114	0.17	265
HFC	Refrigerants, air conditioning, propellants	1.4-270	0.34	116-12400
Other halocarbons	Refrigerants, air conditioning, propellants	10000-50000	0.34	5700-11000
SF_6	Refrigerants, air conditioning, propellants	3200	0.34	23500
NF_3 (nitrogen trifluoride)	Electronics manufacture, PFC replacement	740	0.21	16100

2.2.1 International Agreements on Climate Change Mitigation

Attention was first drawn to global warming and climate change at the ‘World Climate Conference’ by the World Meteorological Society (WMO) in 1979, which highlighted the concern that human activities may cause substantial changes in regional and global climate and this information must be included in planning for development. The 1987 Brundtland Report highlighted sustainable development and the acknowledgement of the sustainable cities concept, which emphasized the role that cities play in addressing environmental issues, especially climate change (Bulkeley and Betsill, 2005). In 1988, the WMO and the UN Environment Programme (UNEP) formed the IPCC to provide the current state of scientific knowledge on climate change and its’ associated environmental and socio-economic impacts (IPCC, 2013). Thus, it is recognized that the focus on climate change should not only be on the science but also the socio-economic and political contexts (Aylett, 2010).

At the 1992 Rio de Janeiro Earth Summit conference on sustainable development, the UN Framework Convention on Climate Change (UNFCCC) was formed as 189 countries endorsed voluntary GHG emissions reductions, which later became mandatory under the Kyoto Protocol in 2005 (Sperling and Cannon, 2006; Couth and Trois, 2010). The purpose of the UNFCCC is to stabilize GHG concentrations at a level that would prevent dangerous anthropogenic interference with the climate system whilst also allowing systems to adapt (UNFCCC, 2014). However, there is no indicator of what is ‘dangerous’, thus it is left to policy makers to make informed decisions based on the best available knowledge (Fuglestvedt *et al.*, 2010; Dhar *et al.*, 2013). The highest authority in the UNFCCC is the Congress of Parties (COP), which reviews current agreements or adopts new ones. Under the UNFCCC, industrialized countries, known as Annex I countries which have ratified the Kyoto Protocol, have to regularly report their climate change policies and submit annual GHG emissions inventories from the base year (usually 1990) and subsequent years. Developing countries (non-Annex I countries) are required to report generally on their climate change mitigation and adaptation actions however, this is dependent on funding, especially for least developed countries (Sookun *et al.*, 2014).

The Kyoto Protocol also provides three flexible mechanisms for Annex I countries to achieve binding targets to reduce GHG emissions: (i) carbon trading, (ii) the Clean Development Mechanism (CDM) and (iii) Joint Implementation (JI). The CDM projects allows the carbon emissions reduction achieved in non-Annex countries, to be allocated to Annex I countries which have supported the project, of which the most popular project is the capture and combustion of landfill gas with energy generation (Couth and Trois, 2010).

The Kyoto Protocol represents the most comprehensive action on climate change as it states climate change must be included in all policy and planning, made provisions for market based approaches, flexible in allowing countries to meet commitment targets in any way they decide, seen as fair due to the principle of common but differentiated responsibility, and also provides a source of funding for sustainable development in non-Annex I countries (Bumpus and Liverman, 2008; Aldy and Stavins, 2010). However, there are various criticisms (Sperling and Cannon, 2006; Aldy and Stavins, 2010) as there are no penalties for non-compliance (Yang and Yanan, 2013), as many big emitters, such as United States of America (USA), have not ratified the agreement. The fastest-growing emerging economies, which are associated with increasing emissions and intense deforestation, did not set emission targets (Aldy and Stavins, 2010). Furthermore, the basic assumption is that the economy of a country is independent of another country's economy, which does not apply with the current global economy (Moghaddam *et al.*, 2013). The flexibility of the Kyoto Protocol has created opportunities for compliance without reducing emissions, such as developed nations reducing their emissions by shifting carbon-intensive production to emerging economies, which is known as 'carbon leakage', that has occurred during the de-industrialization of Europe (Moghaddam *et al.*, 2013; Geels, 2014). The flexibility also resulted in countries aiming to reduce emissions intensity, which is the easier than reducing absolute emissions (Stern and Jotzo, 2010; Cansino *et al.*, 2015).

The distinction between absolute targets and intensity targets are important. An absolute emission target commits to reducing total emissions by a specific amount whereas reducing emission intensity is the decrease of CO_2 emissions per unit economic activity, such as gross domestic product (GDP) (Lin *et al.*, 2014). However, carbon intensity reduction does not guarantee a decrease in overall total emissions, as demonstrated by industries in China (Lin *et al.*, 2014; Liu *et al.*, 2014b). According to Lin *et al.* (2014), an absolute target reduction is viewed as unfeasible for developing countries, due to urbanization and industrialization;

therefore it is vital to reduce CO_2 emissions by reducing energy intensity and carbon intensity. Furthermore, emissions intensity does have value in focusing policies to target structural and technological change (Stern and Jotzo, 2010). However, as Levitt (2006) stated, any increase in GHG emissions from any sector or country is unsustainable, due to the stock nature of GHG emissions (Singer *et al.*, 2014).

Agreements for the Post-Kyoto period aims to restrict temperature increase by 2°C, which translates to stabilization of CO_2 concentrations at 450 ppm (IPCC, 2013). These agreements include the Copenhagen Accord 2009, the Cancun Agreement 2010, and the Lima Accord 2014 (den Elzen *et al.*, 2013; Lu, 2014), which were underlined by the key roles played by developing nations such as China, India, Brazil and South Africa (Lau *et al.*, 2012). Currently, there is a process to develop a protocol to represent a new binding climate agreement to be finalized in 2015 and implemented from 2020. Parties to the UNFCCC are required to prepare their Intended Nationally Determined Contributions (INDCs) (Höhne *et al.*, 2014), which presents what countries are willing to commit to adaptation and mitigation, and provides the foundation for the climate agreement negotiations in Paris in December 2015 (Levin *et al.*, 2015). Some important components of the INDCs concerning mitigation are: (i) the information used to calculate GHG emissions, such as base year and methods used, (ii) evaluation of the emission reduction targets (i.e., if they are fair and ambitious), (iii) and how the reduction targets help to achieve the UNFCCC goals (Höhne *et al.*, 2014; Lu, 2014). Thus, this highlights the importance of emission inventories to quantify emissions, across all scales and sectors to provide timeous information for setting emission reduction goals.

However, the other current agreements are also criticised for not being binding like the Kyoto Protocol. Specifically, there is no explicit requirement on how the temperature restriction is to be realized, lacks a global emissions limit, and countries still retain the freedom to set their own emissions reduction targets (Lau *et al.*, 2012). Furthermore, the financial, human, and resource capacity of developing countries are not significant issues in climate negotiations, even though it is a vital component which determines the success of emissions reduction or prevention of further emissions increase (Garibaldi *et al.*, 2014). Therefore, it must be noted that the current negotiated agreements fall short of what is required to reduce GHGs and limit average global temperature increase by 2°C (Lau *et al.*, 2012; Cam, 2013).

2.2.2 Local Scale Climate Change Mitigation

Development scholars and geographers maintain that sole focus on the international level climate agreements, with national commitments, to reduce emissions are limited as it does not provide context specific solutions for climate change action (Gupta, 2007). This is demonstrated by the lack of progress on international agreements (Singer *et al.*, 2014), which have led to the focus on the local scale for climate mitigation analysis and action, as it is difficult to comply with agreements by only focusing on the global or national scale (Bulkeley and Betsill, 2005; Holgate, 2007; Dhakal, 2010; Knuth, 2010; Hillmer-Pegram *et al.*, 2012).

A city is defined as the physical space with social, economic, and human development (Chen and Zhu, 2013). Cities are sites of high resource consumption and waste production (Bulkeley and Betsill, 2005; Hallegatte *et al.*, 2011) and directly impacts climate due to the warming effect on the near-surface atmosphere, known as the urban heat island effect (Mills, 2014). Broadly, sustainable development also encompasses the various aspects of the ecological, social and economic environment and inter and intra-generational equity (Hannan and Sutherland, 2014). The current warming experienced is due to past GHG emissions, hence our current decisions and emissions will affect future generations (Dulal and Akbar, 2013). With emissions reductions, the current generation will receive benefits in improved quality of life and it is in our best interest to act now according to the prevention principle, which will also benefit future generations.

Place-based mitigation is advocated as the environmental, socio-economic, and political conditions specific to a city influences emissions and thus determines the success of mitigation (Gupta, 2007; D'Avignon *et al.*, 2010; Glaeser and Kahn, 2010; Knuth, 2010; Villalba and Gemechu, 2011; Dulal and Akbar, 2013; Winkler, 2014). For example, airports and seaports, which are vital for the global economy, contribute significant amounts of emissions (Villalba and Gemechu, 2011) and climate mitigation plans are more likely to be taken up if the city has strong environmental values, and least accepted by cities with carbon-intensive industries (Zahran *et al.*, 2008). Specifically, local government can influence emissions through various ways through their functions, as it is responsible for infrastructure and service provision, land use by-laws and zoning, and interactions with other cities (Larsen and Hertwich, 2009; Hillmer-Pegram *et al.*, 2012; Lazarus *et al.*, 2013; Seto *et al.*, 2014). Notably, local government is closest to the people, and thus can influence citizens behaviour and be held accountable by citizens (Kates *et al.*, 1998; Bai, 2007; Aylett, 2010).

Demonstrations of successful local action are Local Agenda 21, which showed that cities are willing to achieve sustainable development agendas, and the International Council for Local Environmental Initiatives (ICLEI) Cities for Climate Protection (CCP), initiated in 1993, which is a global city network that facilitates municipal mitigation responses by providing technical assistance to develop emissions inventory, sharing of best practice, and technical and financial support (Wheeler, 2008). This is further revealed by states with ambitious targets such as California (USA) which aims to cut emissions 80% below 1990 level by 2050 and cities such as London (UK), with 60% reduction in emissions from 2000 levels by 2050 (Jabareen, 2015). Furthermore, per capita emissions have decreased in cities such as Berlin (Germany), Boston (USA), London, New York (USA) and Seattle (USA) (Kennedy *et al.*, 2012). However, this is countered by the lack of progress in emissions reductions, innovative measures, and public involvement in other developed cities even though they have joined these networks (Wheeler, 2008; Jabareen, 2015). In developing cities, these programmes place high administrative costs in already resource-poor local authorities (Bai, 2007; Aylett, 2011). Nevertheless, networks like these are vital especially when political and economic support are lacking from higher levels of government (Bulkeley, 2006; Wilson, 2006; Hoornweg *et al.*, 2011; Bulkeley and Betsill, 2013; Singer *et al.*, 2014). For example, the USA government rejected the Kyoto Protocol, yet 1017 American cities agreed to meet or exceed the mitigation targets of the Kyoto Protocol (Hoornweg *et al.*, 2011). Additionally, cities in developing countries cannot afford not to reduce emissions, as there are increasing global pressure, international agreements, and resource constraints.

However, economists argue that since countries and cities compete and are connected globally, there is a need for more international policies, thus local level actions are weak (Gupta, 2007). Even the UNFCCC does not recognize cities as stakeholders in the climate change negotiations (Roberts, 2013). Furthermore, only in the most recent IPCC Fifth Assessment Report were the roles of cities in adaptation and mitigation defined (Satterthwaite, 2014; Seto *et al.*, 2014). Small scale mitigation projects in cities have been successful (Aylett, 2011) however reducing emissions from large scale systematic causes, such as energy consumption, have not been achieved (Robinson, 2006; Lemon *et al.*, 2015).

Additionally, in developing cities, the capacity, resources, and jurisdiction of local government are limited (Bai, 2007; Aylett, 2011). Mitigation requires the influence of all stakeholders, however the role of local government is necessary but not sufficient (Satterthwaite, 2008). Therefore, it is argued that cities have a limited influence in reducing emissions due to macro-economic and structural factors in the city (Wilson, 2006; Bai, 2007; Holgate, 2007; Burch, 2010; Dhakal, 2010; Geels, 2014), for example, the city is a facilitator instead of an actor, increasing focus on the financial performance of the municipality, and the tendering of municipal utility service delivery to the private sector (Kocabas, 2013).

2.2.3 Low Carbon City

In order to stabilize GHG emissions, various development pathways and associated emission scenarios were developed by the IPCC (Nakicenovic *et al.*, 2000). A low carbon development scenario encompasses social, economic, and technological transitions to reduce emissions from both production and consumption (Dhar *et al.*, 2013; Yang and Yanan, 2013). A low carbon city is a vision for the future and is a combination of low carbon economy and low carbon society. The concept of low carbon economy was first proposed by the British government in 2003 to achieve economic development and job creation through cleaner production systems, and a low carbon society is focused on reducing emissions associated with consumption and lifestyle (Yang and Yanan, 2013). Globally, 110 cities have declared the development of a low carbon city (Lehmann, 2013).

The transition to a low carbon city is achieved through the adoption of a circular economy and clean industrial production, which reduces energy consumption, pollution, and GHG emissions, and recycles waste (Liu *et al.*, 2014b) and is compatible with sustainable development principles (Burch, 2010; Wang, 2011; Cam, 2013; Dhar *et al.*, 2013; Ho *et al.*, 2013; Garibaldi *et al.*, 2014). Thus, the focus is on consuming less resources, however, this approach ignores the situation that a large number of people in cities face the opposite challenge of access to resources to lead a decent life (Satterthwaite, 2009), as the urban poor in middle and low income countries do not have basic housing, energy, and sanitation. The goal of reducing emissions and working towards a low carbon city is important as the convergence concept assumes that regions with low CO_2 per capita emissions will eventually catch up with the regions with high CO_2 per capita emissions (Ezcurra, 2007; Huang and Meng, 2013; Moutinho *et al.*, 2014). Globally, this is also seen as low income nations achieving high growth rates due to the production of emissions-intensive goods and the slow growth rates of developed countries due to the production of cleaner goods (Ezcurra, 2007). This convergence is assumed in most emissions projection models (Huang and Meng, 2013). However, there is no clear definition of what constitutes a low carbon city, as well as how to measure the current situation and evaluate progress (Price *et al.*, 2013; Yang and Yanan, 2013; Zhou *et al.*, 2014). This is because the low-city concept is evolving as more research is undertaken and best practice is identified (Zhou *et al.*, 2014).

Amekudzi *et al.* (2011) identified two types of low carbon development. The first type has emissions reductions as the primary objective, with co-benefits, and the second type involves development as the primary objective and emissions reduction as the co-benefit. The second type of low carbon development is preferred, especially in emerging economies, because their first priority is economic growth (Dhakal, 2010; Dulal and Akbar, 2013; Garibaldi *et al.*, 2014; Jabareen, 2015). Chen and Zhu (2013) presented two classifications of low carbon city based on economics. From a macro perspective, economic development must be decoupled from energy consumption or CO_2 emissions (Figure 2.1; p. 17). The micro-economic point of view focuses on material flows to decrease resource use, increase use of renewable resources, and enhance carbons sinks (Chen and Zhu, 2013).

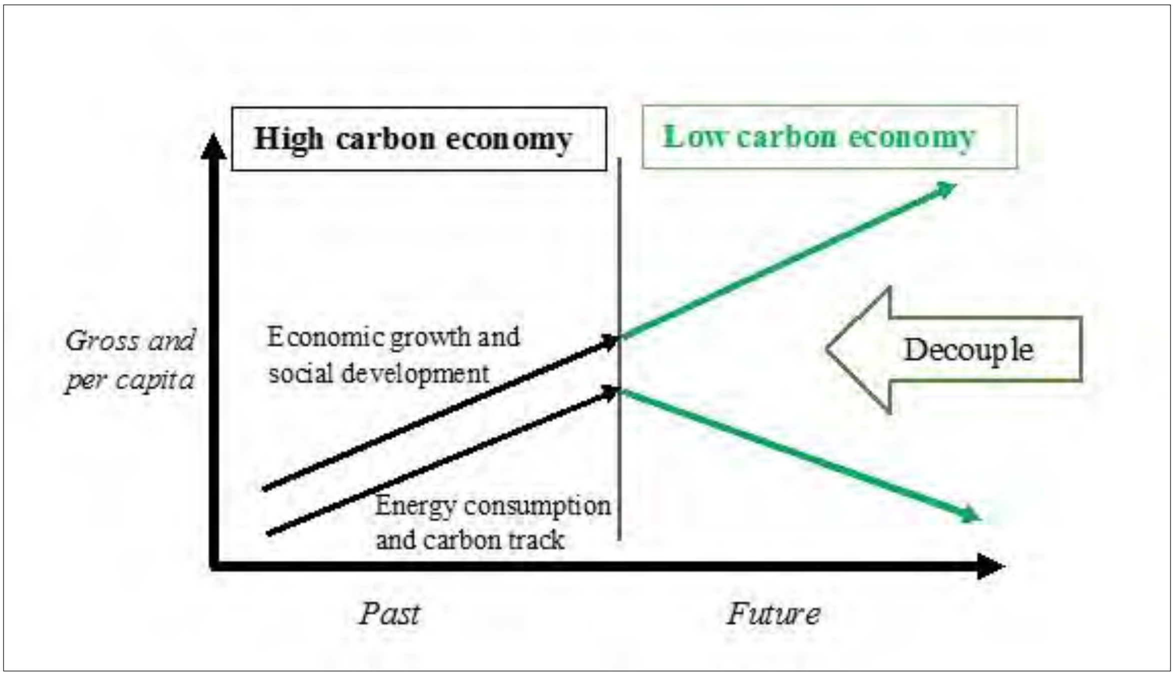


Figure 2.1 Coupling and decoupling of development from carbon emissions. Adapted from Chen and Zhu (2013).

The compact city is identified as a low carbon city because the spatial form can help in both climate change mitigation and adaptation (World Bank, 2010; Faling *et al.*, 2012; Seto *et al.*, 2014). A compact city is characterized by high densities of population and buildings, and high levels of mixed land use (Dodman, 2009b; La Greca *et al.*, 2011; Makido *et al.*, 2012; Ou *et al.*, 2013). This is due to observed trend that older, denser European and North American cities have lower air pollution and GHG emissions, especially from transport (Glaeser and Kahn, 2010; Liu *et al.*, 2014c), due to the city's spatial structure which determines location accessibility, modal choice, and the mobility of people and goods (Rode *et al.*, 2014).

Sprawling cities, which are a result of decentralization and geographic expansion, have low densities of people, buildings, and low land-use mix (Stone *et al.*, 2010). A main feature of sprawling cities are private cars, due to the outlying low-density suburbs, which results in high energy consumption and emissions because of increased car use and traveling distances (La Greca *et al.*, 2011; Romero-Lankao and Dodman, 2011; Gaigné *et al.*, 2012; Rode *et al.*, 2014). For example, in the USA, transport emissions are lower in compact cities such as New York and highest in sprawling cities such as Atlanta (Glaeser and Kahn, 2010). The compact city is also associated with residential energy efficiency and the increased use of public transport by households, which reduce fossil fuel consumption, and thus emissions, as revealed by Ou *et al.* (2013) and Makido *et al.* (2012) for Chinese and Japanese cities respectively.

However, the compact city also brings challenges when densities are too high. Increased densification concentrates urban activities which increases noise, reduces air quality, causes traffic congestion and the urban heat island effect, (Carsjens and Ligtenberg, 2007; Gaigné *et al.*, 2012; Makido *et al.*, 2012; Walsh *et al.*, 2013), overcrowding (Liu *et al.*, 2014c), and the loss of permeable surface and vegetation cover, thus potentially increasing flood risks (Hamin and Gurran, 2009). Simply understood, mitigation requires densification to reduce distances travelled and fuel consumption, however adaptation measures require open space for storm-water management, urban cooling, and biodiversity conservation (Hamin and Gurran, 2009). Therefore, this can lead to conflicts in addressing climate change and termed by de Roo (2000) as the ‘compact city paradox’. Thus, Muniz *et al.* (2013) argued that policies cannot be based on compactness alone.

When considering emissions and urban form, Heinonen and Junnila (2011) revealed that urban density in Finnish cities have a minimal effect on carbon emissions yet the cities have dense centres, diverse public transport whilst suburbs have lower building density and use more private transport. Furthermore, Makido *et al.* (2012) argued that the compact urban form limits flexible building design which uses natural lighting and ventilation. Studies on the benefit of compact cities are largely focused on the residential and transport sectors, and do not include the implications for waste management (Muniz *et al.*, 2013), the impact of industrial structure, technological advancement, and the role of institutions (Makido *et al.*, 2012; Qin and Wu, 2014).

As developing countries grow, the level of social inequality in the country also increases, which is further compounded by urban sprawl (Romero-Lankao and Dodman, 2011). Furthermore, Singh and Kennedy (2015) revealed, in a study of emission scenarios, if urban density stays the same as the rates for the year 2000 and the urban population increases, then by the year 2050, both electricity and transport emissions can double. Therefore, planners do have many reasons to adopt high density compact city planning due to the positive impacts on social equity, the environment and GHG mitigation (Dulal *et al.*, 2011; Seto *et al.*, 2014).

However caution must be applied so that densities are not too high (Muniz *et al.*, 2013). In developing cities, high densities are associated with informal settlements and negative health issues such as poor air quality, sanitation and improper waste management (Friedrich and Trois, 2011; Romero-Lankao and Dodman, 2011). Nevertheless, this is an opportunity for co-benefits, to simultaneously improve reduce GHG emissions and improve local and global conditions, through effective planning and policy (Romero-Lankao and Dodman, 2011).

Therefore, before establishing the opportunities in the city to reduce GHG emissions and identify co-benefits, it is important to quantify emissions from all sectors by producing an emissions inventory (VandeWeghe and Kennedy, 2007; Hillmer-Pegram *et al.*, 2012; Yu *et al.*, 2012; Jones and Kammen, 2014). This information assists policy makers and city planners to make informed decisions about reduction strategies, management systems and infrastructure improvement and thus facilitate low carbon city planning.

2.3 Emissions Inventory

Emissions are the physical transfer of material, across a boundary, from one compartment of the world to another, due to natural or human activities (Winiwarter and Schimak, 2005). In this study, emissions are the flows into the environment attributed to human activities and thus, can be regulated and limited by humans (Winiwarter and Schimak, 2005). An emissions inventory accounts for the anthropogenic emissions of place, system, or boundary for a specified time period (Hillmer-Pegram *et al.*, 2012). The purpose of atmospheric emission inventories are for: (i) regulation (with air pollution emission standards and the declaration of CO_2 and GHG as priority pollutants), (ii) compliance (with international air pollution and climate protocols), and (iii) inputs in air quality and climate change models to develop future scenarios and projections (Ferreira *et al.*, 2013).

According to the World Bank (2010) and the World Resources Institute (WRI, 2014), the compilation of emissions inventory is the first step in the shift towards low carbon development. An emissions inventory indicates the emissions-intensive sectors, so that emissions reduction plans can be developed and progress towards mitigation goals can be tracked (Figure 2.2; p. 20) (Dalvi *et al.*, 2006; Kennedy *et al.*, 2010; Hillmer-Pegram *et al.*, 2012; Ibrahim *et al.*, 2012; Yu *et al.*, 2012; Singer *et al.*, 2014; WRI, 2014).

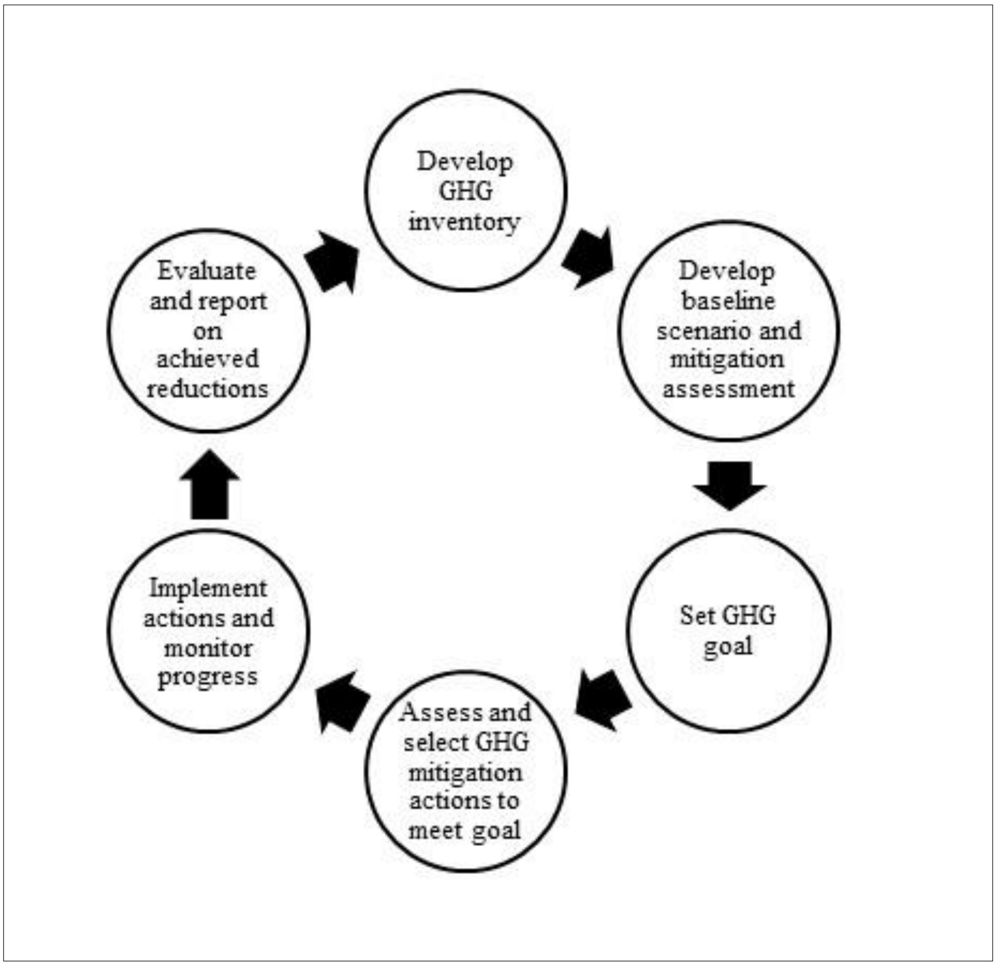


Figure 2.2 GHG emissions inventory and mitigation cycle. Adapted from the WRI (2014).

Moreover, a growing number of researchers (Tuia *et al.*, 2007; VandeWeghe and Kennedy, 2007; Knuth, 2010; Davidson *et al.*, 2011; Jones and Kammen, 2014; Velasco *et al.*, 2014; Guo *et al.*, 2015) stated the need for identifying the spatial distribution of emission activities. Furthermore, the emissions profiles generated, together with the city or country's' resource base, can be used by government to assess future development pathways and their proficiency to apply the changes needed to reduce emissions (Garibaldi *et al.*, 2014). Emissions inventories are significant public policy instruments (D'Avignon *et al.*, 2010) that are vital in determining fairness and equity in global climate change negotiations (Huang and Meng, 2013). The quantification of the impact of human activities in terms of CO_2 emissions is becoming an increasingly popular task, for nations, local governments, corporations and even individuals (WRI, 2014).

The most commonly used method to calculate emissions is building an emissions inventory, which is a list of emission sources and sectors, including their temporal and spatial resolution (Winiwarter and Schimak, 2005; IPCC, 2006; Bellasio *et al.*, 2007). Broadly, there are two methods to quantify emissions in an inventory; (i) direct (in situ) quantification methods through mass balance method, continuous emissions monitoring, and flux measurements, and (ii) indirect, through estimations using emission factor-based method (IPCC, 2006; WRI, 2014).

2.3.1 Direct and Indirect Measurements

The reasoning behind direct monitoring is that higher mixing ratios are found closer to emission sources, under constant atmospheric conditions (Christen, 2014). Direct monitoring of emissions can be made from instruments on board satellites, which measure the GHG mole fractions in the atmospheric column. However, this is done at coarse spatial scales (Manfredi *et al.*, 2009). At finer than local scales, emissions monitoring have focussed on processes (combustion or leaks), transect measurements (using gas analysers) or along a fixed vertical profile (use of towers). These methods measure emissions at the actual location of release and is realistic, however it is expensive and impractical, especially for developing nations (Hillmer-Pegram *et al.*, 2012; Ou *et al.*, 2013).

Flux measurements are from towers that directly quantify GHG emissions and the uptake by eddy covariance (Christen, 2014). Eddy covariance is a micro-meteorological method which measures the exchanges of GHG between the surface and atmosphere (Vaccari *et al.*, 2013), and have been recently applied to urban areas (Vaccari *et al.*, 2013; Christen, 2014; Velasco *et al.*, 2014). The flux measurement area ranges from 0.2 - 5 kilometres square (km^2), and can be used as grid inputs, but cannot be considered as typical of the whole city (Christen, 2014). Furthermore, this method is dependent on specific atmospheric conditions and terrain criteria for monitoring sites, such as neighbourhood scale, with flat landscapes, uniform buildings, land use and land cover (Christen, 2014; Velasco *et al.*, 2014; Gioli *et al.*, 2015) thus is not applicable to all cities. The financial and technological resources required to obtain instruments are other considerable constraints in developing cities (Hsu *et al.*, 2013; Gioli *et al.*, 2015). However, these approaches are important for validating emissions inventory calculations, determining emission factors, and monitoring of CO_2 emissions (Christen, 2014; Gioli *et al.*, 2015). The equation for the direct measurement of emissions from direct monitoring, mass balance or stoichiometry is:

$$GHG\ emissions = Emissions\ data \times GWP \left(\frac{12}{44}\right) \qquad (1)$$

Where, GHG emissions are reported in tCO_2e and emissions data refer to the weight of gas (WRI, 2014).

From a sustainability perspective, there is increasing attention on activities; which can refer to the activity that is responsible for the emissions polluting process, or the activity which has produced the actual emissions pollution (VandeWeghe and Kennedy, 2007; Peters and Hertwich, 2008). The most commonly used method is emission factor-based method (equation 2) where GHG emissions are the product of activity data (AD) and emission factors (EF), which are proxy information (IPCC, 2006; Velychko and Gordiyenko, 2009):

$$GHG\ emissions = AD\ x\ EF\ x\ GWP \qquad (2)$$

Where, AD refers to the level of human activity, such as energy consumption, and EF is emissions from per unit activity and GHG emissions are expressed in tCO_2e per activity. Emission factors express the mass of GHG emitted per activity or energy use and assumes a linear relationship with activities, however, in reality, this is not the case as it is a complex relationship (van Aardenne and Pulles, 2002; Christen, 2014; Wattenbach *et al.*, 2015). Emission factors are determined in controlled environments with small sample sizes (Christen, 2014). Additionally, for CO_2, the emission factor is well defined, however for CH_4 and N_2O there are uncertainties associated with the combustion process (Christen, 2014).

Emission models can also be used to calculate emissions from activity data and emission factors, which are often sector-specific (Winiwarter and Schimak, 2005). However emission models require a large amount of background data inputs therefore the use of emissions models are limited for developing nations due to the data requirements and costs, as it is already difficult to compile emission inventories (Dhakal, 2010). Christen (2014) confirmed the value of both estimations and in-situ measurements of emissions. The calculation of emissions from activities are required for policy and planning to mitigate emissions, and direct measurements are needed to verify and evaluate existing emissions calculations, activity data and emissions sources, emissions inventory models, and identify missing emission sources (Christen, 2014). Ultimately, the best approach for emissions inventory is a combination of direct measurements, activity data calculations, and emissions modelling, as each aspect can be used to verify the others.

2.3.2 Top-down and Bottom-up Approaches

A bottom-up emissions inventory approach involves adding the results of a detailed calculation on each individual emission source (Tsilingiridis *et al.*, 2002; Larsen and Hertwich, 2009). However, the bottom-up approach requires local level data, which is often unavailable and difficult to collect, especially in developing nations, thus it is reasonable to use top-down approaches (Dhakal, 2009). The top-down approach distributes overall emission estimates from the national or provincial scale to individual emission sources by an appropriate disaggregation proxy such as population density, land use and land cover, building density, or road density (Tsilingiridis *et al.*, 2002; Parshall *et al.*, 2009; Christen, 2014). The success of specific local mitigation actions, whether place-based or sector-based, is difficult to assess with the top-down approach (Larsen and Hertwich, 2009). Moreover, the top-down approach is unsuitable for scenario forecasting and projections due to many uncertainties at fine spatial scales (Kellett *et al.*, 2013; Christen, 2014). However, it is generally accepted that the best approach is a combination of top-down and bottom-up (Kellett *et al.*, 2013).

2.3.3 Boundaries and Scopes

The compilation of national emissions inventories is easier as the majority of emissions occur within the country’s boundaries (Hillman and Ramaswami, 2010). The numerous definitions of boundaries for cities (Seto *et al.*, 2014) have produced differing and conflicting results in CO_2 emissions. An example of the disparity was demonstrated by Cai and Zhang (2014) where different urban boundary definitions in China resulted in CO_2 emission differences as high as 654%. This indicated that a fundamental aspect of defining boundaries can result in vastly different emissions. Thus, it is imperative that the boundary of the city is properly defined. To separate emissions from what is generated inside the city boundary and across boundaries, the WRI (2014) developed scopes for cities. Scopes are the conceptual organizational boundaries of emission categories which cities should be held responsible for and guides methodology, data collection, and prevents double counting of emissions (Lebel *et al.*, 2007; Ramaswami *et al.*, 2008; Bader and Bleischwitz, 2009; Kennedy *et al.*, 2009; Kennedy and Sgouridis, 2011; Lazarus *et al.*, 2013; WRI, 2014).

2.3.4 Inventory Methods

Emissions inventories based on activity data are calculated for local municipal operations only or for the whole city, which is referred to as community emissions (ICLEI, 2010; ICLEI, 2014) and also with the help of emissions models. Emissions modelling require assumptions and estimates based on judgement, and are associated with uncertainty (Zheng *et al.*, 2015). However, the commonly used models, such as Long Range Energy Alternative Planning (LEAP), used to develop Durban's emission scenarios (Moolla, 2010), and Market Allocation Model (MARKEL), used to model SA emissions (Merven *et al.*, 2013), do not have a spatial dimension and lacks relation to urban planning and development (Larson *et al.*, 2012; Tanoto and Handoyo, 2014). Furthermore, these models are more suited for the national and regional scales and energy (Bhattacharyya and Timilsina, 2010) and energy-supply side modelling (Merven *et al.*, 2013).

Although high quality emissions modelling are important, municipalities need an inventorying approach that yields results in quick time, can be easily applied and integrates the biggest emission drivers (Baur *et al.*, 2015). Furthermore, the use of datasets which are already available are preferred to save costs, time and resources (Price *et al.*, 2013), as data collection is the most intensive aspect of an emissions inventory (Dhakal, 2009; Weisz and Steinberger, 2010; Huang and Meng, 2013; Price *et al.*, 2013). Furthermore, many local governments in SA do not have the resources to spend on modelling, as these energy models are expensive, specialized software that require detailed data inputs, and even if they are free, municipalities often lack the human and technical capacity (Merven *et al.*, 2013).

Furthermore, the nature of the urban form, which is complex and concentrates people and activities, makes in-situ monitoring of emissions challenging (Kellett *et al.*, 2013). Thus, a growing number of researchers (Tuia *et al.*, 2007; VandeWeghe and Kennedy, 2007; Knuth, 2010; Davidson *et al.*, 2011; Jones and Kammen, 2014) argued for the calculation and mapping of emissions from the end-user location, for example, electricity consumption in buildings, as the end user is ultimately responsible for the action which has led to emissions release and thus, vital for planning and mitigation strategies. The three main methods that are commonly used for local scale emissions inventories are (i) production (ii) consumption, and (iii) life cycle which are discussed in detail below:

2.3.4.1 Production- based Method

The production-based method accounts for emissions which are released directly from sources within the city's geographically-defined boundaries (Weisz and Steinberger, 2010; Minx *et al.*, 2013). For example, electricity emissions are allocated to the location where they are generated and not where they are consumed. This approach is exemplified by the IPCC (2006) national inventory method. The results from production perspective showed that cities can significantly lower emissions through energy efficient urban form (Weisz and Steinberger, 2010). However, Bastianoni *et al.* (2004) reasoned that this method is unfair, specifically, that a place which produces goods for exports will have a high level of GHG emissions, and places which imports goods will have a low level of emissions.

The production method is associated with 'carbon leakage' (Peters and Hertwich, 2008; Muñoz and Steininger, 2010; Paloheimo and Salmi, 2013), that occurs in embodied imports from developing areas to developed areas because of the relocation of high-emitting activities, due to environmental and carbon emissions regulations, and the decrease of emissions in one area is associated with increase of emissions in another area (Parshall *et al.*, 2009; Muñoz and Steininger, 2010; Bednar-Friedl *et al.*, 2012; Geels, 2014). An example was found by Su *et al.* (2010) in China, where the developed regions are net importers of emissions and the developing regions are net exporters of emissions.

The majority of studies on CO_2 emissions are from the production perspective (Dhakal, 2010; Muñoz and Steininger, 2010) due to the prevalence of the IPCC (2006) methodology guidelines. However, it is widely acknowledged that production-based inventories are useful but insufficient for the city-scale (Ramaswami *et al.*, 2008; Kennedy *et al.*, 2009; Hillman and Ramaswami, 2010; Ho *et al.*, 2013). Therefore the production perspective needs to be complemented with the consumption and life cycle approaches to distribute responsibility (Peters and Hertwich, 2008; Minx *et al.*, 2013).

Example of Method: IPCC (2006) Guidelines

The IPCC (2006) emissions inventory guidelines were designed for the national level, but are applied to the local level, as they are the most comprehensive guidelines and the first published guidelines. The main sources of emissions that must be included are energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Use (AFOLU), and waste. The IPCC (2006) uses the concept of three tiers to assess accuracy of the methodology: Tier 1 is the basic method, that uses general activity data and default emission factors therefore it is feasible for all countries. Tier 2 and Tier 3 are intermediate and complex methods respectively, which require disaggregated activity data and country-specific emission factors.

The value of this method is in the provision of detailed information and guidelines, the varied database and default emission factors, when country-specific data are unavailable, which are internationally recognized and applied (Ibrahim *et al.*, 2012). However, the limits of this method are: it does not recognize the WRI (2014) definitions of scopes, which are specifically applied to smaller scale accounting (Ibrahim *et al.*, 2012) and the emission categories cannot be directly related to GDP (Peters and Hertwich, 2008). The major limit is that cities differ from countries in terms of scale, processes, and services; therefore it is not ideal to apply national guidelines to the city-scale, as it will not be representative of cities contribution to global emissions (D'Avignon *et al.*, 2010; Harris *et al.*, 2012).

2.3.4.2 Consumption-based Method

This approach recognizes that the concentration of population and activities in cities rely on a wide array of resources and ecosystem services from outside the cities geographical boundary

(Weisz and Steinberger, 2010; Romero-Lankao and Dodman, 2011) therefore the method used to calculate city emissions need to differ from national inventory method as many cities are service-orientated (Ramaswami *et al.*, 2008; Dhakal, 2010; ICLEI, 2014). Therefore, it is preferable to calculate emissions from the consumption activities as they are ultimately responsible for emissions, therefore the inventory is based on the location of activity and not on the location of physical emissions release (VandeWeghe and Kennedy, 2007; Satterthwaite, 2008; Larsen and Hertwich, 2009; Heinonen and Junnila, 2011; Paloheimo and Salmi, 2013; Jones and Kammen, 2014; Zhang *et al.*, 2014). This approach also accounts for responsibility and carbon leakage (Peters and Hertwich, 2008; Muñoz and Steininger, 2010), however there is a paucity of studies from the consumption perspective (Ho *et al.*, 2013).

The results of consumption-based emissions inventories revealed that urban areas have almost double the amount of emissions, when compared to the production-based method (Dhakal, 2010). However, urbanization is not the main problem but the high-income lifestyles which often accompanies urbanization are responsible for high emissions (Satterthwaite, 2009; Weisz and Steinberger, 2010; Weinzettel *et al.*, 2013; Seto *et al.*, 2014; Huisingh *et al.*, 2015). Furthermore, the significant relationship between high population densities and lower emissions in cities (i.e., the compact city) were discovered through the consumption method (Dodman, 2009b). Additionally, the savings of energy efficiency and consumer choices are often underestimated in emission reduction policies (Girod *et al.*, 2014). The information from consumption-based inventories can be used to track the performance of key sectors and the effectiveness of strategies (Ramaswami and Chavez, 2013) because emissions are expressed based on the location of important sectors, such as residential, commercial, and industrial buildings, transport, and waste (Bulkeley and Betsill, 2005; Dulal and Akbar, 2013; Paloheimo and Salmi, 2013; Jones and Kammen, 2014).

The various criticisms and limitations of this method are: Satterthwaite (2008) and Dodman (2009a) argued that the actual urban contribution to CO_2 emissions are lower because urban areas provide through-traffic and through-services. However, cities consume materials which are produced elsewhere and energy and GHG emissions are embedded in the goods and service flows of cities (Romero-Lankao and Dodman, 2011). Bastianoni *et al.* (2004) and Dhakal (2010) pointed out that the consumption perspective attributes the majority of carbon mitigation burden to commercial cities, due to their service demand, thus releasing industrial cities of the responsibility to adopt cleaner production systems. Therefore, results from this method places much emphasis on consumers and individuals to be responsible and choose products and services associated with cleaner energy and efficiency yet places no encouragement for producers to reduce emissions (Bastianoni *et al.*, 2004).

Example of Method: ICLEI

The ICLEI- Local Governments for Sustainability was one of the first organizations to recognize the importance of addressing emissions at the local scale and to assist local governments in conducting GHG emissions inventories (Wilbanks *et al.*, 2003). Their main objective is to support to local government efforts to reduce emissions, and simultaneously identify sustainable development goals such as curbing urban sprawl and develop efficient public transport systems (ICLEI, 2010).

The major strengths of this method include: the methodology requires minimal time and resources; therefore it is applicable to cities, especially in developing countries, which have limited resources and other challenges to address, that are seen as more urgent than emissions inventory (Holgate, 2007). Furthermore, over 1000 cities and towns are part of the ICLEI network (Feng *et al.*, 2015), which enables comparison, learning, and sharing (Holgate, 2007). However, the ICLEI (2014) method is limited because it is not as comprehensive as the IPCC (2006) emission categories as marine, aviation, and AFOLU emissions do not need to be reported (Ibrahim *et al.*, 2012). Although the energy sector is broken down into sub-sectors, such as residential, commercial, and industry, this method is limited as road transport does not have sub-sectors such as vehicle types. Furthermore, cities undertake and complete the inventories themselves thus have the freedom to choose their own data sources, baseline year, detail level, and also whether to publish the inventory results (Parshall *et al.*, 2009).

2.3.4.3 Life Cycle-based Method

There is a growing number of studies in support of including embodied emissions (Peters and Hertwich, 2008; Ramaswami *et al.*, 2008; Kennedy *et al.*, 2010; Ramaswami and Chavez, 2013). Life cycle assessment (LCA) is a widely accepted method for holistically estimating the GHG emission of a product or service, and is guided by the International Organization for

Standardization (ISO) 14000 environmental management standards (Shi and Meier, 2012). This approach is similar to consumption, as it also avoids carbon leakage. However, the application of LCA is difficult as the urban structure is complex with a wide range of variables (Heinonen and Junnila, 2011). Thus, these studies are limited in understanding the complexity of indirect emissions and responsibility attribution, with the majority of studies undertaken at the product level (Plassmann *et al.*, 2010; Heinonen and Junnila, 2011). Additionally, the flexibility of the LCA method prevents comparisons (Plassmann *et al.*, 2010).

Barton *et al.* (2008) used the LCA for waste emissions and found that sanitary landfills with gas collection and electricity generation emitted the least GHG emissions of 0.09 tCO_2e per ton of waste, and sanitary landfills which lack landfill gas capture produced the most emissions (1.2 tCO_2e per ton of waste). Manfredi *et al.* (2009) undertook a similar study for developed nations only and found that low-organic carbon landfills that are in Europe emits 0.07 tCO_2e per ton of waste.

Example of method: Urban Metabolism

The metabolism of a city is similar to the metabolism of on organism, as it requires inputs of resources (energy, electricity, water, food) and releases outputs, such as waste, heat, pollutants, and GHG emissions (VandeWeghe and Kennedy, 2007). However, natural metabolism systems are self-sustaining and self-maintaining but the urban system requires a constant intake of resources from areas (Kellett *et al.*, 2013). The resources required by the urban system often extend beyond the spatial boundary and extent of the city (Minx *et al.*, 2010). This concept is often used as the framework for calculating city-level CO_2 emissions using energy, census and economic data (Hoornweg *et al.*, 2011; Kellett *et al.*, 2013).

Theoretically, the urban metabolism concept provides a complete and inclusive picture of processes of a city, however there are difficulties in application because the concept requires comprehensive data thus, there is a lack of complete quantification of city urban metabolism (Minx *et al.*, 2010). The majority of the sub-sectors modelled in city urban metabolism studies are buildings, transport, vegetation, and soils (Kellett *et al.*, 2013). VandeWeghe and Kennedy (2007) showed that land-use patterns, road networks, building types, technology and behaviour influences energy demand and carbon emissions, and these factors differs significantly within an urban area. Therefore the application of the urban metabolism framework is most suited for the smaller neighbourhood scale as it is difficult to apply to a whole city, province or country (VandeWeghe and Kennedy, 2007; Kellett *et al.*, 2013).

2.3.4.4 Carbon Footprint

A carbon footprint is a measure of the direct or indirect CO_2 emissions caused by an activity or product from consumption or during its' life cycle (Wackermagel *et al.*, 2006; Wiedmann and Minx, 2008; Plassmann *et al.*, 2010; Muniz *et al.*, 2013) and often used interchangeably with life-cycle perspective (Shi and Meier, 2012); however, there are two views on carbon footprints. The first view regards carbon footprint as the carbon emissions of human activities and measures an emission amount (Wiedmann and Minx, 2008; Shi and Meier, 2012). This view is similar to emissions inventory and typically uses the WRI scope definitions to calculate emissions (Shi and Meier, 2012). The alternate view defines carbon footprint as based on the ecological footprint concept, thus calculates the ecological carrying capacity required to absorb CO_2 emissions from fossil fuel combustion (Wackermagel *et al.*, 2006; Wiedmann and Minx, 2008). The amount is often expressed as carbon footprint per unit area and includes the calculation of carbon sinks, which is the ability of vegetation and soil to absorb carbon (Chuai *et al.*, 2012). Chuai *et al.* (2012) applied this definition of carbon footprint and found the carbon sink from productive land (woodland and grassland) in China is insufficient to reduce the carbon footprint of energy consumption from industrial areas, as carbon emissions increased by 125.46% between 1991-2008 while the carbon sinks can only absorb 16.43% of emissions.

2.3.4.5 Summary of Emissions Inventories

The studies reviewed on urban emissions inventories encompassed a wide range cities that differ in emission sources, economic structure (such as manufacturing and service industries), development, local climate, and state of public transport systems. The sectors covered by urban emissions inventories included energy use and waste from cities in Canada (VandeWeghe and Kennedy, 2007; Hoornweg *et al.*, 2011; Mohareb *et al.*, 2011), USA

(Parshall *et al.*, 2009; Glaeser and Kahn, 2010), Europe (Gomes *et al.*, 2008; Baur *et al.*, 2015), UK (Minx *et al.*, 2013); China (Dhakal, 2009; Bi *et al.*, 2011; Geng *et al.*, 2011; Xi *et al.*, 2011; Zhao *et al.*, 2011; Chuai *et al.*, 2012; Harris *et al.*, 2012; Feng *et al.*, 2014; Liu *et al.*, 2014b; Su *et al.*, 2014; Fang *et al.*, 2015; Feng *et al.*, 2015; Wang *et al.*, 2015), Japan (Makido *et al.*, 2012), and South Africa (Thambiran and Diab, 2011a; Thambiran and Diab, 2011b; Ramsay and Naidoo, 2012; Friedrich and Trois, 2015). Furthermore, the studies on city-scale GHG emissions have used various methods and activity data to account for the emissions; such as combining various data to estimate activity, using average activity levels, disaggregating regional, provincial and national data, and modelling. Due to a variety of methods, definitions, and level of data availability and quality, there are inconsistencies in the gases covered, emission sources and sector, scope and boundaries, and emission factors (Bader and Bleischwitz, 2009; Kennedy *et al.*, 2010; Romero-Lankao and Dodman, 2011; Ibrahim *et al.*, 2012; Seto *et al.*, 2014). The aviation and marine transport sub-sectors also have their complexities because they interact and extend city and national boundaries, and are also estimated through various approaches (Kennedy *et al.*, 2009; Villalba and Gemechu, 2011).

The inventorying methods discussed were devised by researchers and institutions from developed nations, thus the vast majority of studies are focussed on developed cities (Plassmann *et al.*, 2010; Seto *et al.*, 2014). The majority of studies for cities are from the production perspective thus, there is a gap in emissions profiles from the consumption and life cycle perspectives (Wheeler, 2008; Girod *et al.*, 2014). Furthermore, Wheeler (2008) stated that, often when emissions inventories are compiled at the local level, it is regarded as a major achievement itself, therefore falls short in applying the knowledge generated and implementing the recommendations.

Hence, cities, especially developing cities, require an emissions inventory method from a spatial perspective, which is easily applied, to identify zones within the city, so that mitigation efforts can be focused, due to the limited resources available. Furthermore, inequalities in developing cities are increasing, therefore the city cannot be considered as homogenous, because there will be various emissions profiles based on the different conditions within the city. Therefore, there is need to find a way to apply information from the emissions inventory to improve the city, such as delivering developmental co-benefits.

2.3.5 Emission Indicators

The concept of indicators was highlighted at the 1992 Rio Earth Conference to provide a solid basis for decision-making (Hsu *et al.*, 2013). Indicators involve a numerator and a denominator and presents data to describe the state of something (Hsu *et al.*, 2013; Zhou *et al.*, 2014). Emission indicators are essential to measure, evaluate and track the performance and progress of cities towards mitigation targets and respond effectively, thus forming part of integrated environmental management (Parshall *et al.*, 2009; Shen *et al.*, 2011; Lin *et al.*, 2014; Liu *et al.*, 2014a). Emissions indicators are also used to measure efficiency and enables comparison between places (Villalba and Gemechu, 2011).

However, developing countries lack performance indicator systems and strategies, with the majority of indicator studies and use in developed countries (Zhou *et al.*, 2014). Furthermore, indicators are usually prepared at the national level (Moghaddam *et al.*, 2013), thus there is a paucity of indicator studies to assess variability at the local level. In addition, there is a lack of consensus on indicator types, methodology, data sources, weighting of variables, and whether there should be single or multiple indicators (Zhou *et al.*, 2014). Economic based or population based macro-indicators, which measure the carbon intensity of an area, are often used by cities. Furthermore, Ramaswami and Chavez (2013) motivated for the use of per capita indicators for consumption-based inventories and GDP indicators for production-based inventories. These types of indicators are discussed below.

2.3.5.1 Economic-based Indicators

The economic-based emission indicators are based on economic activity, and the most commonly used unit is GDP, which is a measure of the market value of all final goods and services produced in a country in a given period (Moghaddam *et al.*, 2013). For the local scale, gross value added (GVA), which is similar to GDP, is the appropriate unit of analysis (Price *et al.*, 2013). This indicator is expressed as amount of CO_2 emitted per economic activity, based on energy intensity (Price *et al.*, 2013).

Economic based indicators provide sector specific information and measures of efficiency, because the dominant economic sector has political, environmental, and socio-economic impacts on the city (Zhou *et al.*, 2014). These indicators are also considered mixed indicators because they account for both energy efficiency and the economic structure, which drives energy consumption (Price *et al.*, 2013; Lin *et al.*, 2014). The application of these indicators by Lin *et al.* (2014), in low carbon development scenarios for Xiamen (China), revealed that as economic development in the city will increase, the energy intensity will decrease, but carbon emissions will rise.

The implications of this indicator was considered by Moghaddam *et al.* (2013), which claimed that a country will favour this indicator if they have a high GDP and high emissions, such as the USA (Singer *et al.*, 2014), as emissions and GDP are considered proportional. Furthermore, Price *et al.* (2013) found these indicators favour the more economically developed regions, as regions that consume more energy can be given the status of low carbon, and regions that have power plants are designated high carbon areas. Additionally, the energy consumption of buildings is dependent on weather conditions of a region and indicators ignore these differences (Price *et al.*, 2013).

2.3.5.2 Population-based Indicators

One of the most popular emission indicators is based on population which express CO_2 emissions per person (capita) (Moghaddam *et al.*, 2013; Singer *et al.*, 2014). Population growth is considered a threat to sustainability and a major driver of emissions (Friedrich and Trois, 2013; Moghaddam *et al.*, 2013). However, this is countered by minimal contribution to global emissions, from developing nations with large populations, such as African countries (Satterthwaite, 2009). Research has indicated that it is increasing over-consumption by the affluent which are major emission drivers (Hughes and Johnston, 2005; Satterthwaite, 2009; Weinzettel *et al.*, 2013; Shaker, 2015). Therefore, population growth is not a problem itself, but is rather a symptom of unsustainability, such as lack of access to resources, increasing social inequality and poverty, which are features of developing countries.

However, individual scale indicators can help connect citizens to the global scale (Ramsay and Naidoo, 2012) and individual mitigation measures, when viewed collectively, are important for mitigation (Moriarty and Honnery, 2015). Generally, wealthy, more developed nations have higher per capita emissions than less developed countries (Satterthwaite, 2009; Singer *et al.*, 2014). However, there are variations within developing nations, as their economies are rapidly growing, the inequalities are also rapidly increasing, therefore there exists increasingly wealthy and increasingly deprived conditions in developing nations (Romero-Lankao and Dodman, 2011).

According to Singer *et al.* (2014), per capita emissions are considered misleading, as it implies individual responsibility, when there are other factors which often place more pressure than population (Burgalassi and Luzzati, 2015), for example, affluence and economic development (Hughes and Johnston, 2005; Satterthwaite, 2009; Weinzettel *et al.*, 2013; Singer *et al.*, 2014; Shaker, 2015). Furthermore, problems with this indicator arise when there is a city with a small population and heavy industry which produces exports (Ramaswami and Chavez, 2013). This will result in the city having high energy consumption and emissions per capita, yet the population uses little residential energy. Another criticism of this indicator is that cities with a moderate climate will always have less energy consumption than cities with cold climates (Price *et al.*, 2013). Additionally, migrant populations can cause over-estimation or underestimation of the indicator (Price *et al.*, 2013).

Although macro-indicators are commonly used to express carbon intensity and emissions, they are considered too aggregated to provide significant information on whether a city is really low carbon (Price *et al.*, 2013; Lin *et al.*, 2014), as they are based on a top-down approach. Price *et al.* (2013) found that with the GDP indicator, China’s emissions are 20 times more carbon intensive than major international cities. In contrast, the per capita indicator suggested that emissions are similar to major international cities. Macro-indicators do not show inefficiencies or where actions and interventions are required and depending on whether the indicator is economic-based or population-based, it can be well received in one country and rejected in another (Yu *et al.*, 2012; Moghaddam *et al.*, 2013).

2.3.5.3 Other Indicators

In response to the shortcomings of macro-indicators, Moghaddam *et al.* (2013) and Price *et al.* (2013) developed other indicators. Moghaddam *et al.* (2013) developed an international indicator called the Modified GHG Intensity (MGHG-INT), based on GHG intensity, that accounted for a country's production and consumption activities, using GDP, population, and the Human Development Index (HDI). However, high HDIs can correspond with both low and high carbon emissions (Sperling and Ramaswami, 2013). The study by Moghaddam *et al.* (2013) also used the concept of emission debts and credits to define the emission per capita allowed for country. However, Moghaddam *et al.* (2013) results showed the most admissible emissions allowed are for developed countries such as, USA, Japan and Germany (due to high GDP and HDI) and the major emerging countries such as China and India (due to high GDP) whilst African countries are allowed the least admissible emissions (due to low GDP and HDI).

Price *et al.* (2013) developed a sectoral end-use energy low carbon indicator system, for cities and provinces in China, to calculate the energy and carbon intensity of end users (industry, residential, commercial, transport) with a ranking and weighting system. The results from Price *et al.* (2013) revealed both the eastern and southern provinces have the lowest carbon emissions, yet the GDP indicator revealed only the southern provinces have the lowest emissions. However, this method is insufficient in defining low carbon cities, as it does not provide a specific value that is considered as low carbon.

However, the indicators reviewed do not calculate what is required to reduce emissions, as in provide a benchmark. Due to the range of indicators, and lack of standardized indicators, a variety of emission indicators can be used for a city. Furthermore, indicators, whether at a national or city-scale, are considered misleading by Yu *et al.* (2012) because countries or cities are regarded as homogenous. Furthermore, the inappropriate indicator choice has serious implications and can result in missed opportunities to focus on specific areas that could have the most impact achieving a low carbon city (Price *et al.*, 2013). The use of macro-indicators, without the proper context, can result in contradictory conclusions and no single indicator can fully explain the emissions situation of a city or area.

2.3.6 Emission Inventory Uncertainties

Uncertainty refers to a lack of knowledge on accuracy and reliability (van Aardenne and Pulles, 2002). Reliability is the degree in which the inventory can be trusted to meet the user-specific requirements. From a scientific perspective, the reliability of the emissions inventory is directly related to accuracy as atmospheric models require accurate estimations of emissions to understand the chemical and physical processes of emissions in the atmosphere; whilst for policy purposes, accuracy is one of five conditions that need to be met (van Aardenne and Pulles, 2002). Other conditions are transparency, consistency, comparability, and completeness (IPCC, 2006). Accuracy refers to the level which the inventory is a true representation of reality (van Aardenne and Pulles, 2002). There are two types of inaccuracy from inventories, structural and input value, each with their own associated categories (Table 2.2; p. 37) (van Aardenne and Pulles, 2002).

Uncertainties in the inventory are due to assumptions, diverse data sources, various emission factors, inventory processes, and the random errors associated with measurement and statistics (Rypdal and Flugsrud, 2001; Zhang *et al.*, 2013; Lesiv *et al.*, 2014). Firstly, the processes that generate emissions are variable in time and space, therefore this requires the appropriate emissions data (Rypdal and Flugsrud, 2001; Rypdal and Winiwarter, 2001). Thus, due to the variabilities, it is impossible to monitor each emission source therefore inventories are assumptions based on limited data (van Aardenne and Pulles, 2002). Secondly, errors may arise in data processing and even in the data itself (Rypdal and Winiwarter, 2001). Additionally, a linear relationship is assumed between activity and emissions (Wilbanks *et al.*, 2003; Christen, 2014; Zhang *et al.*, 2014; Wattenbach *et al.*, 2015).

Table 2.2 Summary of emission inventory uncertainty types and categories. Adapted from Rypdal and Winiwarter (2001), van Aardenne and Pulles (2002), and Wilbanks *et al.* (2003).

Type	***Categories***	***Explanation***
Structural: the emissions inventory structure	Aggregation	Emissions calculated for a different spatial and temporal scale from which they occur in reality
	Incompleteness	Missing data sources and lack of understanding of emissions processes
	Mathematical formula	Linear relationship is assumed between emissions and activities
Input value: activity data and emission factor values	Extrapolation	Lack of measurements on emission rates and activity data at the appropriate temporal and spatial scale
	Unknown developments	Constructing future emission and socio-economic development scenarios
	Reporting	Typing errors

Uncertainties are often reportedly separately or undertaken as a separate study, derived from indirect sources or expert knowledge and judgement (Rypdal and Flugsrud, 2001; IPCC, 2006), because there is a lack of knowledge in assessing emissions inventory uncertainties (Minx *et al.*, 2013; Lesiv *et al.*, 2014). The analyses of inventory uncertainties are through direct measurements (Christen, 2014). However, verification is only considered possible in a closed system where all components are independent (Oreskes *et al.*, 1994) but cities are open systems, with interconnected components (Weisz and Steinberger, 2010). Uncertainties are commonly assessed internally or externally (van Aardenne and Pulles, 2002; IPCC, 2006). Internal assessments involve the qualitative or quantitative assessment of the method and data used to compile the emission inventory. Examples of internal assessments (van Aardenne and Pulles, 2002) are qualitative discussion, data quality ratings, calculation checks, and expert estimations. External assessments refer to the differences between the emissions inventory and other independent information, in order to identify and quantify the inaccuracies (Christen, 2014). External assessments include comparisons with other emissions inventories, direct and indirect measurements, and air quality and inverse modelling studies (van Aardenne and Pulles, 2002; Christen, 2014). However, the main factor in reducing uncertainties and improving emissions inventory methods and models is increasing knowledge and research in activity data collection and emission factors, which encompass ‘learning by doing’ (Lesiv *et al.*, 2014).

2.4 Emissions Inventory and Spatial Planning

The role of spatial planning in climate change mitigation has only recently been discussed and addressed in climate literature and research (Campbell, 2006; Biesbroek *et al.*, 2009; Qin and Han, 2013; Jabareen, 2015). Spatial planning is an approach to shape development, by coordinating socio-economic objectives and identifying the effects of spatial measures in the long-term (Biesbroek *et al.*, 2009). However, there is a lack of agreement on what is specifically required due to various types of governments, policies and socio-economic and environmental contexts. Nel (2011) stated that spatial planning is the core of the land-use management system, whereas the emerging perspective is that it is wider than land use planning, as it integrates social, economic, and ecological policies to organize future development (Wang *et al.*, 2014a). It is from the latter view, that the spatial planning process is identified as holistic, strategic, reiterative regulative and facilitative, and each of these roles can deliver low carbon development as the urban area is never 'complete' and requires progress and improvement towards a vision (Crawford and French, 2008; Broekhof and van Marwijk, 2012; Williams, 2012).

There are two main approaches of spatial planning: (i) Rational planning and (ii) Communicative planning. Rational planning has been the main planning paradigm since the 1900s, and maintains the planner as the expert to achieve the balance between public and private interests (Dymen, 2014). The criticism of the rational planning approach led to the development of communicative planning, which realizes that social, economic and environmental processes underlie spatial organization, and stakeholders, citizens, and civil society are considered the experts with the planner as the mediator (Wilson, 2006). Nevertheless, there are concerns that consultations and participation are tokens (Dymen, 2014).

Spatial planning can shape sustainable development and emissions mitigation, especially in developing countries as their development is occurring (Romero-Lankao and Dodman, 2011; Broekhof and van Marwijk, 2012; Seto *et al.*, 2014; Wang *et al.*, 2014a). Biesbroek *et al.* (2009) highlighted the changing perception of climate change issues, from an environmental concern to a development issue, and also from mono-disciplinary to trans-disciplinary research. Baur *et al.* (2015) indicated that the linkages between GHG emissions and urban development and policy are expected to become stronger. Currently, there is a lack of knowledge on new and comprehensive approaches in spatial and urban planning, especially as the traditional plans are inadequate for developing countries (Wende *et al.*, 2010; Lehmann, 2013; Taylor *et al.*, 2014). This will entail shifting attention towards establishing new values and standards in already existing and familiar practices, institutions and social habits to mitigate GHG emissions (Burch, 2010; Garibaldi *et al.*, 2014).

Urban spatial planning is not a direct emission reduction technology but is a platform for strategic policies to be integrated and implemented (Guo *et al.*, 2015). Therefore, there is increasing attention on the compilation of emissions inventories with the associated spatial distribution of such emissions, to provide technical and theoretical information to support planning for a low carbon city (Bulkeley, 2006; DEFRA, 2010; Williams, 2012; Asdrubali *et al.*, 2013; Zhang *et al.*, 2013; Guo *et al.*, 2015). The spatial dimension is important due to the long-lasting nature of infrastructure (Wackermagel *et al.*, 2006) and there are uncertainties associated with new energy sources and energy efficiency improvements (Qin and Han, 2013; Moriarty and Honnery, 2015).

There are few studies on emissions mitigation at the local level and the majority of studies that were undertaken, are non-spatial (Ramaswami *et al.*, 2008; Dhakal, 2009; Qin and Han, 2013; Sperling and Ramaswami, 2013; Singh and Kennedy, 2015). Emissions inventories at a local and community scale creates awareness by connecting their activities to the global impact (Kuzyk, 2012; Ramsay and Naidoo, 2012). Emissions inventories with spatial distribution are often top-down and based on proxy information such as land use and population. Thus, there is lack of bottom up emissions inventories based on activity data and emission factors (Velasco *et al.*, 2014). Singer *et al.* (2014) highlighted issues with visioning the spatial distribution of emissions from the production perspective, such as power plants, as it only reflects the spatial distribution of resources, and is not a measure of consumption. Additionally, the scale of emissions reduction required is large therefore all options should be considered. However it has not received the recognition as a viable instrument of mitigating GHG emissions (Dulal *et al.*, 2011). This is due to a lack of a single representative spatial planning approach or best practice example as each city is unique with its own characteristics such as natural environment, level of socio-economic development, and industrial structure (Su *et al.*, 2012).

City spatial planning has the potential to reduce emissions by determining the form of development; whether the city is compact or sprawled, building design standards and regulations, and guidance on energy efficiency and renewable energy measures (Bulkeley and Betsill, 2005; Ou *et al.*, 2013; Qin and Han, 2013). Furthermore Nel (2011) suggested that the land-use management system, which includes the regulatory and enforcement element of the spatial development framework, has a role to play in reducing carbon emissions as without strong enforcement of regulations and harsh penalties, compliance would be limited and voluntary. The determination of LEZs depends on the identification of the spatial location of emissions. LEZs are the geographic area, such as a road network or land area, in which the low emission strategy is applied (DEFRA, 2010). A low emission strategy is a broad package of measures to mitigate the impacts of development and complement other mitigation options such as planning and infrastructure (DEFRA, 2010). Furthermore, Garibaldi *et al.* (2014)

explained that mitigation approaches which are aligned with the developmental priorities are more likely to be accepted and successfully implemented.

The mitigation targets set by cities, whether current or future will shape spatial planning objectives (Wilson, 2006; Crawford and French, 2008). The already established planning guidelines are often outdated and have to follow past precedents which are ineffective for the present challenges (Burch, 2010; Taylor *et al.*, 2014). Moreover, the traditional focus of spatial planning consists of control and service provision, instead of proactively promoting innovative development, and the integration of mitigation and adaptation strategies in municipal function (Bulkeley, 2006; Crawford and French, 2008; Burch, 2010). Furthermore, cities lack precise estimation of their contribution to global GHG emissions, especially from consumption perspective, and the emission profiles and underlying factors (Romero-Lankao and Dodman, 2011; Minx *et al.*, 2013). Therefore the integration of climate change mitigation into spatial planning represents an opportunity for cities to move away from conventional spatial planning, and associated limits, by investing in local-specific knowledge to generate place-based solutions, especially at the community level (Bulkeley and Betsill, 2005; Crawford and French, 2008; Hamin and Gurran, 2009; Burch, 2010; Knuth, 2010; Su *et al.*, 2012; Rogerson, 2013; Jones and Kammen, 2014).

Crawford and French (2008) further explained how climate change considerations can transform spatial planning in two divergent directions. One direction is the setting of national spatial planning standards and measures to deliver rapid, large scale transformation to a low carbon society. However, this vision will inhibit local innovation as decisions are made by national government. The other direction is transformation through decentralization and innovation by developing a local low carbon development framework that is compatible with the local vision, thus increasing the role of local government. Bulkeley (2006) stated that local government spatial planning plays an important part in facilitating the development of mitigation strategies with a spatial component, as it has experience in integrating many components, stakeholders, and interests.

The challenges associated with climate change are complex, multifaceted and dynamic therefore Campbell (2006) and Biesbroek *et al.* (2009) stated that it cannot be handled by spatial planning alone. There are limits associated with emissions reduction and spatial planning in the short-term, due to uncertainties (Wilson, 2006). However, spatial planning can be highly effective in reducing emission in the long term, as planning takes time and involves the relocation of activities, and modification of existing and construction of new buildings and infrastructure (Grazi and van den Bergh, 2008). It is countered by Kocabas (2013) that municipalities do not have control over key infrastructure and service delivery in developing countries anymore due to the increasing role of the private sector in service delivery.

Campbell (2006) maintained that although spatial planning can contribute to abatement of the causes and impacts of climate change, there exists a gap between policy and action, referred to as implementation deficit (Robinson, 2006). Reasons for the implementation deficit are varied and include: lack of knowledge amongst official about climate change issues, inter-departmental tensions in the local authority, and resistance to changing already existing institutionalized practices and entrenched policies (Bulkeley and Betsill, 2005). Thus, planning becomes a contest between the economic, social and environmental concerns, therefore inhibiting integrated resource management, innovation, and action (Lehmann, 2013). Nevertheless, the contributions of cities to global emissions have gained increasing attention (Seto *et al.*, 2014). The opportunity for cities to integrate climate change considerations into spatial plans is vital as it demonstrates leadership (Crawford and French, 2008; Bulkeley and Betsill, 2013) and must be included in the early stages of planning process, instead of assessments later in the process (Carsjens and Ligtenberg, 2007; Jabareen, 2015).

Investigations on the spatial analysis and characteristics of urban air pollution emissions inventories are vast, well documented, and studied for long periods as the formulation of efficient Air Quality Management requires accurate emissions inventories. This is because ambient measurements of air pollutants describe concentrations but does not identity sources, health impacts and exposures (Hsu *et al.*, 2013). Studies highlighted as examples of such investigations using activity data and emission factors were found in Tsilingiridis *et al.* (2002), Streets *et al.* (2003), Dalvi *et al.* (2006), Tuia *et al.* (2007), and Zhang *et al.* (2013). Less frequent are studies on the spatial characteristics of carbon emissions, especially from the consumption perspective. Therefore the approach of addressing GHGs as one would with air pollutants is valid, as the majority of GHG and air pollutants share the same source, which are fossil fuels.

Similar to the intent of this study, Guo *et al.* (2015) integrated the emissions inventory of Guangzhou (China), which is a low carbon city pilot project, into urban spatial planning, which revealed that spatial planning must focus on industrial energy efficiency and road transport, which contributed 56% and 17% to total emissions respectively, to achieve the most carbon emission reductions. However, the study provided generic recommendations to develop into a low carbon city and did not look at variations within the city by using a smaller scale of analysis, but data were collected for a longer time period (2005 to 2010).

In China, residential, industrial and commercial spaces were responsible for the highest carbon emissions (Zhao and Huang, 2010; Huang *et al.*, 2013). Similarly, Minx *et al.* (2013) revealed that municipalities in northern England have the highest emissions due to large industrial facilities and London has the highest per capita emissions as it is a business district and associated with high-income households and lifestyles. Furthermore Huang *et al.* (2013) found that centralizing industrial land may reduce carbon emissions but the centralization of residential, commercial, traffic or agricultural land can increase carbon emissions intensity.

The study on the determinants of CO_2 emissions from manufacturing firms in Japan by Cole *et al.* (2013) was distinct as it focussed solely on the spatial analysis of industry emissions, which found that firms improved their emissions mitigation due to location-specific environmental regulations and also revealed the iron, steel, chemicals, petroleum, paper and cement industries are major contributors to emissions. Similarly, in the USA, land use regulations are low in places with high emissions and places with low emissions have high land use regulations (Glaeser and Kahn, 2010).

A production-based emissions inventory to assess the performance of an eco-industrial park in Beijing, China was compiled by Liu *et al.* (2014b). The results showed GHG emissions intensity decreased by 20% from 2005 to 2010; however, under the same time period, total GHG emissions increased by 94% with the construction industry emissions overtaking the manufacturing emissions (Liu *et al.*, 2014b). This has serious implications because due to energy efficiency, production is increasing thus increasing actual emissions. Therefore, this is an important lesson, as the eco-industrial park has met the national target however total emissions are not decreasing and the situation has created the opportunity for other sectors to increase emissions.

A spatial analysis of emissions inventory from residential and transport energy use were calculated on a census tract level in Toronto (Canada) by VandeWeghe and Kennedy (2007). The results revealed that per capita emissions from zones in the city core were less than the surrounding tracts, however buildings in the central core were more energy intensive than the surroundings, and transport was the main contributor to emissions from suburbs (VandeWeghe and Kennedy, 2007). Similar results of lower emissions in the city core than surrounding suburbs were found by Dodman (2009a), Satterthwaite (2010), Hoornweg *et al.* (2011), and Hillmer-Pegram *et al.* (2012). Furthermore, the implication is that high emissions from suburbs undermine the benefits of low emissions associated with the compact core (Jones and Kammen, 2014). A production and consumption based emission inventory for Pennsylvania (USA), was assembled by Hillmer-Pegram *et al.* (2012), to find the tracts with the highest energy emissions, of which electricity consumption dominated (59% of total energy emissions). The tracts with the highest population also contributed the most to emissions, and these findings were presented to residents who were actively involved in identifying place-based mitigation options.

However, Reckien *et al.* (2007) found that local and regional planning alone had a smaller than expected potential to reduce GHG emissions from road transport, therefore other integrated approaches such as green infrastructure, management, and pricing measures were required for mitigation. According to Minx *et al.* (2013), carbon accounting has a limited role in overall local infrastructure planning, but has a vital role in specific sectors such as housing and transport planning to reduce emissions. Additionally, an emissions inventory only quantifies environmental pressures and does not express concepts that are vital, such as resilience and carrying capacity.

2.4.1 Emissions Inventory and Spatial Planning Challenges

An emissions inventory is reliant on a large variety of input parameters, which includes the extensive data collection, assumptions, consistent methodology and time series, and justification if sectors or gases are excluded (IPCC, 2006; Satterthwaite, 2008; Bader and Bleischwitz, 2009; Zhang *et al.*, 2014). Furthermore, timeously produced emissions inventories are required for robust mitigation analysis and action (Seymore *et al.*, 2014). There are many challenges faced when inventorying emissions since there is a lack of a standardized methodology to calculate emissions, and variations in definitions of urban boundaries, which creates confusion, limits comparisons, and can be overwhelming, due to the open nature of cities (Bader and Bleischwitz, 2009; Biesbroek *et al.*, 2009; Weisz and Steinberger, 2010; Wattenbach *et al.*, 2015).

The most critical component of an emissions inventory is data availability and quality (Winiwarter and Schimak, 2005; Lesiv *et al.*, 2014). Data are often not unavailable, withheld or only available at great expense (Wilbanks *et al.*, 2003), and when data are available, it is often inadequate for the task and need to be downscaled, aggregated or weighted (Parshall *et al.*, 2009) and the consequence is that local variability is disregarded (Wilbanks *et al.*, 2003). Such examples are for fuel and electricity consumption data, which are only available at national or provincial level for most places, which inhibits bottom up emissions inventories (Wilbanks *et al.*, 2003; Dhakal, 2009; Weisz and Steinberger, 2010) or companies unwilling to share data (Ramsay and Naidoo, 2012). The majority of data available are non-spatial in nature (Kellett *et al.*, 2013). Parshall *et al.* (2009) explained the challenges experienced in preparing a spatially resolves emission inventory at the local level, even with energy consumption and industry stack monitoring data, as data intersects more than one census tract. Therefore there is difficulty in integrating, assembling and reconciling an emissions inventory with spatial information.

There is a lack of local activity data and emission factors (Qin and Xie, 2011; Zhang *et al.*, 2014), especially in developing countries, as they are not mandated to report emissions and also lack the expertise (Crawford and French, 2008; Dhakal, 2009; Friedrich and Trois, 2011). Furthermore, due to the small datasets which are available, even in developed cities, studies are focussed on descriptive analysis and not statistical analysis (Minx *et al.*, 2013). In almost all inventories, the data inputs required were available from the government therefore there are concerns about data reliability, for example, there were discrepancies in national and aggregated provincial coal consumption data in China (Qin and Xie, 2011; Huang and Meng, 2013). Although climate change issues are increasingly gaining attention there is still a paucity of data from industries especially at the plant level (Cole *et al.*, 2013).

From a local government planning perspective, there are key internal challenges that municipality's face, of which there are four broad categories Dymen (2014):

- Cognitive: lack of knowledge about climate change science
- Strategic: different interests of stakeholders in the municipal
- Institutional: decisions are made at different levels and sectors with competing objectives (Wilson, 2006; Hannan and Sutherland, 2014)
- Value: the different views within the municipality regarding climate change, such as, the climate scientist views climate change as one of the main challenges for society but the spatial planner views climate change as one of the many environmental and socio-economic challenges, and is largely contextual dependent (Robinson *et al.*, 2006; Biesbroek *et al.*, 2009).

2.5 South African Perspective

The response of sub-Saharan Africa to climate change is focused on adaptation, rather than mitigation, due to their low contribution to global emissions (Devarajan *et al.*, 2009). However, SA is an exception, as it is the largest GHG emitter in Africa and 11th largest per capita GHG emitter in the world (World Bank, 2012). According to the latest national GHG emissions inventory prepared by the DEA (2011c), more than 80% of SA's emissions are related to energy supply and use and CO_2 emissions contribute 79% to total emissions, with the energy industries, manufacturing and transport sectors as the major emitters.

The South African economy is energy-intensive (Seymore *et al.*, 2014) with the reliance on coal due to the combustion of low grade coal, the provision of cheap electricity rates to inefficient industrial consumers, and the coal to liquids process to provide liquid fuel (Raubenheimer, 2011; Roman, 2011). The emissions intensity of the economy is highlighted by the national contribution to global GHG emissions that is three times more than the national contribution to global GDP (Seymore *et al.*, 2014). This must also be noted in the context of a highly divided society where, according to the national Department of Energy (DoE, 2012), 3 million households do not have access to grid-supplied electricity.

2.5.1 National Mitigation Policy

South Africa has taken steps to reduce emissions by signing and ratifying many international agreements such as the Kyoto Protocol (signed in June 1993 and ratified in August 2004) and the Copenhagen Accord and has also prepared three national GHG emissions inventories for the years 1990, 1994, and 2000 (DEA, 2011c). SA has set ambitious mitigation targets to reduce GHG emissions by 34% and 42% below baseline by 2020 and 2025 respectively (DEA, 2011b). In March 2014, the six Kyoto Protocol gases were declared priority pollutants, and activities which emit more than 0.1 $MtCO_2e$ must submit an air pollution prevention plan (DEA, 2014a). The main documents relating to emissions mitigation are the Long Term Mitigation Scenarios (LTMS), the National Climate Change Response Policy (NCCRP) White Paper, and the GHG Mitigation Potential Analysis (MPA) (DEA, 2011b; DEA, 2011c; Winkler *et al.*, 2011; DEA, 2014b).

SA's approach to mitigation, provided in NCCRP, aims to balance the country's emissions reduction, with social and economic opportunities that are available in the transition to the low carbon economy (DEA, 2011b). The NCCRP provides a package of strategic mitigation and adaptation measures, based on sustainable development, within the context of national development goals (Winkler, 2009; DEA, 2011b; Winkler, 2014). The National Development Plan (NDP), which is the long-term plan to reduce inequality and eliminate poverty by 2030 (National Planning Commission, 2012), highlighted the transition to a green economy by 2030, and has provided policy and planning instruments such as Integrated Resource Planning (IRP) and carbon pricing (Msimanga and Sebitosi, 2014).

The NCCRP was informed by the LTMS (Winkler *et al.*, 2011) which defined national government's commitments under international climate agreements, and shaped long-term climate policy. The LTMS emission scenarios, completed in 2007, were based on the 1994 national emissions inventory (DEA, 2014b). The boundaries of the LTMS scenario framework were defined by a 'growth without constraints' (GWC) emission scenario (based on an assumption of growth without any carbon constraint) and a 'required by science' (RBS) emission scenario. The NCCRP highlighted mitigation from the energy, industry, and transport sectors and also addresses adaptation and disaster management. The mitigation framework (DEA, 2011b) included the compilation of a carbon budget, i.e., emissions inventory, as the first step in determining emissions reduction. The second step involves the submission of mitigation plans on how to achieve the emissions reduction and to develop a GHG monitoring system. Thereafter, a range of economic instruments and monitoring and evaluation (M&E) must be in place to support emissions reduction (DEA, 2011b). The NCCRP recognized the role local municipalities play in the implementation of projects and calls for increased capacity and knowledge sharing between government departments and spheres (DEA, 2011b). Specifically, the adaptation aspect of the NCCRP has a stronger local framework that mitigation, as adaptation benefits are seen more quickly and have more job creation potential.

The mitigation aspect of the NCCRP was criticized for the technological and economic focus, rather than a behavioural and social justice focus (Rogerson, 2013). Technologies or practice that have already been demonstrated as effective are promoted, therefore innovative measures are not investigated. Furthermore, the requirement is on government and state-owned enterprises to align their plans with climate change considerations, however there are no mandates for private establishments and industry to fulfil the requirements of the NCCRP, by compiling emissions inventories, therefore their actions are voluntary. However, the DEA (2011a) is currently in the process of developing a South African National Atmospheric Emissions Inventory System (NAEIS), which will include the mandatory reporting of entities with annual GHG emissions exceeding 0.1 Mt or consume electricity which emits more than 0.1 Mt of emissions. This information will be used to allocate carbon budgets at the company-level. However, the information reported by entities to the NAEIS will remain confidential.

Presently, there are difficulties in accessing information from major industries, due to the National Key Points Act 102 of 1980 put in place by the Apartheid government (Scott and Barnett, 2009) and have not been repealed. Ramsay and Naidoo (2012) recorded the challenge in obtaining data from major industries, despite numerous attempts, due to confidentiality and competition issues. Furthermore, drafted legislation such as the Protection of Information Bill 6 of 2010 aims to restrict public access to publish and distribute scientifically and politically sensitive data (Ramsay and Naidoo, 2012). This is problematic, as citizens need to know who is responsible for the most emissions and energy use and, according to social justice; citizens need access to information (Rogerson, 2013).

The National GHG MPA revealed the measurable amount of GHGs, expressed in tCO_2e, which can be reduced and is an update of the LTMS (DEA, 2014b). The MPA identified the mitigation potential of key economic sectors highlighted in the NCCRP and addressed various shortcomings of the LTMS, such as the optimistic growth rates assumed in the LTMS, lack of detailed sectoral and sub-sectoral information and socio-economic and environmental impacts, and is based the on updated emissions inventory from 2000-2010 (DEA, 2014b). The mitigation potential is also based on economic growth trajectories were used in the NDP thus highlighting the link between reducing emissions and also ensuring development.

The main mitigation measures highlighted for electricity generation are wind and nuclear power and carbon capture and storage (CCS) from coal-fired power plants (DEA, 2014b). However, there are various risks associated with nuclear energy and carbon CCS (Roman, 2011). Furthermore, a one per cent increase in nuclear power would lead to uranium shortages (Dittmar, 2013). For industries, the implementation of energy monitoring and management systems and on-site electricity generation are recommended (DEA, 2014b). The shift from private passenger cars to public transport, and freight from road to rail, in the road transport sector achieves the most emission reductions in the road transport sector (DEA, 2014b). The successful implementation and effectiveness of modal shift is site-specific (DEA, 2014b), therefore the role of local government is vital. Therefore, this is an opportunity for areas to be pilot programmes in implementing sectoral and sub-sectoral mitigation and carbon offsets, to align with the national strategy.

The National Treasury (2014) has plans to introduce carbon offsets as part of the package of mitigation strategies to achieve the DEA (2011b) sectoral Desired Emission Reduction Outcomes (DEROs). Other strategies include carbon tax, environmental regulations, renewable energy projects, and targeted support programmes (DEA, 2011b). A carbon tax, which is planned to be implemented in 2016, is one of the main economic instruments to encourage low-carbon economic growth (National Treasury, 2013) however, there is lack of standardized method to calculate emissions, and thus firms can use different methods, as it is open to interpretation. An environmental offset is an intervention implemented to counterbalance for an adverse environmental impact of land use change, resource use, discharge, emissions, or other activities at one location which is implemented at another location to deliver net environmental benefit (Paauw, 2014), thus relates to place-based mitigation. Carbon offsets are projects or activities which avoid, reduce or sequester CO_2 (Ramseur, 2007). The National Treasury (2014) further defined carbon offset as an external investment made by a firm to mitigate emissions, in a way that is cheaper than investing within its own operations, to cost-effectively lower their tax liability (National Treasury, 2014).

Eligible projects must present mitigation and development co-benefits, such as rural development, energy efficiency, conservation, and job creation and ineligible projects are those subjected to carbon tax (such as reducing industrial gases), and lack co-benefits (National Treasury, 2014). Carbon offsets implies responsibility (Paauw, 2014), which is what emissions inventories from the consumption perspective provides. As carbon offset projects and activities are undertaken, the pool of potential carbon offset options will grow smaller (Ramseur, 2007), therefore it is important to be a leader.

Since emissions mitigation is a cross-cutting issue, there is a concern on the lack of coordination between government departments and the capacity of departments themselves (Msimanga and Sebitosi, 2014), for example, the DEA (2011b) developed the NCCRP but other departments are also vital for mitigation, such as DoE, which is responsible for energy provision. Moreover, the NDP focused on a low carbon economy, and many current decisions do not fit in with the low carbon society, such as nuclear energy and fracking which brings risks to society and the environment.

The emphasis on the NDP to reduce SA's vulnerability to climate change impacts while simultaneously reducing emissions, through sustainable development, are further consolidated in SA's INDC submission to the UNFCCC (DEA, 2015). Furthermore, the importance of all scale and sector responses and policy in the short, medium, and long-term constitutes the collective action that is required. However the implementation of significant, large-scale mitigation actions such as increasing expansion of renewable energy, decarbonising electricity production, CCS, and hybrid and electric vehicles require investments from developed countries (DEA, 2015). The prioritization of the mitigation actions mentioned above further underlines the technological focus of mitigation by the South African government.

2.5.1.1 National Spatial Planning Context

Many countries have recognized the importance of urban planning in energy conservation and GHG emission reductions such as the UK, Germany and China (Bulkeley, 2006; Wende *et al.*, 2010; Huang *et al.*, 2013). However the spatial planning policies and framework in SA lacks this vital aspect. There are two main plans and policies for spatial planning in SA, which are the NDP (National Planning Commission, 2012) and the Spatial Planning and Land Use Management Act (SPLUMA), No. 16 of 2013 (The Presidency, 2013). SPLUMA and the NDP requires spatial planning to be practice in all tiers of government and also requires municipals to include guidelines on land use management in their Integrated Development Plan (IDP) in the form of a Spatial Development Framework (SDF).

The SPLUMA legislation has moved away from control towards holistic land use management which links spatial planning and development (The Presidency, 2013), in keeping with international trends, however the legislation lacked the mention of climate change impacts, adaptation and mitigation. The NDP is the long-term plan to reduce inequality, eliminate poverty, and transition to the green economy by 2030 by improving service delivery and integrating policies and programmes from all spheres of government (National Planning Commission, 2012). The spatial component of the NDP is the Integrated Urban Development Framework (IUDF) which provides the context for urban development at a national level. Furthermore, the NDP has highlighted social and economic infrastructure which can fast track growth and development, which are Strategic Integrated Projects (SIPs) (National Planning Commission, 2012). According to the Presidential Infrastructure Coordinating Commission (PICC, 2012), there are 18 SIPs which covers the whole country, of which there are seven foci: five for geographical; three for energy, spatial, and social infrastructure; two for knowledge, one for regional integration, and one for water and sanitation.

The Infrastructure Development Act (IDA, 2014), No. 23 of 2014 was promulgated to provide the legislation to fast track and meet the objectives of the SIPs. A major implication of the IDA (2014) is the timeframe of approval for projects must be met within 250 days, including the Environmental Impact Assessment (EIA). However, this is in conflict with the Environmental Management Act which requires at least 300 days for an EIA to be undertaken (Bond, 2014a; Vecchiatto, 2014). Furthermore, another critique is that although the NDP highlighted the transition to the green economy, the SIPs are not required to be green infrastructure, and climate change issues are not core aspects of urban spatial planning.

The spatial planning policies that address energy conservation do so indirectly, from an economic perspective, as the national entity responsible for electricity, Eskom, could not meet electricity demand, due to rapid electricity demand coupled with no growth in generation capacity, therefore load shedding, which are rotational power cuts, were implemented in 2008, 2011 and 2014 (Eskom, 2014), to prevent the collapse of the electricity grid (Aylett, 2011). Therefore, cities were instructed to reduce electricity consumption by 10% (Nel, 2011). Furthermore, the focus of the national electricity conservation programme is on encouraging households to reduce electricity consumption; however 70% of households are energy poor and reliant on paraffin and biomass burning which is detrimental to their health and the cause of home fires (DoE, 2012).

2.5.2 GHG Emissions Inventories Research in SA

In addition to the three national emission inventories submitted as communications to the UNFCCC, Seymore *et al.* (2014) identified other national emissions inventories prepared by researchers and government departments. The time period of the emissions inventories range from 1971-2008, and are based on the IPCC (1996) guidelines, except for the DEA inventory for 2000, which used the IPCC (2000) guidelines (Seymore *et al.*, 2014). Other limits identified were the top-down approach and the out-dated nature of the older inventories as they have not been updated with new inventory guidelines (Seymore *et al.*, 2014). In response to these limitations, Seymore *et al.* (2014) developed an emissions inventory, based on energy balance and fuel consumption, for the years 2007-2008. However, this method is production-based so emissions were calculated from electricity generation. The emissions inventory compiled by Seymore *et al.* (2014) did not calculate electricity demand and does not help with mitigation policy as activities need to reduce electricity consumption.

Tongwane *et al.* (2015) compiled a road transport emissions inventory for the nine South African provinces, based on the distance travelled method, and used the IPCC (2006) Tier 2 method, which recommended the use of local fuel specifications. Nationally, road transport contributed 43.5 mega tonnes of CO_2 emissions ($MtCO_2$) emissions in 2009, of which freight accounted for 48% and light passenger vehicles contributed 41%, and minibus taxis 5.5% (Tongwane *et al.*, 2015). Gauteng had the highest contribution of CO_2 emissions from cars (47%) to total provincial emissions and in Kwa-Zulu Natal (KZN), freight contributed ~51%, followed by light passenger (39%), and minibuses (~6%).

Emissions inventory studies specifically focussed on Durban, for the road transport, industrial, commercial, residential, and waste sectors were compiled by Thambiran and Diab (2011a), Thambiran and Diab (2011b), Ramsay and Naidoo (2012), and Friedrich and Trois (2015). Thambiran and Diab (2011a) used the European Environment Agency (EEA) Computer Programme to Calculate Emissions from Road Transport (COPERT) to model both CO_2 and air pollution emissions from the road transport sector in Durban for the year 2008. The results from Thambiran and Diab (2011a) indicated that road transport emissions contributed 6.03 $MtCO_2$ in 2008, of which heavy duty vehicles contributed the most to CO_2 emissions from road transport, at ~41%, followed by passenger cars (35%), which was similar to the national and provincial situation revealed by Tongwane *et al.* (2015). However, Thambiran and Diab (2011a) did not further disaggregate the modal emissions into fuel type. Thambiran and Diab (2011b) revealed that emissions from industrial energy use was responsible for 6.6 $MtCO_2$ in 2008, of which electricity consumption contributed 41%, followed by coal (28%), and refinery gas (22%). However, GHG emissions from process and fugitive emissions were omitted due to the paucity of direct measurements from industries (Thambiran and Diab, 2011b).

Friedrich and Trois (2015) estimated the GHG emissions from solid waste disposal from three municipal landfills in Durban for the year 2012 from a life cycle perspective, thus included emissions from the collection, transport, and recycling of waste. The method used by Friedrich and Trois (2015) was based on the methane commitment method, which is suited for planning, whereas the waste in place method is appropriate for emissions inventory (Mohareb *et al.*, 2011). The authors (Friedrich and Trois, 2015) calculated emissions which excluded landfill gas (LFG) collection and electricity generation at two landfill sites (753740 tCO_2e), and also included the savings from LFG collection and electricity generation, which resulted in net GHG emission savings of -161780 tCO_2e. However, the LFG collection and electricity generation are CDM projects, therefore the emission savings attained are attributed to the party that has funded the project or purchased emission credits. Nevertheless, the study highlighted the importance of LFG collection and electricity generation for large reductions of waste emissions.

A study undertaken by Ramsay and Naidoo (2012) revealed the per capita footprint of household, traffic, and commercial activities along a main road (Tara Road) in South Durban were comparable to Asian cities. However, this was due to CO_2 stack emissions from industry, which was responsible for 98% of the total carbon footprint (Ramsay and Naidoo, 2012). When industrial CO_2 stack emissions were excluded from the total, then 80% of CO_2 emissions were from residential (5%) and commercial electricity use (75%), followed by road transport (18%). When considering emissions from the road, which were calculated from traffic counts, cars contributed 58%, followed by trucks (13%) and minibus taxi's (7%), which differs from other studies undertaken at the city, provincial and national scale (Thambiran and Diab, 2011a; Tongwane *et al.*, 2015). The study was limited by the lack of socio-economic information from households, road transport categories were not consistent with South African convention (Merven *et al.*, 2012; Tongwane *et al.*, 2015) and did not disaggregate road transport emissions into vehicle types and fuel usage, as it was based on traffic count data, and lacked electricity consumption information from industry. However, the value of this study was in GHG emissions research in a developing city at a small spatial scale of analysis and use of surveyed information.

2.5.3 Local Scale Mitigation in SA

South African cities will play a vital role in achieving the national reduction targets. The current development decisions made by SA cities will impact on their ability to mitigate emissions, reduce vulnerability and adapt to the impacts of climate change. However, there is a lack of city-specific mitigation targets, and no guidelines on emissions inventories for SA cities or the mandatory preparation of emissions inventory. Thus, city-scale emissions inventory preparation is voluntary and initiated by international organizations such as ICLEI (2014), and not driven by the national government. Furthermore, South African cities are characterized by urban sprawl with high density areas found in former townships, which are associated with low-income households, due to Apartheid and modernism planning (Nel, 2011; Merven *et al.*, 2012; Sutherland *et al.*, 2013), therefore a study of spatial form and emissions would be futile.

A low carbon city report was developed for Durban by the Academy of Science of South Africa (ASSAf, 2011). This report highlighted the Apartheid legacy that has resulted in inequalities and an inefficient city form, and the increasing development on the city fringes, such as the airport. The core recommendations of the report include the transition to the green economy, reduce consumption, realize co-benefits of low carbon development, the use of land use planning for low carbon development, industry and road transport (specifically, the heavy trucks vehicle class) sector mitigation, and the focus on the neighbourhood scale to implement mitigation and adaptation actions (ASSAf, 2011).

However, the report lacked specific recommendations which deal with the city context. Additionally, many of the recommendations to transition to a low carbon economy were considered ‘greenwash’, due to the overtly technological mitigation recommendations (Bond, 2011). According to Chen and Zhu (2013), low carbon development must include the government-administration, company-market, and non-governmental organizations (NGO) and social factors in the low carbon development strategy. However, the low carbon city report lacked the integration of these factors. The report highlighted the road freight sector as the highest potential to reduce emissions, but the transport sector is not included as a polluting activity in the declaration of GHG as air pollutants (DEA, 2014a). Bond (2011) criticized the emphasis on residential behaviour to reduce emissions, as there are still many households in the city who do not have access to basic services, such as electricity, housing, water, and sanitation (EM IDP, 2015). Thus, it is vital to identify the locations of high consumption and low consumption within the city.

Although the report mentions industry mitigation, it failed to identify the role of Durban’s largest industrial zone, the South Durban Industrial Basin (SDIB), which is a major air polluter, in mitigation (Ramsay and Naidoo, 2012). This is especially since there are proposed industry and port expansions, of which the impact is not considered in the report (Bond, 2011; Ramsay and Naidoo, 2012). These developments will result in increased carbon emissions due to increased ship and heavy truck vehicle activities, loss of significant carbon sinks and livelihoods, and the displacement of residents (Bond, 2014b; Mottiar, 2014). Furthermore, the final EIA prepared for the port was rejected by the DEA (2013) as it lacked climate change considerations. This indicates that the development decisions of Durban are incompatible with mitigation. Therefore, there is an urgent need for the identification of development and mitigation options which are compatible and able to deliver co-benefits.

2.6 Synthesis and Conclusion

Significant action is required to stabilize CO_2 concentrations at 450 ppm and restrict the global average temperature increase by 2°C (IPCC, 2013). International agreements are important and have increased attention on climate change, however there is increased focus on the local scale because the international agreements have not delivered what is urgently required. This has led to cities identified as the appropriate scale to address climate change issues, and take up mitigation efforts, especially as co-benefits are realised. This is particularly important for cities in developing countries, as their share of emissions are increasing and their priorities are on economic development and service delivery. Therefore, there is a gap in the identification of co-benefits from emissions mitigation and development, so that informed choices can be made for integrated development. This is further exemplified by cities that have undertaken emissions reductions initiatives, even without the support of national government. This is due to global city networks which have provided support and facilitated knowledge-sharing between cities.

Place-based mitigation is advocated because the specific environmental, economic, social, and political conditions of a city influence emissions. A low carbon city is identified as the main development pathway to reduce emissions from production and consumption. This must be noted as there are also many people in cities, especially emerging cities, which do not have secure access to resources. Thus, it is important to identify areas which need to decrease resource use and the areas which need to secure access to resource. This is especially relevant in developing nations, as there are increasing inequalities.

Thus, an emissions inventory is the first step in developing place-based mitigation plans. An emissions inventory quantifies the direct or indirect emissions from sectors to facilitate low carbon city development. The most common approach for an emissions inventory is activity data based, with the majority of the studies from the production perspective. However, the transition to a low carbon city must focus on both production and consumption. Furthermore, the production perspective is not ideal for cities as emissions are underestimated and lacks attribution of responsibility. The consumption and life-cycle perspectives are more suited for cities as increasing consumption is a major driver of environmental pressure.

However, the inventory methods were devised for developed world cities. These methods do not consider developing cities context and lacked integration with socio-economic factors. Specifically, South African cities are unique due to Apartheid planning and legislation inequalities, which local government is mandated to redress. There are a few studies on emissions at the city level. Additionally, there are limited studies regarding emissions inventories and spatial planning, as this is an emerging concept. Of the limited studies, the majority of the research reviewed is carried out in developed countries with the only emerging economy is China. However, there is a lack of a single approach due to the various contexts of cities due to various emission drivers. An important lesson from the research reviewed is the importance of reducing both actual emissions and emissions intensity, and also be cautious that emissions reductions in one place or sector is not associated with an increase in emissions in another place or sector, due to simple relocation of activities.

There is an overwhelming focus on emissions from household and transport energy sectors and a general lack of studies on industry emissions. This is due to difficulty in obtaining data from industries due to confidentiality and competition laws. This is recognized as one of the major barriers to activity data collection, especially as the industrial sector is a major emitter of GHGs.

In conducting the literature review, a variety of methods and approaches were discussed which adds to the challenges of undertaking an emissions inventory. It is clear from the studies reviewed that for climate change mitigation to be effective in developing cities, it needs to be aligned with local development. Therefore strategies are required that tackle climate change and development. When preparing an emissions inventory to be integrated with local development plans, many assumptions need to be made. Thus, guided by the literature review, the research design is presented in the next chapter, detailing the direction of this study.

CHAPTER 3: RESEARCH DESIGN

3.1 Introduction

Due to the variety of emissions inventory methods discussed in Chapter 2 and the paucity of approaches to allocate GHG emissions spatially, an approach to estimate these emissions for Durban was developed. This chapter outlines the approach developed, to attribute GHG emissions according to the location of activities, and identify local development plans, which has guided data collection and the materials used, to identify high emissions areas. This chapter also provides information on Durban and also the choice of emissions inventory method. Thereafter, the data collection for the compilation of emissions inventory for the energy, transport, and waste sectors, and the qualitative analysis of local development plans to identify the specific areas prioritized by the municipality for development are discussed.

3.2 Key Sectors of GHG Emissions

All human activities contribute various GHGs and aerosols to global warming and climate change therefore it is ideal for an emissions inventory to be accurate, precise, comprehensive, transparent, complete, reliable, and comparable; accounting for all emissions from all sources, and have gone through internal and external assessments and quality control (IPCC, 2006). However, the challenge of collecting comprehensive activity data are well-documented (Wilbanks *et al.*, 2003; Winiwarter and Schimak, 2005; Dhakal, 2009; Parshall *et al.*, 2009; Weisz and Steinberger, 2010; Friedrich and Trois, 2011; Qin and Xie, 2011; Ramsay and Naidoo, 2012; Zhang *et al.*, 2014). Nevertheless, the ability to compile an annual emissions inventory is vital to track progress towards mitigation targets, and this requires easily obtainable activity data (Price *et al.*, 2013; Baur *et al.*, 2015). Therefore, the activities with the greatest contribution to climate change is referred to as ‘key sectors’ (Dhar *et al.*, 2013) and the inclusion and exclusion of sources and activities are context-dependent (Bader and Bleischwitz, 2009; Knuth, 2010; Hillmer-Pegram *et al.*, 2012). The latest South African national GHG emissions inventory prepared by the DEA (2011c) stated that 86% of SA’s emissions are related to energy supply and use (Figure 3.1), with the energy industries, manufacturing and transport sectors as the major emitters.

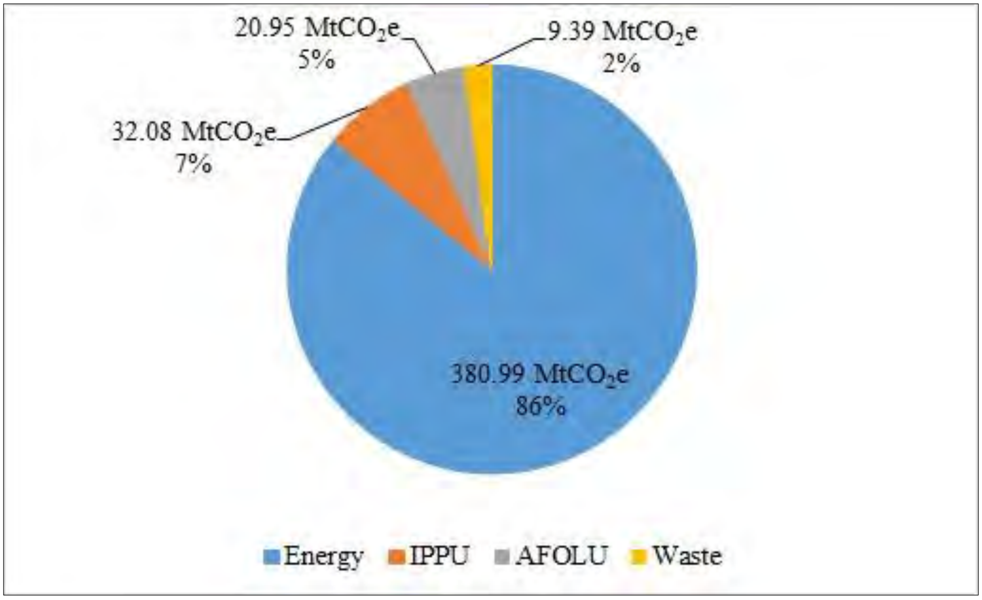


Figure 3.1 Total (in MtCO$_2$e) and percentage (%) share of South Africa's GHG emissions, according to the IPCC categories. Adapted from DEA (2011c).

3.3 Emissions Inventory Framework

The emissions calculations are based on the emission factor-based method (equation 2) where GHG emissions are the product of activity data (AD) and emission factors (EF), which are proxy information (IPCC, 2006; Velychko and Gordiyenko, 2009):

$$GHG\ emissions\ =\ AD\ x\ EF\ x\ GWP \tag{2}$$

Emissions are expressed in tCO$_2$e of activity, which is a source that produces emissions of the GHG considered (Ramachandra *et al.*, 2015). Activity data are information on the extent of actions which result in GHG emissions over a specific time period and spatial boundary (Wattenbach *et al.*, 2015). The activity data are based on the spatial location of consumption activity (VandeWeghe and Kennedy, 2007; Peters and Hertwich, 2008; Jones and Kammen, 2014) for energy emissions and the location of actual emissions release (i.e. production perspective) for waste emissions. This is due to the lack of information on waste in South Africa. Furthermore, waste is related to consumption, and is the only sector which municipalities directly manage and plan (Manfredi *et al.*, 2009; Friedrich and Trois, 2011). Emission factors are the conversion values used to relate the amount of emissions released into the atmosphere with an associated activity (Ramachandra *et al.*, 2015). Emission factors are the averaged emission rates, which assumes a linear relationship between activities and emissions (Wattenbach *et al.*, 2015). Furthermore, there are also default and geographically specific emission factors, which are based on the country or local context.

3.3.1 Energy

The reliable supply of energy is a driving force for human development (Liu *et al.*, 2011). However, the current non-renewable energy sources contribute to environmental problems. The main factors which drive energy consumption are industrial production, transport, and households (Chen and Zhu, 2013). The most widely-supported mitigation policies relate to technology and the supply-side, such as renewable energy on a commercial scale, carbon capture and storage, and biofuels (Roman, 2011; Moriarty and Honnery, 2015). However, there are concerns about this focus as there are questions on the development, availability, and uptake of new technology. This is highlighted by Geels (2014), where renewable energy and technology is in policy but not implemented. This highlights the importance of the demand-side, which is often overlooked as a crucial component in climate change mitigation Knuth (2010).

Electricity is of particular focus in SA because it is key to achieving emissions reduction (DEA, 2011c; Inglesi-Lotz and Blignaut, 2011; DEA, 2014b) and the national development goal (National Planning Commission, 2012) to ensure universal access to energy, which entails that all households in SA have access to modern energy sources, which includes electricity and renewable sources, and excludes energy sources which are detrimental to health and the environment (Aylett, 2010; DoE, 2012). Coal-fired power plants generate ~90% of electricity in SA, and is also a major source of CH_4 and N_2O, and air pollutants such as sulphur dioxide (SO_2), nitrous oxide (NO_x), and particulate matter (PM) (Gaffney and Marley, 2009). Eskom is one of the highest CO_2 emitters in the world and is also currently unable to comply with the National Atmospheric Emission Standards for air pollution (Eskom, 2012; Eskom, 2014).

3.3.1.1 Residential

Energy consumption from the residential sector accounts for 17% of global CO_2 emissions and is the sector that is recognized to have the greatest potential to achieve energy efficiency (Nejat *et al.*, 2015). Electricity is used for heating, air-conditioning, geysers, appliances, and lighting (Chen and Zhu, 2013). Other energy sources, such as candles, paraffin, firewood, coal, and gas are also used for lighting, cooking, and heating (DoE, 2012). Direct fuel and gas combustion is a major source of energy used household space heating in many of the emissions inventories studies (VandeWeghe and Kennedy, 2007; Qin and Han, 2013; Jones and Kammen, 2014). However in SA, according to the national household energy use survey by the DoE (2012), the main source of heating is electricity (44%), whilst 34% of households do not use an energy source for heating, and the rest use firewood, paraffin or coal.

3.3.1.2 Industry

According to the International Energy Agency (IEA, 2007), industry energy use has risen by 61% from 1971 to 2004. Heavy industry is a major consumer of electricity and a source of environmental impacts (IEA, 2007; Cole *et al.*, 2013), such as air pollution, due to the direct combustion of energy sources, such as coal, coke, natural gas, heavy fuel oil, bitumen, liquefied petroleum gas, paraffin wax, and refinery gas (Gaffney and Marley, 2009; ICLEI, 2014). A third of global CO_2 emissions are due to manufacturing industries, specifically, the chemical, petrochemicals, iron and steel, cement, paper and pulp, and minerals and metals industries (IEA, 2007). The analysis of industrial energy consumption and emissions are divided along economic sectors to enable comparison with economic data to identify energy intensity (Moghaddam *et al.*, 2013).

3.3.1.3 Road Transport

Globally, road transport contributes almost three-quarters to transport emissions (Grazi and van den Bergh, 2008; Raux and Lee-Gosselin, 2010). The share of transport emissions from developing cities are increasing due to increasing population, rising affluence, availability of cheaper private vehicles, increase in road freight, rapid urbanization and suburbanization

(Dulal *et al.*, 2011). GHG emissions from motor vehicles are attributed to the following three factors (Yu *et al.*, 2012; Merven *et al.*, 2013; Ramachandra *et al.*, 2015; Tongwane *et al.*, 2015):

(i) the amount of driving (mileage), expressed in vehicle kilometres travelled (VKT),
(ii) fuel (petrol and diesel) consumption, which is related to fuel economy of the vehicle type, and
(iii) the GHG intensity of the fuel type, which is the EF of the fuel.

However, only CO_2, which is the dominant GHG emissions produced by road transport (Dulal *et al.*, 2011), is dependent on the above three factors. CH_4 and N_2O are not dependent on fuel consumption, but on driving, fuel properties, and technology (Graham *et al.*, 2009; Merven *et al.*, 2012). The road transport sector in SA differs greatly from global averages as road transport emissions accounts for 80% of transport emissions (DEA, 2011c). Furthermore, generally road transport emissions have a linear relationship with population growth, however in SA, road transport emissions growth tracks GDP growth (Merven *et al.*, 2012), which is similar to China (Huang and Meng, 2013). Additionally, Tongwane *et al.* (2015) revealed that road transport emissions in SA are closely correlated with vehicle population. Therefore, calculating emissions or disaggregating according to proxies such as population or road density would be inappropriate.

3.3.2 Waste

The waste sector contributes 3-4% to global GHG emissions, of which developing nations contribute 29%, however there is a lack of studies on waste emissions in developing countries, especially Africa (Couth and Trois, 2010; Friedrich and Trois, 2011). Reductions from waste emissions have been achieved in many European municipalities (ISWA, 2009), thus decoupling waste from economic growth (Couth and Trois, 2010). The factors which determine the amount of GHG emitted from waste are the amount of waste generated, the carbon content of the waste, and the technologies used for waste handling and disposal (Friedrich and Trois, 2011).

3.3.2.1 Wastewater

Wastewater, from domestic and industrial sources, is treated to remove the soluble organic matter, suspended solids, pathogenic organisms, and chemical contaminants (Bao *et al.*, 2014). Treatments occur on-site, through septic systems, or off-site, in centralized treatment systems, which includes lagoons and advanced treatments (ICLEI, 2010). The treatment process produces CH_4 and N_2O depending on the type of treatments. CH_4 is produced due to microbial activities, where the soluble organic material is biodegraded under anaerobic conditions and N_2O is produced by the nitrification and denitrification of domestic wastewater, with urea, ammonia, and proteins (Shrestha *et al.*, 2012; Bao *et al.*, 2014).

3.3.2.2 Solid Waste

Solid waste is primarily disposed of in landfills, from which emissions are expected to increase (Friedrich and Trois, 2011). The major emission from waste is CH_4 from landfill gas (LFG), due to anaerobic degradation of organic matter in the landfill, which is dependent on the carbon content of waste, and is higher in developing countries (Manfredi *et al.*, 2009; Friedrich and Trois, 2013). CH_4 can be recovered or converted to electricity, which is the most common CDM project undertaken; thus, landfills can potentially offset emissions (Manfredi *et al.*, 2009).

There are six types of landfills, identified by Manfredi *et al.* (2009): (i) open dump, (ii) conventional landfills without gas collection, (iii) conventional landfills with gas collection and flaring, (iv) conventional landfills with gas collection and electricity generation, (v) engineered landfills, and (vi) landfills receiving low-organic-carbon waste. An open dump lacks engineering plans to compact and cover the waste and prevent gas and leachate emissions into the environment, and is the most damaging landfill type (Manfredi *et al.*, 2009). In SA, there are no municipal-run open dumps as the main solid waste disposal method is in conventional landfills with engineering plans (Friedrich and Trois, 2013).

3.3.3 Local Spatial Development Plans

Reducing emissions are complicated as economic and social development are the main priorities for developing cities (Romero-Lankao and Dodman, 2011; Dulal and Akbar, 2013; Liu *et al.*, 2014b). Thus, when determining mitigation efforts, the development strategies of the region must be included as this defines emissions responsibility, ensures policy coherence, and provides co-benefits and cost-effectiveness (Chen and Zhu, 2013; Dhar *et al.*, 2013; Dulal and Akbar, 2013; Garibaldi *et al.*, 2014; Winkler, 2014).

Planning in South African municipalities is shared by various strategic frameworks (Hannan and Sutherland, 2014). Local governments are tasked with the Long Term Development Framework (LTDF) policies that guide the future development of the city and the Integrated Development Plan (IDP), which is produced every five years and progress is tracked annually (Sutherland *et al.*, 2013). The IDP communicates the requirements and vision of city, and serves the role of addressing backlogs in service delivery, due to Apartheid, and also ensure economic growth (Ballard *et al.*, 2007). The IDP requires the alignment of municipal departments with its objectives and regarded as a high status document, therefore it should be a "powerful vehicle for mainstreaming climate change considerations" (Aylett, 2011; p. 12). This is further reinforced by the LTMS which requires the inclusion of mitigation actions in the IDP (Nel, 2011). The IDP also includes the Spatial Development Framework (SDF), which is the principal spatial planning guidance and is dependent on the city's development context (Sutherland *et al.*, 2013). The IDP and SDF make up the main development framework of the municipality. Therefore the mitigation actions included in the IDP will need to deliver development goals and the enabling of co-operative mitigation.

Mitigation strategies are required to be within the traditional administrative framework of states, provinces and municipalities. However, the places that have major concentrations of GHG emitters and the regions impacted by climate change do not necessarily match the traditional administrative boundaries (Biesbroek *et al.*, 2009), thus making mitigation policy a challenge to implement. Therefore there is a need to frame mitigation policies within the planning framework of the municipality.

The conceptual framework is summarized (Figure 3.2; p. 66) to identify the spatial location of key energy emission sources, from a consumption perspective, in each ward. The non-energy emissions are from a production perspective, at the location of wastewater treatment plans and solid waste disposal sites, but are still the result of consumption, thus generated and disposed of within the city. Furthermore, it represents localized emissions, which has impacts on the surrounding communities. The framework informs the activity data required and the relevant local development policy, as both are required to be defined by spatial locations. After the emissions inventory is complete and emissions are calculated, together with indicators, the high emission wards are identified. The spatial development priorities are identified from the municipal plans. The information from the identification of key development plans for wards and the identification of high emitting wards, and their associated emitting sectors, will be used to identify opportunities for both development and emissions reductions.

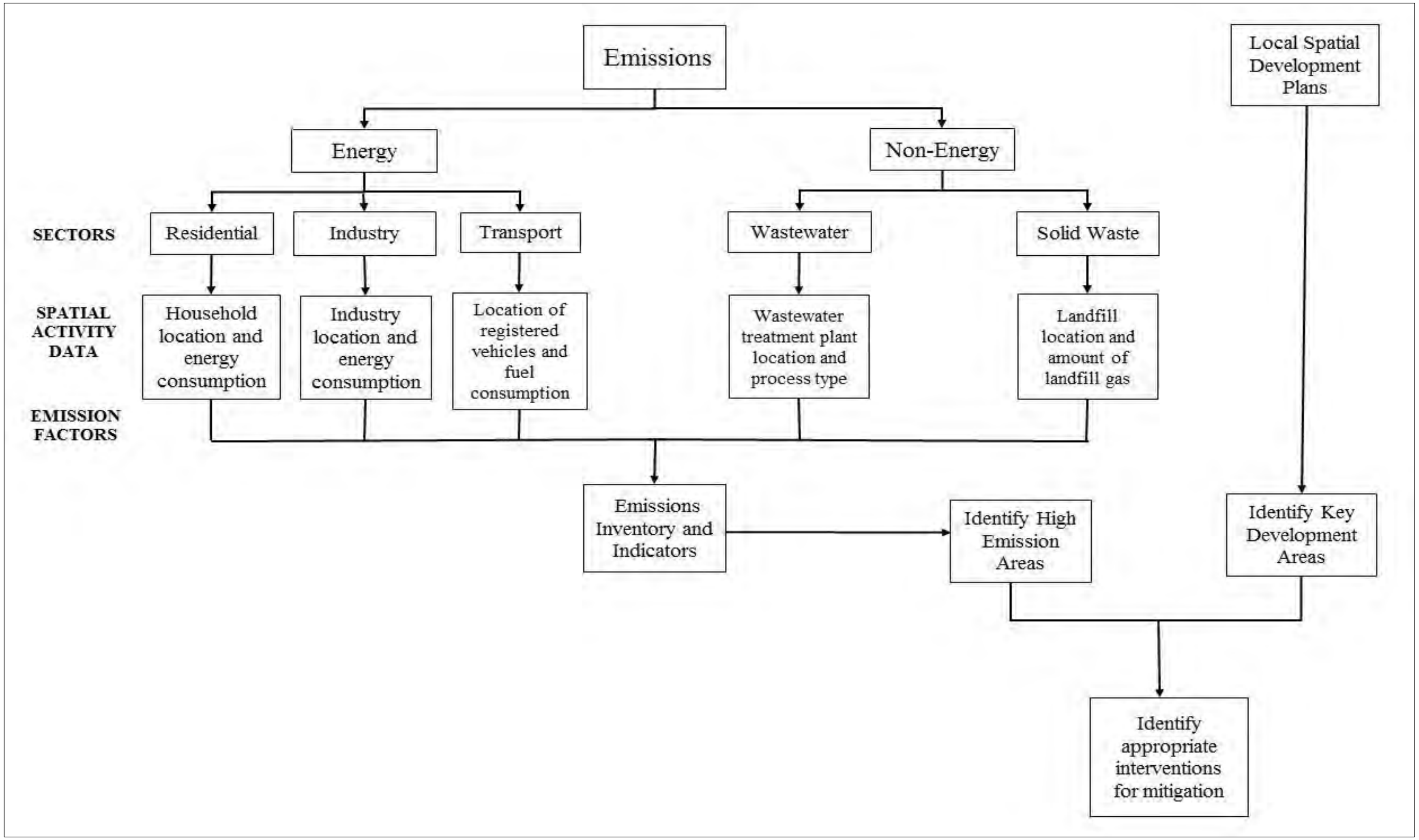


Figure 3.2 The conceptual framework developed to integrate emissions inventory in spatial planning (VandeWeghe and Kennedy, 2007; Brown and Logan, 2008; Gallivan *et al.*, 2008; Knuth, 2010; Merven *et al.*, 2012; Dhar *et al.*, 2013; Garibaldi *et al.*, 2014; Liu *et al.*, 2014b; Winkler, 2014; Feng *et al.*, 2015; Guo *et al.*, 2015).

3.4 Case Study: Durban (eThekwini Municipality)

The spatial configuration of South African cities is due to Apartheid regulation, which restricted the movement and ownership of land for the majority of the population, which resulted in racially segregated cities. Since the abolishment of these regulations in 1994, the legacy of Apartheid spatial inequalities continues as there are developed and developing world conditions in South Africa cities (Hannan and Sutherland, 2014). South African cities are characterized by urban sprawl due to Apartheid and post-Apartheid developments (Faling *et al.*, 2012). Furthermore, South African cities are influenced by globalization which encourages the re-branding of their image based on physical, social, environmental, and economic advantages (Hannan and Sutherland, 2014). Hence, the role of South African cities are significant to address both local challenges such as, to re-dress Apartheid inequalities and also global concerns, such as sustainable development and climate change.

The eThekwini Municipality (EM), located on the east coast of SA in the KwaZulu-Natal (KZN) province (Figure 3.3; p. 68), is the local authority which governs the city of Durban. The EM has a population of 3.5 million and covers an area of 2297 km^2 (EM IDP, 2015). The EM is the third largest municipality in SA, contributing 10.9% and 65.5% to the national and provincial GDP respectively (EM IDP, 2015). The city is noted for having the busiest port in Africa (EM IDP, 2015), thus, the major economic activities of the city are shipping, logistics, manufacturing industries, and tourism.

The EM was chosen as the case study as it is representative of a developing city, faced with many socio-economic and environmental challenges yet has the potential for innovation. An example of the city's innovation was the provision of free basic water to indigent households in 1998, which was adopted as national policy in 2000 (Galvin, 2012). Furthermore, the EM provides free basic services such as water to over 300 000 households, electricity to 70 000 households and property rates exemptions to 200 000 households (Roberts and O'Donoghue, 2013). However, developmental challenges still persist, such as high poverty levels, informal settlements and housing backlogs, an unemployment rate of 20.4%, high rate of infectious diseases such as Human

Immunodeficiency Virus (HIV) and Acquired Immune Deficiency Syndrome (AIDS) (EM IDP, 2015).

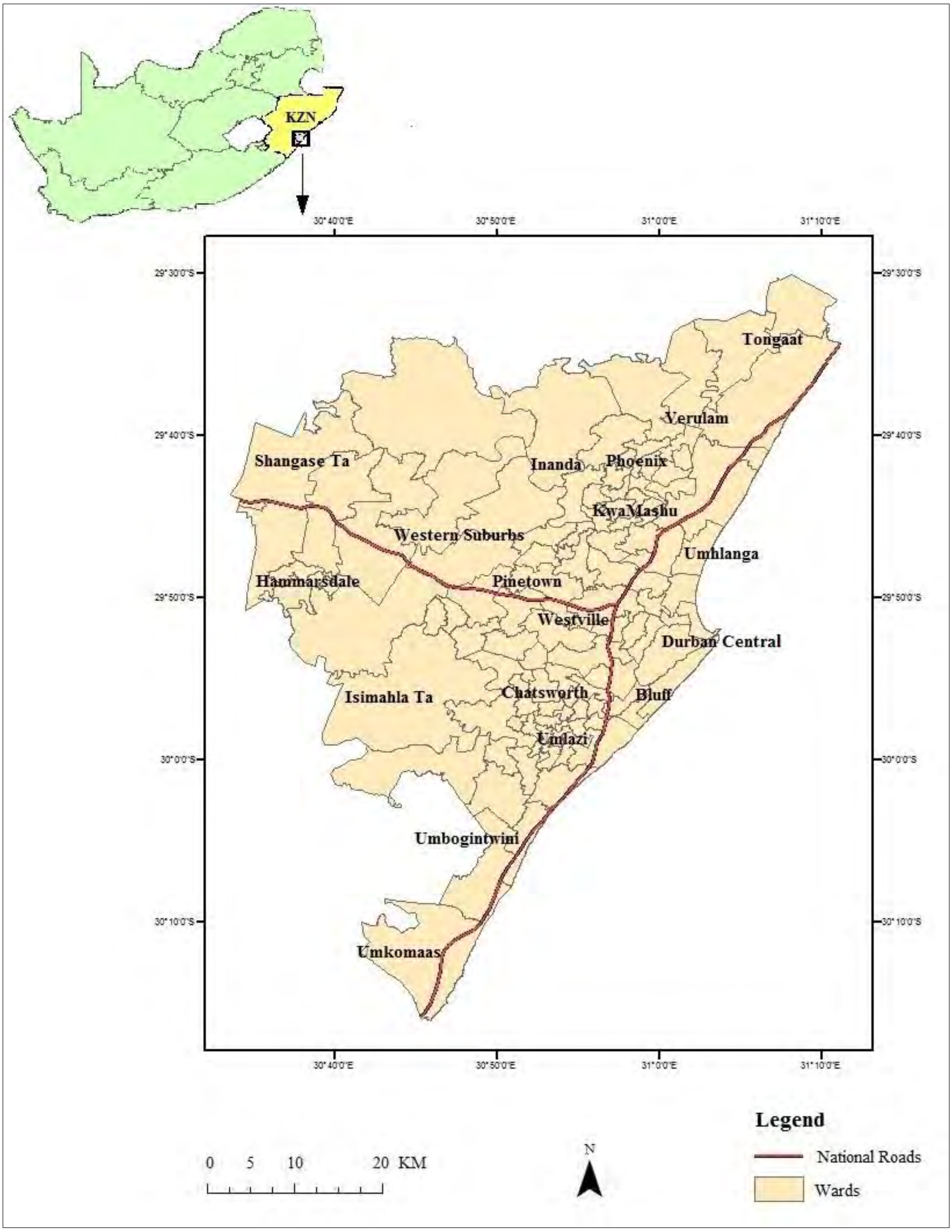


Figure 3.3 Major suburbs of Durban and the city location within SA and KZN (top).

Durban is also located in one of 34 global biodiversity hotspots therefore the Durban Metropolitan Open Space System (DMOSS) was created, to meet conservation targets and secure ecosystem services, which are also valuable in emissions offset and adaptation (EM IDP, 2015). DMOSS covers 23% of the municipal area, but is under threat of development (Aylett, 2011). Since the late 1990s sustainable development has arisen in EM planning and policy (Roberts, 2008; Hannan and Sutherland, 2014), in response to national government objectives (Ruwanza and Shackleton, 2015), however has lacked application in large-scale development plans (Hannan and Sutherland, 2014).

According to Turok (2012), development and spatial planning is considered challenging in the EM, as the topography is steep and dissected with hills and valleys and the spatial form is the most fragmented of South African cities. Furthermore, only 25% of the land is considered urban, 30% is peri-urban, and 45% is rural (EM IDP, 2015). Specifically, the urban sprawl spatial form consists of an urban core surrounded by less dense rural areas along the periphery, the majority of which are under traditional ownership (Michel and Scott, 2005; Turok, 2012; Sutherland *et al.*, 2013; EM IDP, 2015). Additionally, the Durban population density profile by Breetzke (2009) revealed that areas within 10 km of the central business district (CBD), which represents the urban core, is low density, comprised of predominantly wealthy and white suburbs and higher densities are found in low income, black townships and informal settlements (Figure 3.4, p. 70). Therefore there is a separation of the majority of residential areas from places of work; however the exception is the SDIB (Sutherland *et al.*, 2013). The SDIB is one of four air pollution hotspots in South Africa, due to the proximity of residences to heavy industry and traffic, especially heavy trucks (Scott and Barnett, 2009; Ramsay and Naidoo, 2012).

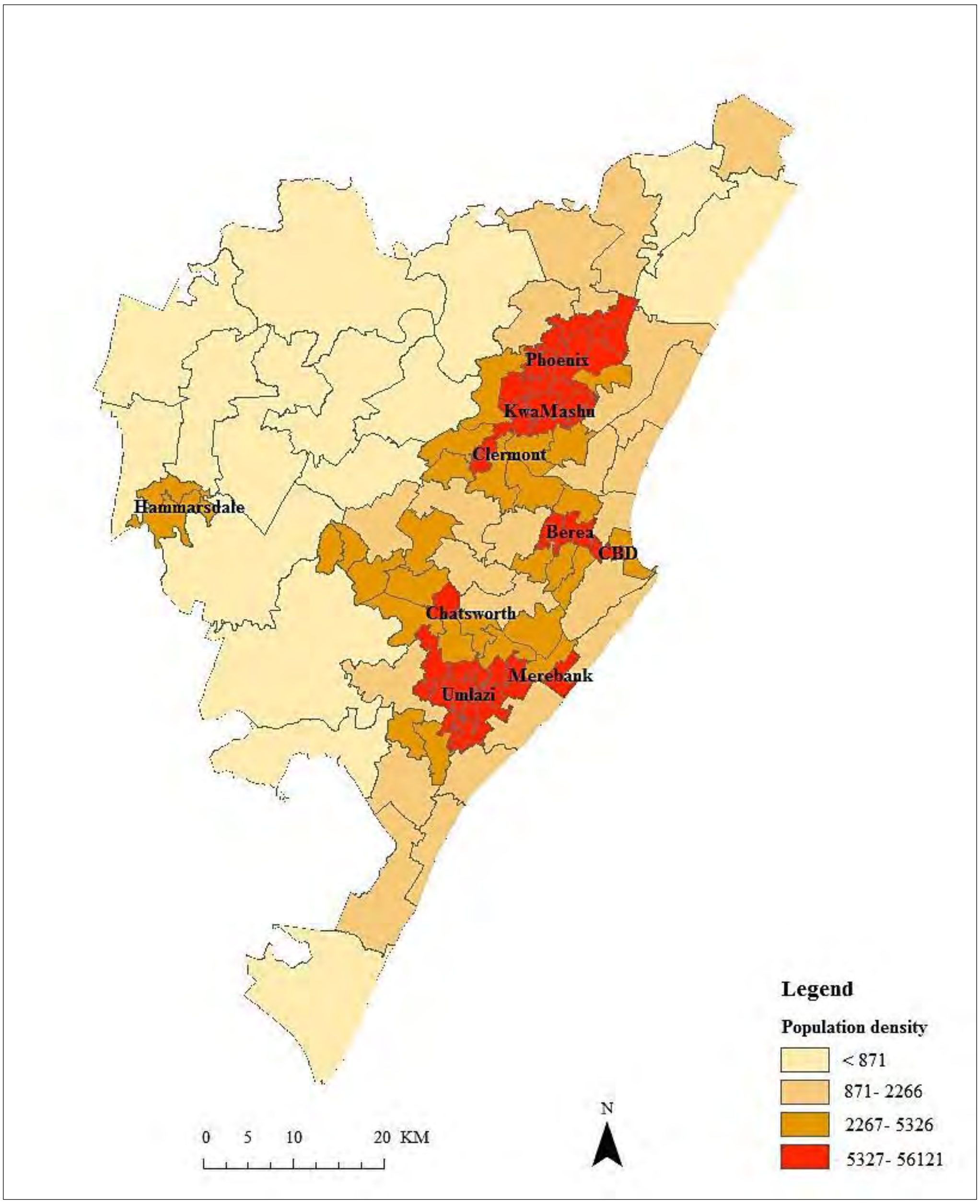


Figure 3.4 Durban ward population density (in population per square kilometre). Source: StatsSA (2013).

Climate change and associated impacts projected for Durban includes (EM IDP, 2015): (i) sea level rise (ii) temperature rise between 1.5°C-2.5°C and 3°C-5°C by 2065 and 2100 respectively, (iii) increase in the number and intensity of extreme rainfall events interspersed with long drought conditions, (iv) species extinction which will negatively impact on DMOSS, (v) food insecurity and water shortages, (vi) health impacts such as heat stress, increase in vector-borne and water-borne diseases, and respiratory problems due to decreased air quality. The city has experienced impacts of extreme weather, such as coastal storms on the north and south coast of Durban and flooding (Aylett, 2011; Smith *et al.*, 2013).

Durban is also considered a leader in climate change efforts in South Africa (Roberts, 2008; Roberts and O'Donoghue, 2013), as it was the first South African city to compile a low carbon development report, a comprehensive GHG emissions inventory, and a Municipal Climate Protection Programme (MCCP), which focused initially on adaptation and then mitigation (Aylett, 2011; Walsh *et al.*, 2013; EM IDP, 2015). However, the adaptation and mitigation departments are separated, and their efforts have not been streamlined with other departments or included in the everyday practice of the municipality (Aylett, 2011).

Specifically, the mitigation efforts have produced emission inventories and CDM projects. Durban is a participating city in ICLEI’s CCP, and produced its first inventory of municipal operations in 2002 and included a community inventory for years 2003/2004. Inventories for both the municipal operations and community emissions were produced from 2010, with the most recent inventory for the year 2012. However, there are no emissions reduction targets (Aylett, 2011). Durban’s CDM-approved projects are LFG to electricity run at two landfills (Aylett, 2011), one of which is the Bisasar Road landfill, which is the largest landfill in Africa (Friedrich and Trois, 2013). The above has shown that action on mitigation is focused on single projects, and has not addressed the major emitters, such as industry and transport, despite the potential opportunities for major emissions reduction due to the innovative municipality (Aylett, 2011).

Furthermore, the Environmental Planning and Climate Protection (EPCP) department in the municipal developed an integrated assessment (IA) model, documented in Walsh *et al.* (2013), to focus on mitigation, adaptation and spatial development. The development of the IA model was a data-intensive and time-consuming process, yet it has not been fully implemented by planners and included in policy to inform development, due to data limitations, and the lack of sectoral analysis (Walsh *et al.*, 2013). Thus, this example stresses the importance of an easily applied approach and method, calculated from already available data, so that it can be widely utilized.

The conceptual framework is applied to the case study of Durban. The framework guides the method, specifically, the activity data sources, the collection of activity data sources which are available, the calculation of emissions, and the identification of relevant municipal spatial development plans and policies.

3.5 Study Scope and Boundary

The focus of this emissions inventory and spatial analysis is on the key energy sectors from the location of consumption activity, and also non-energy emissions from waste, as this is the sector which the municipality has direct control over. Energy emissions are from the residential, industrial sector, and road transport sector. Road transport emissions are only considered due to the difficulty in spatializing aviation and marine transport emissions. Waste emissions are from solid waste landfills and wastewater treatment plants. The emission calculations were guided by ICLEI (2014) as these are specifically designed for local scale emissions, The method involved the ICLEI (2014) guidelines as well as suggestions identified in other similar studies (VandeWeghe and Kennedy (2007), Brown and Logan (2008), Gallivan *et al.* (2008), Knuth (2010), Qin and Xie (2011), and Hillmer-Pegram *et al.* (2012). Sectoral and total emissions were calculated for each of the 103 wards (i.e. neighbourhoods) in Durban.

A study of the urban spatial form, population densities, and emissions will be futile as South African cities are characterized by urban sprawl, with high densities in low-income areas (Nel, 2011). Therefore, there is a need for a framework that covers the key sectoral emissions that are spatially allocated, but is not disaggregated according to proxy information such as population or building density, as there is a lack of bottom up studies from the activity data and emission factor approach (Velasco *et al.*, 2014). The results from applying the framework will be used to inform mitigation strategies based on the emission profiles and the development required for areas. Furthermore, future emission scenarios complex uncertainty analysis (such as Monte Carlo simulations) of the emissions inventory and spatial statistics are not investigated, as it is outside the scope of this study.

The spatial focus of this approach is on the ward scale, which is equivalent to the neighbourhood scale. GHG emissions for the individual 103 wards in the EM for the year 2013 were calculated. Due to data availability limits, this study focuses on CO_2 emissions from energy and CH_4 and N_2O from waste that could be spatialized, expressed as tCO_2e. Ideally, all Kyoto Protocol gases should be covered in an emissions inventory. However, it is still appropriate to focus on those three gases as they are prevalent GHGs. Emissions were calculated for consumption activities related to households, road transport and industry, from within the municipality boundary only, and which could be attributed to the ward spatial scale. Initially, this study was expected to be prepared for the year 2010, as this is considered the baseline year by the EM, but data were requested from 2010-2013. However, data from a key sector, which was annual electricity consumption for individual industry customers, were only provided by the EM Electricity Department for the year 2013. In the next section that follows a description of the data for the key sectors, assumptions, calculation methods and analysis are provided.

3.6 Data Collection and Inventory Calculations

The compilation of an emissions inventory requires the collection of activity data from a variety of sources, of which data are available at different scales. This section details the sources of activity data, emission factors, and tools used to apply the framework.

3.6.1 Residential

The EM does not produce its own electricity, and is reliant on electricity produced outside its borders and supplied by Eskom. Electricity is supplied to households by the

EM Electricity Department and Eskom however; the municipality has a much larger household customer base than Eskom in Durban (EM Energy Office, 2012). Initially, the electricity consumption of individual residential customers were requested from the EM Electricity Department, however this information was not provided. The EM Electricity Department residential customer billing system does not record actual consumption, but is based on the residential electricity meters which are read only a few times a year, and estimated for the rest of the year (EM Energy Office, 2012). Therefore, it was decided to calculate residential electricity consumption based on the bottom up methods found in VandeWeghe and Kennedy (2007) and Brown and Logan (2008) for spatial analysis, where the average annual electricity consumption of households was multiplied by the number of households per ward.

However, calculating the emissions from electricity consumption in the EM, and even SA, is not comparable to developed countries because there are two types of electricity consumers: (i) conventional (credit) and (ii) prepaid. Credit customers receive bills based on estimated electricity consumption, and prepaid customers buy cards or payment slips which activates an electricity amount (DoE, 2012). The prepaid and credit customer split of the EM for 2013 was 52% and 48% respectively (EM Electricity, 2014). Furthermore, prepaid customers use significantly less electricity (~200 kilowatt hours (kWh) per month) than credit customers (~740 kWh per month) (EM Electricity, 2014). This information needs to be accounted for, thus electricity consumption was calculated as follows:

1. The number of households per ward, available from Statistics SA Census (StatsSA, 2013) (StatsSA, 2013), was multiplied by the credit and prepaid customer ratio (EM Electricity, 2014) to get the number of prepaid and credit customers per ward. The assumption was made as the number of households in the census data are similar to the EM electricity customer base.
2. The number of credit and prepaid customers per ward were multiplied by the average credit and prepaid electricity consumption respectively.
3. Steps 1 and 2 constitutes the activity data, expressed in megawatt hours (MWh), which was multiplied by the Eskom (2014) grid emission of 0.93 tCO_2e/MWh,

to express emissions in tCO_2e. The emission factor excluded electricity transmission and distribution losses as justified by ICLEI (2014).

3.6.2 Industry

The electricity consumption of industry customers were requested from the EM Electricity Department. The monthly raw electricity consumption data from 711 customers, which represents 43% of total electricity consumption (EM Electricity, 2014), were provided. The data were summed to get the annual electricity consumption in kWh. The addresses of the customers, and the economic sector they belonged to, were identified using Google Maps (www.google.co.za/maps) and Braby's Business Directory (www.brabys.com) searches. Electricity consumption from buildings was considered as point data, however, due to ethical considerations at the request of the EM Electricity Department, the customer name, address, and electricity consumption could not be revealed. Thus, the addresses were sorted into wards and then summed to calculate the total electricity consumption per ward. This value for the total electricity consumed was then multiplied by the Eskom emission factor to calculate tCO_2e emissions per ward.

Industry customers were categorized into economic sectors, to calculate sectoral emissions intensity. The following economic sectors were identified, based on the EM economic sub-sector analysis:

- Agriculture
- Construction
- Education
- Financial services
- Food, beverages, and tobacco products
- Fuel, petroleum, chemical and rubber products
- Health and social services
- Hotels and restaurants
- Metals, machinery, and appliances

- Non- metallic materials
- Paper, pulp, printing, and publishing
- Retail and wholesale
- Textiles and clothing
- Transport equipment manufacture.

Emissions intensity indicators for the various economic sectors listed previously were calculated, to enable cross-sectoral comparisons. The emissions intensity of a sector is the ratio of its emissions to its GVA, calculated according to equation (3):

$$Emissions\ intensity_{i,j} = \frac{Total\ emissions_{i,j}}{GVA_{i,j}} \tag{3}$$

Where, emissions $intensity_{i,j}$ is the amount of GHG emissions released per economic activity of sector i for the year j, expressed in tCO_2e/ GVA. Total $emissions_{i.j}$ refers to the total emissions calculated for sector i for year j, expressed in tCO_2e. $GVA_{i,j}$ is the economic output of sector i for year j, in millions of Rands.

GVA is a measure of the economic output of each individual producer, industry, or sector to the economy, and is used in the estimation of GDP (StatsSA, 2014). Whereas GDP provides an indication of the state of the whole economy and is calculated using production, income, and expenditure; GVA only considers the contribution from the production of goods and provision of services (StatsSA, 2014), and therefore, is preferred for local scale analysis (Turok, 2012; Price *et al.*, 2013). The individual industry customers were sorted into sectors, as described previously, and the emissions were summed to get total emissions for each sector. The sectoral GVA for the EM for 2013 was sourced from the projected GVA for 2013 found in EM Economic Review (2012), which was found on the EM municipality website.

3.6.3 Road Transport

The calculation of road transport emissions from fuel consumption and fuel sales as proxy data are recommended by ICLEI (2014); however, this method assumes that the amount of fuel sold is equivalent to fuel use. Furthermore, this method does not consider the storage and stockpile of fuel which results in temporal offsets (Gregg *et al.*, 2009) and the fuel sold in one area may be consumed in another area, outside of the city's boundary therefore, another assumption is made, that fuel is sold and consumed within the same boundary (Gregg *et al.*, 2009; Parshall *et al.*, 2009). Furthermore, the fuel sales method is suited for the national scale (Ramachandra *et al.*, 2015). In SA, fuel sales are only reported according to magisterial district, which is outdated, and incompatible with the local scale, thus limiting disaggregation. Furthermore, the South African Petroleum Industry Association, (SAPIA, 2008) estimated that 95% of petrol and 51% of diesel sold are used for road transport, as other sectors also use petrol and diesel (Tongwane *et al.*, 2015). Thus, fuel sales alone cannot identify where interventions to decrease road transport emissions can be made.

Therefore, many studies (Bandivadekar and Heywood, 2006; Gallivan *et al.*, 2008; Knuth, 2010; Yu *et al.*, 2012; Merven *et al.*, 2013; Zhang *et al.*, 2013; Ramachandra *et al.*, 2015; Tongwane *et al.*, 2015) used a bottom up emissions inventory method based on annual mileage and registered vehicle population and type, which are the factors that influence CO_2 emissions from road transport. The distance travelled method is preferred over fuel consumption (fuel sales) method for the local scale, as the latter is more suited for the national level (Ramachandra *et al.*, 2015). This information is easily accessed by policy makers to make decisions on how to limit fuel consumption, transform the transport system, and change travel behaviour (Gallivan *et al.*, 2008). Furthermore, Tongwane *et al.* (2015) showed that road transport GHG emissions in SA correlated closely with vehicle kilometres, which is the product of vehicle population and mileage, than with distance travelled alone. Therefore, this further justified the calculation of emissions based on vehicle population, fuel type, and mileage, which can be used to identify interventions and assess the success of policy implementation.

Emissions from road transport (in tCO_2e) were calculated for each ward as follows in equation (4) (Bandivadekar and Heywood, 2006; Knuth, 2010; Hillmer-Pegram *et al.*, 2012; Merven *et al.*, 2012; Yu *et al.*, 2012; Zhang *et al.*, 2013; Ramachandra *et al.*,

2015) (Bandivadekar and Heywood, 2006; Knuth, 2010; Hillmer-Pegram *et al.*, 2012; Merven *et al.*, 2012; Zhang *et al.*, 2013):

$$E = \sum(VP_{ij} \times VKT_{ij} \times FE_{ij} \times EF_j) \qquad (4)$$

Where,

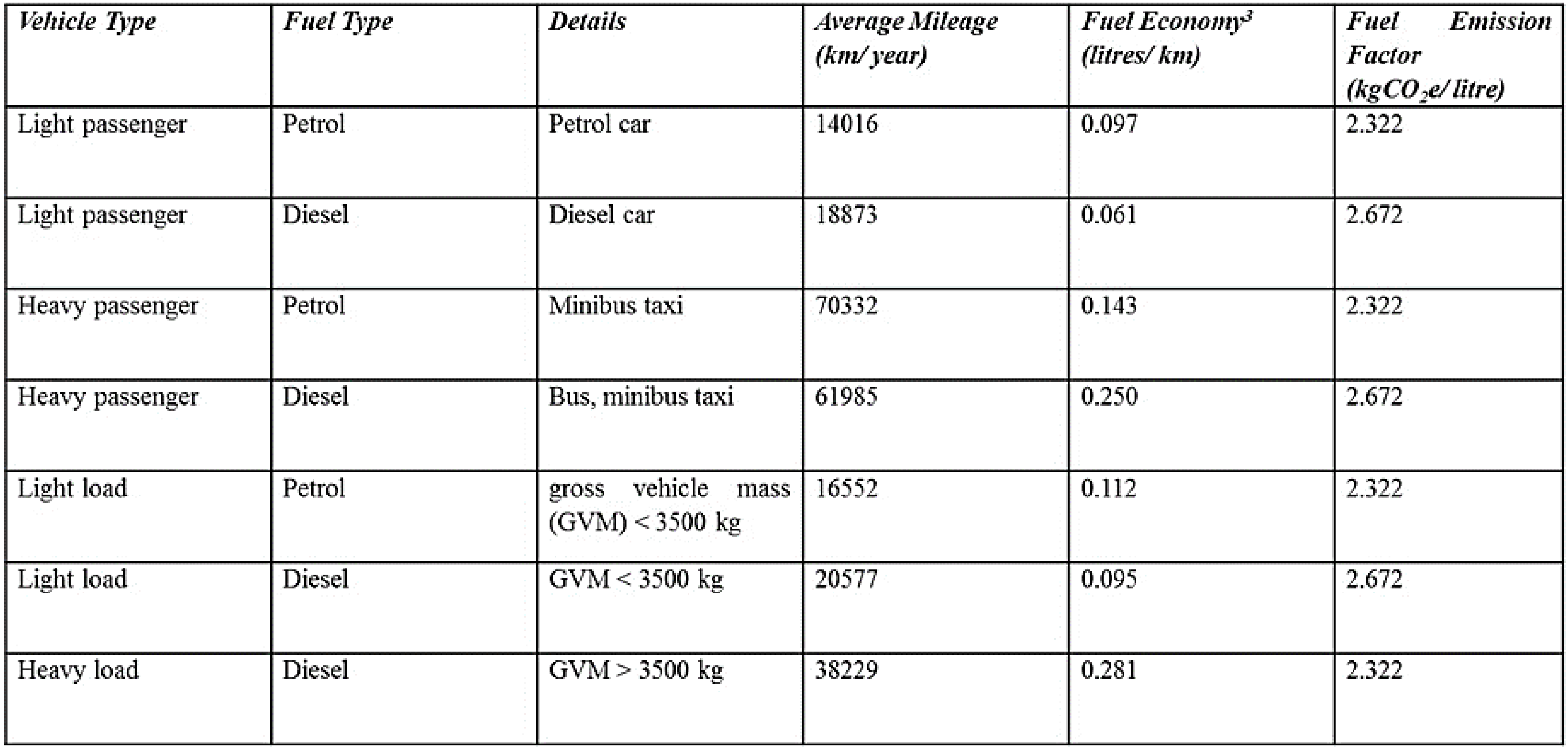
E = GHG emissions in tCO_2e per year
VP = vehicle population of vehicle type i and fuel type j
VKT = vehicle kilometres travelled by vehicle type i and fuel type j per year (km/year)
FE = Fuel economy of vehicle type i and fuel type j, expressed as the litres of fuel consumed per kilometre of vehicle travel (litres/ km)
EF = Emission factor of fuel type j in tCO_2e per litre.

The vehicle population was based on the number of registered vehicles in Durban were available from the Department of Transport (DoT) Road Traffic Management Corporation's (RTMC) electronic National Traffic Information System (eNATIS, 2014) database, which records vehicle type, fuel type, age, and engine size of vehicles, according to postal codes, which was subjected to confidentiality. The eNATIS database provides high quality, up to date information on SA's vehicle population (Tongwane *et al.*, 2015). The main vehicle types (Table 3.1; p. 80) were identified, together with petrol and diesel as the main fuel types. Hybrid vehicles and vehicles running on renewable energy were identified, but these types are minimal and were excluded from calculations. The postal codes, and thus vehicle information, were sorted into to the wards that they belonged to, based on postal code areas found on the South African Post Office website (www.postoffice.co.za).

SA lacks official statistics on mileage and fuel economy; therefore assumptions were derived from literature summarized in Merven *et al.* (2012). The average mileage and fuel economy values found in Stone (2004) were used, because the values are specific to coastal KZN vehicles (Table 3.1; p. 80). Recent mileage and fuel economy data are available and were used in similar studies (Merven *et al.*, 2012; Ramsay and Naidoo, 2012; Tongwane *et al.*, 2015) but are national or international averages. Fuel economy was assumed to increase by 1% every year (Merven *et al.*, 2012) and the UK DEFRA

(2010) default emission factors for petrol and diesel were used (Table 3.1; p. 80), as SA lacks specific fuel emission factors.

Table 3.1 Main vehicle types and their associated fuel types, mileage, fuel economy, and emission factors. Adapted from Stone (2004) and Merven *et al.* (2012).



Vehicle Type	***Fuel Type***	***Details***	***Average Mileage (km/ year)***	***Fuel Economy[3] (litres/ km)***	***Fuel Emission Factor (kgCO_2e/ litre)***
Light passenger	Petrol	Petrol car	14016	0.097	2.322
Light passenger	Diesel	Diesel car	18873	0.061	2.672
Heavy passenger	Petrol	Minibus taxi	70332	0.143	2.322
Heavy passenger	Diesel	Bus, minibus taxi	61985	0.250	2.672
Light load	Petrol	gross vehicle mass (GVM) < 3500 kg	16552	0.112	2.322
Light load	Diesel	GVM < 3500 kg	20577	0.095	2.672
Heavy load	Diesel	GVM > 3500 kg	38229	0.281	2.322

[3] Assumed 1% improvement in fuel economy per year from 2004 to 2013 (Merven *et al.*, 2012

3.6.4 Solid Waste Disposal

There are five landfills in Durban of which there are two types: (i) landfills without gas collection, and (ii) landfills with gas collection. The municipality owns, controls, and operates three landfills: two landfills which collect gas (Bisasar and Mariannhill), and one landfill without gas collection (Buffelsdraai). The other two landfills (Shongweni and Bulbul) are operated by independent contractors and do not collect gas.

Accounting for emissions from landfills are complex, due to the various types of landfills, ages, and degradation levels (Manfredi *et al.*, 2009). Furthermore, the waste that currently contributes to emissions are from the past and there is a lack of records on historical waste composition (Manfredi *et al.*, 2009), especially in developing nations, therefore they are estimated or extrapolated (Friedrich and Trois, 2011).

CH_4 emissions from landfills without LFG collection are rarely directly measured but are calculated with models that condenses the complex decomposition processes (Friedrich and Trois, 2011). These models have different kinetic orders such as zero-order, first-order, and second-order. The most widely used are first-order decay (FOD) models (Kamalan *et al.*, 2011). The FOD model assumes LFG production peaks soon after waste is disposed of in the landfill, and then exponentially decreases as the organic matter in the waste decays. Thus, an exponential equation is used to estimate the amount of LFG generated based on three factors: (i) the amount of waste in the landfill (waste-in-place), (ii) the capacity of the waste to generate emissions (based on the organic material), and (iii) the rate that the solid waste is expected to decay, which is a constant. The ICLEI FOD model, created in partnerships with the USA Environmental Protection Agency (EPA) Air Resources Board, The Climate Registry and the Climate Action reserve, is a Microsoft Excel-base model used to calculation CH_4 emissions, expressed in tCO_2e. The FOD model was downloaded from the EPA Air Resources Board website (http://www.arb.ca.gov/cc/protocols/localgov/localgov.htm). The model requires various inputs (Table 3.2; p. 82), such as waste in place, landfill lifetime, and average annual rainfall, which were provided by the EM Energy Office, and the waste composition of landfills, which was sourced from Friedrich and Trois (2013).

Table 3.2 Data inputs required for the ICLEI FOD model for landfills without gas collection.

FOD model input	***Unit***	***Further details***
Waste in place	Tons/ year	Wet weight
Waste composition	% per waste type	Friedrich and Trois (2013)
Landfill lifetime	Year	Landfill open year and close year (if applicable)
Average annual rainfall	Inches/ year	Determines CH_4 generation rate constant (k) value (Appendix A)

The ICLEI (2010) equation for the calculation of annual fugitive CH_4 emissions from landfill with comprehensive LFG collection systems were used (Appendix A). The LFG collection systems are assumed to be comprehensive, as both the landfills are CDM projects. The landfill-specific information required for the equation (Table 3.3; p. 83) were provided by the EM Energy Office.

Table 3.3 Data inputs require for the calculation of emissions from landfills with gas collection.

Data input	***Units***
LFG collected	Million standard cubic feet (MMSCF) per year
CH_4 fraction in LFG	Percentage
CH_4 destruction efficiency	Percentage
Collection efficiency	Percentage

3.6.5 Wastewater Treatment

The EM owns, controls, and operates 21 wastewater treatment plants (WWTP) in Durban (EM Energy Office, 2012). The wastewater treatment plant types identified were: (i) stationary combustion of digester gas, (ii) anaerobic treatment lagoons, (iii) with nitrification/ denitrification, (iv) without nitrification and/or denitrification, and (v) effluent discharge into aquatic environment. Due to lack of data in this sector (DEA, 2014b) emissions calculations were based on population. The ICLEI (2010) equations for the five wastewater treatment types (Appendix B) were used to calculate CH_4 and N_2O emissions based on the population served by the wastewater treatment plant and industrial effluent discharge, expressed in tCO_2e. The population data, based on the consumption of 400 litres per person per day, and industrial effluent discharge information were provided by the EM Energy Office, which was subjected to confidentiality.

3.6.6 Local Development Plans

A qualitative document analysis of EM strategic planning documents were undertaken to (i) identify existing mitigation efforts in the development plans of the municipality, (ii) identify spatial locations relating to development, referred to as key development areas, which are the areas of economic, social, and environmental priorities highlighted in the municipal plans. This information was summarized in a table, according to location, economic sectors and sub-sectors, the stakeholders involved, and also project specific details, and compared to the areas of high and low emissions to identify synergies and links for emissions reduction and development co-benefits.

The local development plans of importance are the Long Term Development Framework (LTDF), which is 'Imagine Durban', the IDP, SDF, and Industrial Land Strategy (ILS), from 2010-2015, as this represents the five year planning cycle of the municipality. The municipal planning documents were found on the EM website (www.durban.gov.za).

3.6.7 Analysis

Microsoft Excel spreadsheets were used to sort data, calculate emissions equations and indicators, and build the emissions inventory database, from which graphs and tables were created. For the spatial analysis, a Geographic Information Systems (GIS), was used to create maps. GIS is a tool that has the means to store, manipulate and process digital information and to provide it in an appropriate format (Dalvi *et al.*, 2006). GIS also integrates different data sets to provide support in estimations and decision-making in planning, develop policy and analyse the spatial-temporal effects of policy (Wang *et al.*, 2014b). ArcMap 10.1, developed by the Environmental Systems Research Institute (ESRI), was used to spatially analyse and visualize the emissions inventories results. All shapefile layers for Durban, used in ArcMap, were found on the EM mapping website (citymaps.durban.gov.za), which is publicly accessible.

The emissions inventory calculation spreadsheets were joined to the wards layer by tabular joins and displayed as maps. Maps were created to visual emissions and emissions intensities to identify the wards with the highest amounts. The sectoral emissions maps were combined to produce a total emissions map. Rankings or weighting were not applied, as all the sectors were considered equal and linked in the development of a low carbon city. The spatial analysis of total emissions reveals the distribution of emission activities and the areas with the highest emissions in Durban. Thus, the high emission areas were identified from the emissions inventories and presented in relation to development priorities so that interventions for emissions reductions and development co-benefits can be recommended.

3.7 Challenges and Limitations

The emissions inventory was constructed using the best available data collected under the time and budget constraints of this project. Furthermore, in SA there is a lack of detailed information on energy (Inglesi-Lotz and Blignaut, 2011) and waste (Friedrich and Trois, 2013; DEA, 2014b). Thus, various assumptions were made, which contributes to uncertainties and limits in this study. The main challenges and limitations are related to activity data sources as it is the most critical aspect of the emissions inventory, and the use of default emission factors.

3.7.1 Data Collection

The information and data collected for the compilation of the emissions inventory were sourced from organizations and agencies, such as the EM Energy Office, EM Electricity Department, and the national DoT, which lacked meta-data. Average values for residential electricity consumption, mileages, fuel economy, and waste received at landfills were used, which hides variations in the data. The bottom up approach of this study scales up and accumulates errors and uncertainties. The use of default emission factors to convert activity to emissions for all sectors, except to electricity, is another major implication, because there is a lack of SA-specific emission factors. The default emission factors used are based on the developed nations context, and therefore not suited for SA-specific conditions and processes. Furthermore, in the literature review and research design chapters of this study, the importance of accounting for the South African context was highlighted yet there is a lack of national emission factors, which limits the accuracy, reliability, representability, and completeness of the emissions inventory.

3.7.2 Spatial Scale

The spatial unit for emissions calculation and representation were the ward scale, which is equivalent to neighbourhood scale. However, this is still an aggregated unit, as average values were used to represent individual amounts. Individual point data were required to be aggregated, due to data confidentiality. This masks the variation within wards, as it treats all sources within the ward as homogenous (Kennedy *et al.*, 2009), of which the common concept which this uncertainty is related to is ecological fallacy (Loveland, 2012). Furthermore, the boundaries used to delimit wards and the EM are artificial and can change in the future.

3.7.3 Residential

This study assumed that residential prepaid and credit customer average electricity consumption were representative of the residential energy sector, and therefore used to calculate emissions. The use of electricity averages to calculate household consumption is a limitation as it does not show the variations in electricity use. Furthermore, electricity consumption meter readings are based on averages (EM Electricity, 2014). Furthermore, many households in Durban do not have access, or have limited access to electricity; therefore other sources of energy are used, such as candles, paraffin, firewood, and gas (DoE, 2012), which has health and safety implications in the form of outdoor and indoor air pollution, and fires. This study lacks emission from the other household energy sources mentioned, because there is a paucity of studies in SA, specifically on the amounts that are combusted (DoE, 2012). Although the uses of other energy sources are low, they create localized emissions which are harmful to human health and the environment. This information can also be used to identify potential areas for air pollution and carbon emission offsets (National Treasury, 2014; Paauw, 2014), for example, high air polluting and GHG emitting industries can invest in reducing emissions from domestic burning, in communities, instead of large emissions on-site, which may be limited by infrastructure (Moriarty and Honnery, 2015).

3.7.4 Industry

This study only included emissions from electricity consumption and excluded other energy sources, such as coal and refinery gas. Data on the consumption of other sources of energy, based on fuel sales, are available from the DoE but are aggregated at the magisterial district scale. Therefore it was difficult to disaggregate this information to attribute to the economic sub-sectors, and even to the individual facility level. Additionally, this study lacked emissions from industrial processes due to the lack of data on direct measurements of GHG emissions from industrial processes (Thambiran and Diab, 2011b).

Furthermore, the annual sustainability reports for major industries located in Durban were sourced to provide information on energy consumption and industry process emissions, but it does not provide the relevant information that could be useful in this study, as they were expressed in different units. For example, the sustainability report for the South African Petroleum Refinery (SAPREF, 2013) presented electricity and furnace fuel consumption, however the same amount is recorded for both MW and MWh, yet there is a difference between those two energy terms. The use of electric power (MW) over a period of time is expressed in MWh (Climate Council, 2013), however the same figure is reported for both MW and MWh, which means that the information is unreliable. Other sustainability reports presented total energy consumption or CO_2 emissions for all their facilities within SA, and thus cannot be disaggregated for the facilities located in Durban.

An issue applicable to the calculation of emissions from electricity consumption for households and industry was the use of the Eskom (2014) emission factor to convert electricity consumption to carbon emissions. Although the Eskom emission factor is for SA, there is a lack of agreement on how to calculate the electricity emission factor (National Business Initiative, 2013). The Eskom emission factor is 1.03 tCO_2e per MWh but this value includes the emissions from losses in electricity transmission and distribution. Therefore, it is not ideal when calculating electricity consumption emissions (ICLEI, 2014). This study excluded emissions from electricity transmission and distribution, in accordance with ICLEI (2014) guidelines.

Additionally, the emission factor is based on the Eskom grid, which is reasonable as they produce the majority of electricity. However, there also exists electricity generated and consumed on–site such as coal, gas, or diesel which are not accounted for, therefore there is a need for a country specific emission factor (National Business Initiative, 2013), which includes both Eskom grid and non-Eskom (independent) sources.

3.7.5 Road Transport

The method used to calculate emissions from road transport assumed that the number of registered vehicles in Durban is indicative of the actual vehicle population; however, there may be vehicles which are not registered and driven, and also vehicles which are registered but are not driven. It was also assumed that the vehicles registered in Durban are driven within the city; however, there are vehicles which are registered in Durban but driven in other parts of SA, and vehicles which are driven in Durban, but registered elsewhere in SA. Furthermore, this study also does not show traffic but rather the fuel demand of vehicles, with the expectation that the place where the vehicle is registered is the starting and end point of travel. Additionally, only CO_2 emissions from vehicle fuel consumption were calculated because CH_4 and N_2O are dependent on driving, fuel properties, and technology (Graham *et al.*, 2009; Merven *et al.*, 2012), and thus were not considered as these factors fall outside the scope of this study.

The mileage and fuel economy information used in this study from Stone (2004) are more than 10 years old but is specific to coastal KZN. Furthermore, Merven *et al.* (2012) used recent, national average mileages and fuel economy, and found the most discrepancies from between model and actual diesel fuel consumption, due to the movement of road freight from Durban to Gauteng. Thus, all vehicle types were subjected to the same driving conditions by using average mileages and fuel economy.

The default UK DEFRA (2010) petrol and diesel emission factors were used to convert fuel consumption calculated to CO_2 emissions, due to the lack of SA-specific petrol and diesel emission factors. However, the UK DEFRA (2010) emission factors were based on UK vehicle conditions but were also used in the emissions inventories prepared by the EM Energy Office (2012) and Ramsay and Naidoo (2012).

The second largest contributor to total transport emissions is aviation, which is more damaging as GHGs are released directly into the upper atmosphere (Chapman, 2007). However, air and marine transport emissions are difficult to spatialize and there is lack of consensus on how to attribute those emissions (Villalba and Gemechu, 2011).

3.7.6 Waste

In SA, there is a scarcity of information in the waste sector (Friedrich and Trois, 2015). Specifically, according to the Department of Environmental Affairs (DEA, 2014b), there is a lack of direct measurements of GHG emissions from wastewater treatment processes in SA. The estimated population served by the wastewater treatment plant was used as proxy information, according to ICLEI (2014) guidelines, which are catered for American WWTP. Furthermore, default ICLEI (2014) values for industrial wastewater discharge into WWTP, biological oxygen demand (BOD) values, and emission factors where used, which were based on American averages.

More data were available for the solid waste disposal at landfills sub-sector. However, this information is limited by short timescales, as landfill waste annual volume received and composition data were only available for the past five years from the municipal landfills, and 15 years from the private landfills. However, the above data were available on a monthly scale for the municipal landfills, and yearly scale for the private landfills

Furthermore ICLEI (2010) equations and default emission factors were used to calculate emissions from landfills with LFG collection and electricity generation. The emission from landfills without LFG collection and electricity generation were modelled with the ICLEI (2014) FOD model. The implications of using equations and models devised by international organizations from developed countries, is that the equations, emission factors, and models were developed for cities and countries that have a different context from SA. Specifically, developing countries have high volume of organic waste (Friedrich and Trois, 2015).

3.7.7 Local Development Plans

The key development areas identified are based on strategic development plans, which are visions. Therefore, this does not mean that the developments mentioned are approved or implemented as they are intents (Ruwanza and Shackleton, 2015). Furthermore, the drawing up of municipal plans, such as the IDP, is based on guidelines which focus on the preparation processes and not on the contents. However, the plans do provide an indication of how the city defines itself and its environmental and socio-economic development future.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

The aim of this study was to identify the spatial distribution of anthropogenic GHG emissions in Durban, which indicated the areas of highest emissions for place-based mitigation to achieve a low carbon city. Therefore, this information will be used to identify the opportunities for using emission inventories to inform low carbon spatial development at a local scale in SA. A conceptual framework, based on the consumption perspective, was developed to combine the spatially-resolved emissions inventory and municipal development plans. The results and discussion from applying the framework are presented in this chapter.

The first section of this chapter presents the analysis of the key development plans and projects identified from the qualitative analysis of local development plans. This information provides the spatial development framework and context of the EM. Thereafter, the results of the emissions inventory are presented which identifies the high emission zones. Subsequently, the emissions profiles of the high emission zones are discussed in conjunction with key development plans to identify place-specific mitigation options and developmental co-benefits. The final part of this chapter discusses the limitations and opportunities in using emissions inventories to inform spatial planning, specifically what was established in this research.

4.2 Policy Analysis for Climate Change and Spatial Development in the eThekwini Municipality

This section will discuss the context of spatial planning in the EM, and current and future development plans. Prior to the formation of the eThekwini metropolitan municipality in 2000, there existed six local councils, designated according to their geographical location. The six councils were: North Local Council, South Local

Council, Inner West Local Council, Outer West Local Council, North Central Local Council, and South Central Local Council, which were responsible for spatial planning and service delivery, primarily to the white suburbs, within their respective jurisdiction (Breetzke, 2009). Thus, this demonstrated that the use of spatial planning in the municipality is not a new phenomenon, but due to the different local councils the EM inherited the impacts of fragmented spatial planning.

This study is focused on the EM strategic plans, which are the Long Term Development Framework (LTDF), Integrated Development Plan (IDP), Spatial Development Framework (SDF), and Spatial Development Plan (SDP) (Table 4.1; p. 93). The LTDF provides the development direction for the municipality and the IDP is the implementation of the LTDF and provides the imperatives for the municipality. The SDF as a conceptual plan that spatially represents the growth nodes and corridors and the SDP focuses on each of the four sub-metro planning regions, to identify the long term land use carrying capacity (Breetzke, 2009). The details and analysis of the LTDF ('Imagine Durban'), the IDP Eight Point Plan, SDF and SDP and the Industrial Land Strategy (ILS) are discussed in the sub-sections that follow. The industrial land strategy is not a compulsory document required by local government, but is also reviewed as manufacturing is a major economic activity, and also represents the industrial development vision of the EM.

Table 4.1 Scope and purpose of the EM plans studied. Adapted from the EM SDF (2014; p.35).

Plan	***Scope***	***Purpose***
LTDF	Strategic economic, social, and environmental objectives	Provides the strategic development direction for the municipality
IDP	Strategic operational implementation	Provides the strategic implementation direction and imperatives for the municipality
SDF	Strategic spatial development	Provides the strategic development intentions based on the LTDF and the IDP
SDP	Strategic spatial development	Translates the spatial development intentions of the SDF into land use plans, transport, environmental, and infrastructure implications.

4.2.1 LTDF- 'Imagine Durban'

The LTDF, known as 'Imagine Durban', was a community-based process on the shared developmental pathway of the city towards sustainability (Imagine Durban, 2010). The LTDF included specific programmes and outcomes, and measurable targets for its six thematic areas, which are:

- Creating a safe city;
- Ensuring a more environmentally sustainable city
- Promoting an accessible city
- Creating a prosperous city where all enjoy sustainable livelihoods
- Fostering a caring and empowering city
- Celebrating our cultural diversity, history and heritage.

Furthermore, the framework developed by the EM provided targets to achieve the milestones from the thematic area (Figure 4.1; p. 95). For example, the EM stated that climate protection interventions should begin now so that the sustainable city can be achieved by 2100 (Imagine Durban, 2010). However, it does not state how it will be achieved or integrated with the other priorities. The framework itself displays climate protection as the last step in achieving sustainability, separated from service delivery, job creation and economic development goals. Furthermore, the framework only mentions adaptation and not mitigation, and this is a concern as future development, especially economic development, tourism, spatial development, bulk infrastructure, and energy resources can either increase or decrease future emissions. Therefore, the consideration of emissions mitigation is vital to development, specifically climate risk management, and in preparation for future emission limits.

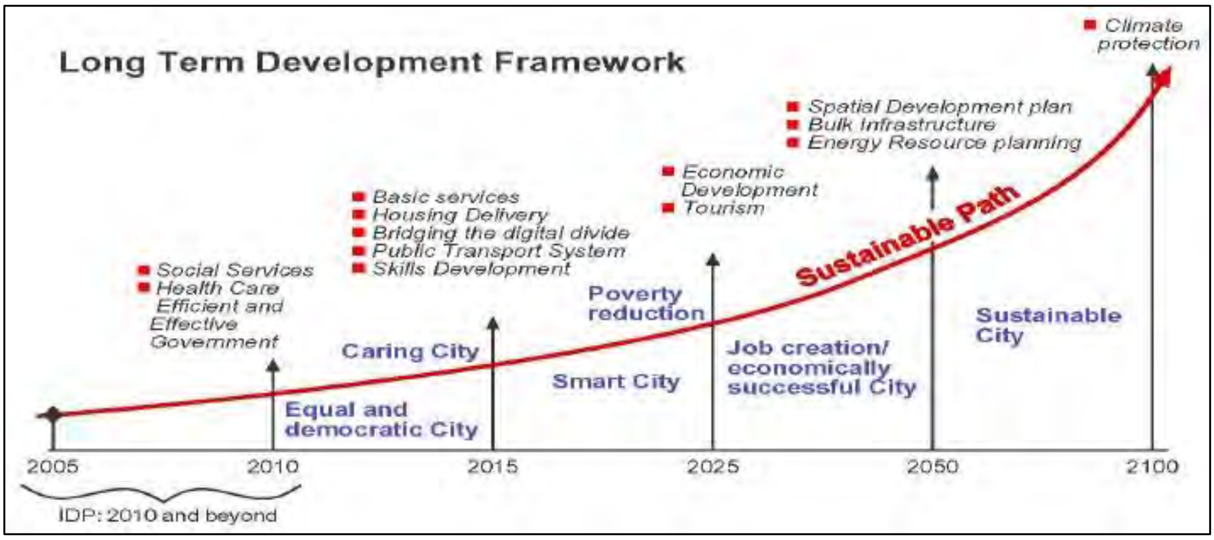


Figure 4.1 Visual representation of the EM LTDF 'Imagine Durban' (Source: EM IDP, 2015; p. 401).

Emissions mitigation is a cross cutting issue, which applies to all the thematic areas listed above, as all human activities and behaviour has an impact on emissions. Climate change mitigation is only addressed, albeit indirectly, in the second thematic area of ensuring a more environmentally sustainable city. Although, Garibaldi *et al.* (2014) stated that mitigation actions do not need an explicit climate change purpose and can fall under the umbrella of sustainable development actions. The environmentally sustainable city theme aims to ensure that the environment protects and promotes human and biodiversity health (Imagine Durban, 2010), which can be achieved through various strategies such as:

1. Incentives and discentives to ensure sustainability
2. Information and education
3. Integrated waste management systems
4. Pollution prevention
5. Water conservation
6. Energy efficiency and alternative energy production
7. Climate change prevention and preparedness
8. Productive ecosystems.

All of the above strategies require critical behaviour changes from individuals, business, and government to become responsible in using resources sparingly (Imagine Durban, 2010). The strategies are used to achieve short term (10 years), medium term (20 years) and long term (50 years) targets. The targets specifically related to emissions mitigation are that the city must be carbon neutral and energy is produced from renewable sources are long term targets. Short term targets are mitigation and adaptation measures for climate change must be put in place and citizens must use energy efficiently. Ensuring that the air in Durban is not harmful to human health is both a short term and medium term target and another medium term target is a zero waste city, which does not need landfill sites.

4.2.2 IDP Eight Point Plan

IDP plans are drawn out for a five year period, but are reviewed annually. The IDP and SDF were studied from the years 2011/2012- 2015/2016, as the pre-2011/2012 IDP's main developmental challenges were sufficiently summarized by Sutherland *et al.*, (2013), and still remain the same, such as high poverty and unemployment, HIV/AIDS and lack of access to basic services. Furthermore, Sutherland *et al.*, (2013) found that unsustainable development was only mentioned in the pre-2011/2012 IDP's and climate change considerations were only included in the IDP's from 2011/2012 onwards. The short term outcomes of the IDP are to address key challenges in delivering the LTDF, and are expressed in the Eight Point Plan. The EM IDP (2015) stated that the plans are separate yet supportive of each other. The current (2011/2012- 2015/2016) eight plans are:

1. Develop and sustain our spatial, natural and built environment.
2. Developing a prosperous, diverse economy and employment creation.
3. Creating a quality living environment.
4. Fostering a socially equitable environment.
5. Creating a platform for growth, empowerment and skills development
6. Embracing our cultural diversity, arts and heritage.
7. Good governance and responsive local government.

8. Financially accountable and sustainable municipality.

The IDP also mentions urban sprawl prevention, public transport provision, and a focus on ecosystem services. The EM has highlighted the need to reduce economic inequalities, and to identify sustainable livelihoods and economic opportunities for economic growth and job creation. Specifically, the focus of the EM local development opportunities are the identification of industrial land and the logistics corridor, which are derived from the national SIP, which aims to fast track large scale infrastructural projects. Therefore, the focus is only on the economic aspect of sustainable development.

The EM IDP has also recognized the importance of spatial planning to identify the ideal location of these economic opportunities, such as "economic nodes and transport corridors, and to contribute to urban service delivery efficiency, address rural needs and historical inequalities for the benefit of previously disadvantaged populations" (EM IDP, 2015; p. 98). However, the IDP does not mention the impact of economic and spatial development on the environment and lacks climate change considerations, including the spatial representation of climate change impacts or the areas of high emissions, to inform development options. Furthermore, the information on climate change in the IDP has remained the same in the annual reviews, and lacks new information. The transition to a green economy is highlighted from 2010 but lacks concrete plans and objectives.

Furthermore, the threat and impacts of climate change are mentioned but the mainstreaming of mitigation and adaptation measures are absent in the IDP, even though mitigation measures are short term and medium targets of the LTDF. However, the LTDF does not state the specific mitigation measures to be achieved in 10-20 years. Furthermore, climate change considerations lack details and a small fraction of the EM budget is set aside for environmental programmes (Aylett, 2010). This is similar to findings of Sowman and Brown (2006) and Ruwanza and Shackleton (2015), where environmental and sustainable measures have small budgets in the South African municipals, as other socio-economic developmental issues are more pressing. However, mitigation plans are cross-cutting, so does not require a specific budget, hence they could be included in each department's budget, to set aside for mitigation measure. Yet, the mitigation initiatives undertaken by the city such as the preparation of a low carbon report (ASSAf, 2011) and the results of the municipal and community emissions inventories (EM Energy Office, 2012) are not used to inform development planning in the IDP or used to set specific targets and actions to achieve the LTDF goals.

4.2.3 SDF and SDP

The SDF is a spatial representation of the IDP and the SDP which guides municipal decisions on the use, development, and planning of land, as well as the form and location of future spatial development (EM SDF, 2014). The SDF was formally adopted by the EM in 1997 in preparation for metropolitan consolidation to foster integration of the local councils (Breetzke, 2009). However, the six local councils followed their own plans, which increased competition to attract development in their own jurisdiction, even if it had negative implications on other councils or the metropolitan (Breetzke, 2009). One of the key tenets of the IDP is public participation, however the SDF is an internal process, undertaken by city planners, often guided by an external consultants, and lacks public participation during the process but undertaken at the end process (Hannan and Sutherland, 2014). This is based on planners know best, and also required to be aligned with national and provincial spatial development priorities.

The vision of the EM SDF (2014), since 2002 (Breetzke, 2009), is to develop a compact city to overcome the inefficiency of low density urban sprawl and to spatially restructure the Apartheid city (Figure 4.2; p. 100). The key strategies of the SDF are inner city urban renewal, densification and intensification of the urban development nodes and corridors, public transport infrastructure development, and projects which fulfil both the social and economic agendas, with the focus on industrial development. The development of the Integrated Rapid Public Transport Network (IRPTN) is key as densification is recommended along and within 4000 metres (m) of the network (EM SDF, 2014) and urban development is limited by the Urban Development Line (UDL)

(Sutherland *et al.*, 2013). Furthermore, the automotive, tourism, agriculture, chemicals, construction, textile, wood, pulp and paper sectors are highlighted as key in achieving job creation and local economic development. The spatial principles of the SDF are:

1. Mainstreaming and coordinating environmental planning:
    - Emissions mitigation and environmentally sensitive development.
2. Promoting spatial concentration and efficiency:
    - Densification and development of effective public transport and non-motorized transport.
3. Enhancing economic potential, coordinated planning and implementation to support economic growth:
    - Priorities are the promotion of Dube Tradeport in the north, freight and logistics, and ensure greater industrial land in south Durban, specifically Prospecton and Clairwood.
4. Promote balance and sustainable urban and rural development

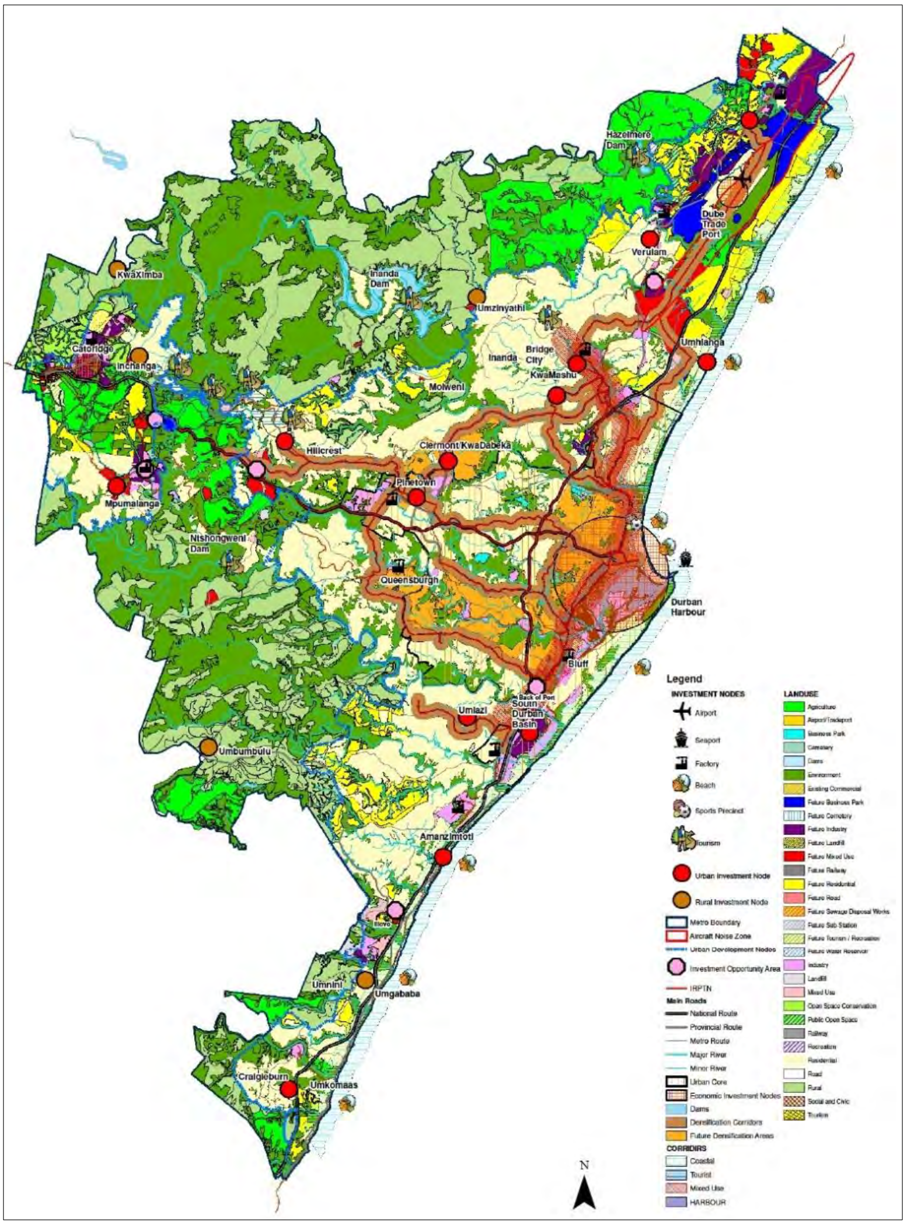


Figure 4.2 The SDF of the EM for the years 2010-2015. Source: EM SDF (2014; p. 163).

4.2.4 Industrial Land Strategy

The industrial land strategy is not a compulsory document required by local government, but is reviewed in this study because manufacturing is a major economic activity, and also represents the industrial development vision of the EM. The EM ILS vision is to be a proactive "facilitator of industrial land development, in order to build confidence in the market to invest in Durban and contribute towards economic growth and job creation" (The Planning Initiative, 2014; p. 7). A three-pronged approach is recommended for the municipality to facilitate industrial development, which are through: (i) decisive business and political culture, (ii) proactive infrastructure development, and (iii) innovation, research and development. It is under the third approach that green industrial development and climate change is considered. Specifically, the development of strategies to offset CO_2 emissions, the reduction of energy use of buildings and transport, and the support for renewable energy are applicable to emissions mitigation. The EM ILS also recommended the fast tracking of EIAs for major developments (The Planning Initiative, 2014). However, a thorough EIA was pertinent to the success of Mariannhill and Buffelsdraai landfill sites, as the EIA process with stakeholders took about 10 years (Payne, 2005; Moodley *et al.*, 2011).

4.2.5 Key Development Priorities

The spatial planning of the EM is considered fragmented due to the past Apartheid legacy and the competing local authorities (Breetzke, 2009). The current post-Apartheid spatial planning has given prominence to private developers in the north, which is in conflict with the EM plan to limit urban sprawl. Since 2006, Umhlanga has undergone high rates of development from undeveloped land, which was previously used for commercial sugar cane agriculture, to upmarket residential, commercial, and tourist buildings (Ahmed, 2008; EM IDP, 2015). Furthermore, there is increasing emphasis by the municipal for industrial development in the western edge, such as Cato Ridge and Hammarsdale, which lies outside the UDL, thus also contributing to urban sprawl by increasing edge development. The focus on these areas for green-field development will also threaten vital carbon sinks, as the majority of green spaces in these areas are not protected. Therefore, this demonstrates the rhetoric of the municipal IDP; that two opposing strategies that are found within the same document. Northern eThekwini (DubeTrade Port and Cornubia) is highlighted for future industry and business park development. Pinetown, DSIB, and CBD are rated as high potential for brownfields development, together with road upgrades for increasing road freight as much of the development in Durban is centred on the dig out port.

The SIP for Durban is the geographically-focused SIP 2, which aims to strengthen the logistics and transport corridor between SA's main industrial hubs (which are Gauteng, Free State, and Durban), improve access to export and import facilities, and the new port development. Although the NDP highlighted the transition to the green economy, the SIPs are not required to be green infrastructure. However, the IRPTN which is currently under construction in various road networks in the city and aims to be completed in 2027, can be considered a mitigation action, as it aims to improve public transport. The IRTP will have dedicated routes for public transport (bus, rail, and taxis), cycling, and walking which will connecting the major residential and mixed land use areas of Umlazi, KwaMashu, Hillcrest, Chatsworth, Tongaat, and Umhlanaga to the major places of employment such as Pinetown, Warwick CBD, the airport, Rossburgh, and Prospecton (EM IDP, 2015).

Faling *et al.* (2012) highlighted the following spatial planning measures for the development of a low carbon compact city:

- Identify strategic nodes and corridors which are the already existing concentrated, high density, mixed land use developments and develop public transport routes along these corridors.
- Developments should be located at established nodes to discourage urban sprawl and ensure efficient service provision and optimal resource use.
- Encourage mixed land use development so that infrastructure and facilities are shared
- Develop brownfields and vacant sites in city centre.

The EM has developed the above plans highlighted (Faling *et al.*, 2012) in the IDP's and SDF's, however there are inconsistencies, as urban sprawl needs to be limited and densification must be prioritized, yet commercial and private residential developments are prioritized at the edges of Durban. Moreover, the value of the SDF and SDP are criticized as it is the infrastructural limits, such as roads and the sanitation network, which are considered limits to urban sprawl rather than the actual development plans (Breetzke, 2009).

The EM has also developed a deprivation index, which shows the wards with the greatest needs. The deprivation index is a composite measure that includes engineering and social infrastructure backlogs, unemployment, and income. The most deprived wards are the peri-urban and former township communities, such as Cato Ridge, and INK. Therefore, this highlighted the wards which are in most need of development. The least deprived wards are the urban core, which are well developed, such as the CBD, Pinetown, and Umhlanga (EM IDP, 2015).

In addition to limiting urban sprawl, the densification of the city is mentioned as a strategy. The nodes which are the foci of the city IRTPN are the same nodes which are highlighted for densification. However, densification in Durban is limited due to the limited viable land due to topography, green space and natural resource protection (Breetzke, 2009). Furthermore, guidelines on densification are lacking in SA, as the municipality will have to overcome several barriers, such as the importance of land and house ownership in SA due to culture and history (Nel, 2011). An institutional barrier to constructing multi-storey residences in central areas, which are near places of work and easily accessible to the population, is financial viability because it costs more to build than single houses (Breetzke, 2009). Furthermore, there is a lack of market testing on higher density residences in SA (Breetzke, 2009). Thus, densification will only be possible in few locations in the city as well as there is a need to change the mind-set in the long-term, therefore other strategies are required to achieve a low carbon city, such as greening household infrastructure.

It is often stated that municipals in SA, and other developing countries, do not consider climate change mitigation, as they have other pressing issues such as economic development (Sowman and Brown, 2006; Holgate, 2007; Winkler, 2009; Romero-Lankao and Dodman, 2011; Ruwanza and Shackleton, 2015). However, this is not unique to South African cities, as Jabareen (2015) revealed that major developed cities have included emission targets but limited adaptation measures in their city plans, and the majority of developing African, Asian and Middle Eastern cities and Eastern European cities, lack emission mitigation targets and adaptation measures (Jabareen, 2015).

In summary, most of the development projects are initiated by private developers and national government (Table 4.2; p. 106). Private developers and owners do not allow municipalities to negotiate on the release of land at appropriate locations, as they have the advantage, thus rapid development takes place on an ad hoc basis (Ahmed, 2008) or even when they are not warranted (Michel and Scott, 2005). Furthermore, the national SIPs, which are based on socio-economic developmental needs, without recognizing the distinct strengths and potential of places. Thus, key development projects are seen to lack geographical context as places are not regarded as influencing factors in economic productivity and performance (Turok, 2012). Furthermore, this is similar to other studies which indicated that the local scale emissions reductions are limited due to macro-economic and structural factors (Wilson, 2006; Bai, 2007; Holgate, 2007; Burch, 2010; Dhakal, 2010; Kocabas, 2013; Geels, 2014), which are beyond the control and jurisdiction of local government (Bai, 2007; Aylett, 2011).

The economic development and large scale infrastructural plans show the most alignment because they are the national development plans. The plans for compact city development and limiting urban sprawl are disjointed and in conflict with the economic development and infrastructural plans of both local and national government. Emissions mitigation and environmentally sensitive development are mentioned but are considered as rhetoric because strong policies and guidelines are lacking, let alone implemented. Furthermore, none of the major developments summarized in Table 4.2 (p. 106) pertain to the green economy. However, although the municipality has undertaken the construction of public transport infrastructure, which can be considered a mitigation action, it is expected that the amount of road freight transport will increase due to the expansion of the current port and development of the new port.

Additionally, the recommendations of the ASSAf (2011) Low Carbon Report for Durban, such as focusing on reducing emissions from heavy trucks, were not considered by the municipal. Furthermore, the results of the EM Energy Office (2012) emissions inventory does not inform city plans and policies or even mentioned in the IDP. Thus, the emissions inventory has not been used to set targets, and identify interventions for emission reductions and low carbon development. Moreover, the municipal lacks spatial representation of climate change impacts, information on areas of high emissions, or potential areas for low carbon pilot programmes.

Table 4.2 Summary of key development projects in the EM for the years 2010- 2015. Adapted from the EM SDF (2014) and the EM IDP (2015).

Location	***Sector and sub-sectors***	***Project details***	***Project stakeholders***
• Cato Ridge Inland Hub • Kings Estate • Hammarsdale	Logistics Industry	Linked to Aerotropolis development	EM
	Road transport Industry Logistics	Upgrade of N3 road and the development of Keystone Industrial Park	SANRAL for road upgrade EM for industrial growth
• Prospecton and Isipingo	Port and logistics	Dig-out port	Transnet, national government and EM
	Transport equipment manufacture	Automotive supplier park	KZN government with assistance from private corporation (Toyota)
• Point • Durban Gauteng Corridor	Tourism Logistics Manufacturing Commercial spaces Tourism and sport	Passenger terminal for cruise liners Revitalization of Pinetown and CBD	Transnet and KZN Government National government and EM
• Mount Edgecombe and further development of Umhlanga Ridge town centre as well as the western expansion of Umhlanga Ridge • Northern Urban Development Corridor	Road transport Commercial and retail Residential Greenfields development	Construction of corporate offices, private hospital and residential development and subsidised housing in Cornubia. Revitalization of town centre links between Durban and Richards Bay (INK, Verulam, Tongaat)	Private developers EM and the National Department of Human Settlements (Cornubia) EM and private developers
• INK, Umlazi, Clermont-KwaDabeka	Road transport Retail	Township development	EM, national government, and private developers

4.3 Total Emissions in Durban

The total emissions calculated for Durban for the year 2013 amounted to 12.21 $MtCO_2e$. Road transport fuel use contributes the most to emissions (43%), followed by industry and residential electricity use (Figure 4.3; p. 108). Overall, electricity consumption from industry and residential use contributed to more than half of emissions (55%). The EM GHG emissions inventories for 2010-2012 also indicated that the transport sector was the highest contributor to emissions, followed by industrial and residential sectors (EM Energy Office, 2012). Only CO_2 emissions were calculated from road transport fuel, and industrial and electricity consumption, as it is the dominant GHG emitted from those sectors, due to the combustion of fossil fuel (DEA, 2011c; IPCC, 2013; DEA, 2014b; Eskom, 2014; Tongwane *et al.*, 2015). Thus, CO_2 is the dominant GHG, represented by ~98% of the total emissions.

CH_4 and N_2O are the dominant gases emitted by solid waste disposal and wastewater treatment (Manfredi *et al.*, 2009; Mohareb *et al.*, 2011; Shrestha *et al.*, 2012; Bao *et al.*, 2014; Friedrich and Trois, 2015). However, CH_4 and N_2O emissions from the waste sector makes minimal contributions to global, South African, and Durban total emissions, when compared to CO_2 (DEA, 2011c; EM Energy Office, 2012; DEA, 2014b). However these emissions are expected to rise, with the specific focus on solid waste disposal, as it creates localized emissions and also has the potential to offset emissions (Manfredi *et al.*, 2009). Therefore, in this study, CH_4 and N_2O emissions were calculated from solid waste disposal and wastewater treatment disposal, expressed in tCO_2e. CH_4 contributed ~2% and N_2O contributed 0.11% to total emissions in 2013 in Durban.

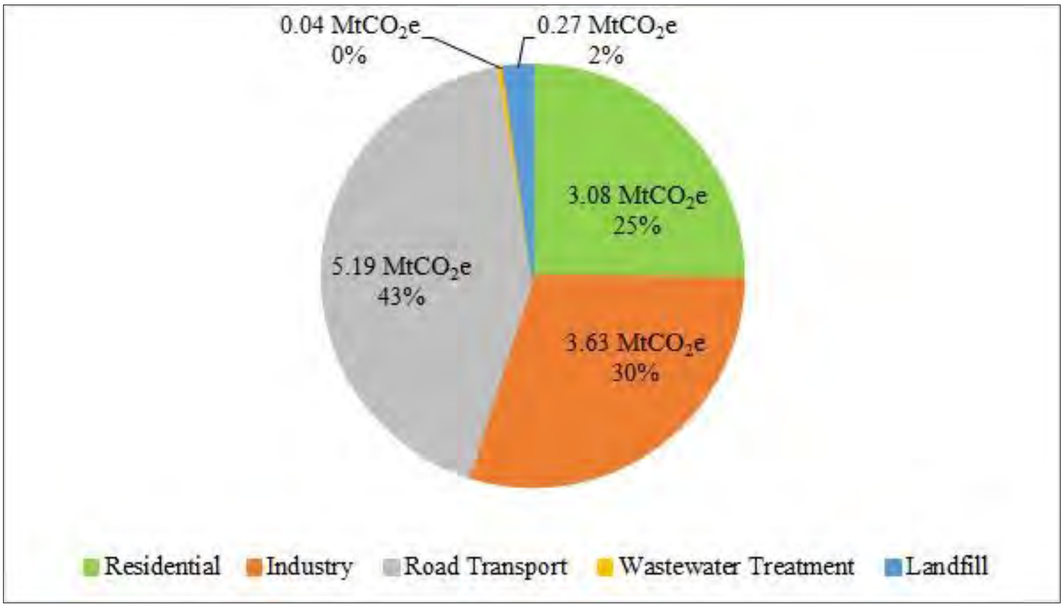


Figure 4.3 Sectoral shares of GHG emissions (in $MtCO_2e$ and percentage) in the EM for the year 2013.

4.3.1 Emissions Inventory Comparisons

The results from this study are compared to the official EM community emissions inventories (EM Energy Office, 2012), and other studies undertaken for Durban for the transport (Thambiran and Diab, 2011a), industry (Thambiran and Diab, 2011b), and solid waste (Friedrich and Trois, 2015) sectors, to determine the suitability of the emissions inventory for further analysis.

The total emissions from this study are significantly less than the EM inventories from 2010-2012, due to the varying approaches of the study. This study was limited by the spatial location of consumption activities, and also lacked data on direct energy consumption from industry. Other energy types used by industries in the municipality, such as coal, fuel oil, refinery gas, paraffin, liquid petroleum gas, and methane rich gas data are only available at the magisterial district scale, therefore it is difficult to disaggregate into economic sub-sectors and, furthermore, industries are not obligated to provide information on their energy use. Additionally, this study lacked emissions from air and marine transport, because there are uncertainties on how to attribute those emissions and also to spatialize the emissions.

Therefore, this study is not comprehensive but does account for the key sectors which are discussed in section 4.3.2.

Overall, the sectoral emissions calculated for this study are in agreement with similar studies (Table 4.3; p. 110), with the most variations in the road transport, industrial electricity consumption, and solid waste disposal emissions, due to the different approaches and emission factors used. For the road transport sector, both EM Energy Office (2012) and Thambiran and Diab (2011a) recorded higher emissions due to the fuel balance method, which assumed that all fuel sold within the municipality is used within the boundaries, and also that all petrol and diesel were consumed by road transport vehicles. Therefore, the method used by EM Energy Office (2012) and Thambiran and Diab (2011a) did not account for usage from other sectors, such as off-road vehicles used in agriculture, mining, and construction (SAPIA, 2008; Tongwane *et al.*, 2015).

This study recorded lower industrial and residential electricity consumption emissions than the EM Energy Office (2012), despite industry and residential electricity use increasing by 0.26% and 0.92% respectively, from 2012 to 2013. The EM electricity consumption emissions are higher due to the use of the Eskom emission factor, which included losses from transmission and distribution (Eskom, 2012). This study did not include losses from transmission and distribution in accordance with ICLEI (2014) guidelines. Similar to this study, Thambiran and Diab (2011b) accounted for CO_2 emissions from industry electricity use and excluded GHG emissions through process and fugitive emissions related to manufacturing due to the lack of data on direct measurements.

Friedrich and Trois (2015) recorded higher emissions from solid waste disposal at the three municipal landfill sites, whereas this study calculated emissions from the three municipal and two private landfills. However, Friedrich and Trois (2015) used a life cycle approach, thus included emissions from the collection and transportation of waste, of which the authors developed their own emission factors. Furthermore, the authors (Friedrich and Trois, 2015) used a methane commitment method, which is suited to planning and the waste in place FOD method, which was used in this study, is appropriate for emissions inventory (Mohareb *et al.*, 2011). Furthermore, ICLEI (2014) stated that GHG emissions calculated with the methane commitment method will be higher than emissions estimated with the FOD model. The increase in wastewater treatment emissions are expected, due to population increase.

Table 4.3 Comparison of this study's emissions inventory with other studies, expressed in $MtCO_2e$, with the year of study within brackets.

Sector	***EM Energy Office (2010)***	***EM Energy Office (2011)***	***EM Energy Office (2012)***	***Other studies***	***This study (2013)***
Road transport	5.26	5.66	6.18	6.03 (2008)[4]	5.19
Industrial electricity	4.81	4.74	4.84	2.71 (2008)[5]	3.63
Residential electricity	3.56	3.41	3.58	-	3.08
Solid waste	0.30	0.36	0.28	0.75 (2012)[6]	0.27
Wastewater treatment	0.02	0.02	0.03	-	0.04

[4] Thambiran and Diab (2011a), [5] Thambiran and Diab (2011b), [6] Friedrich and Trois (2015)

4.3.2 Sectoral Emissions in Durban

The comparison of sectoral emissions with published studies and the municipal inventory suggested the emissions inventory compiled in this study is suitable for further analysis. Emissions from the road transport, industry and residential electricity consumption, and waste sectors will be examined in detail, together with the respective sectoral emission maps to indicate the wards within Durban that are associated with high sectoral emissions. Therefore, the sectoral specific information will help to develop sectoral specific mitigation strategies, as the areas of high emissions activity can be identified. The road transport emissions are discussed in relation to the vehicle population in Durban. Emissions from industrial and major commercial electricity are further disaggregated into economic sub-sectors, and compared to the specific contribution of these sub-sectors to Durban's economy, to provide an indicator of emissions intensity. The residential electricity consumption emissions are examined in the context of household access to electricity. Wastewater treatment emissions are considered in relation to the UDL and solid waste emissions are compared to the amount of waste received in landfills, and also the household access to waste collection and disposal services.

4.3.2.1 Road Transport

The highest total emissions from both petrol and diesel fuel use are above 200000 tCO_2e. In comparison, the average eThekwini road transport emissions are at 50000 tCO_2e and below (Figure 4.4; p. 112). The spatial distribution of emissions from road transport fuel demand is from central Durban to the North coast, and Durban South, which is concentrated in Isipingo (Figure 4.4. p. 112). Specifically, the highest emitting wards such as Umhlanga, Effingham, and Durban North have high emissions from both petrol and diesel consumption. These areas are associated with affluent residential suburbs, tertiary economic activities, such as business and office parks, and light industry. Isipingo and Umbilo road transport emissions are mainly due to diesel consumption. Petrol emissions are from wards which are associated with light industry, commercial activities, and middle to high income residential neighbourhoods. Diesel emissions are from wards which are associated with heavy and light industry. Specifically, the wards with the highest emissions are associated with light passenger petrol and heavy load diesel vehicle ownership and heavy passenger petrol vehicles, which are minibus taxis, are mostly located in Umlazi.

In Durban, light passenger vehicles make up 68% of the total vehicle population registered, which is higher than the national level of 54.5% (Merven *et al.*, 2012). This is due to rising affluence and the status associated with private vehicle ownership, as well as the inadequate and unreliable public transport infrastructure. Light load vehicles are the second most common vehicle type, followed by heavy load vehicles. Nationally, heavy load vehicles make up 3.2% of the vehicle fleet (Merven *et al.*, 2012), but constitutes 5% of the vehicle fleet in Durban, thus indicating the influence of logistics and port activities, specifically the movement of goods between Durban and the economic hub of Gauteng. Heavy passenger vehicles are the least represented vehicle type, indicating the low level of public transport available on roads. Furthermore, approximately 25500 heavy passenger vehicles are classified as minibus taxis (eNatis, 2014), which are the most popular mode of public transport available, as it is easily accessible and flexible (Merven *et al.*, 2012). Moreover, Apartheid planning and racial segregation of neighbourhoods have resulted in low densities (Nel, 2011) and a large number of commuters, whom are often located far from their employment (Merven *et al.*, 2012).

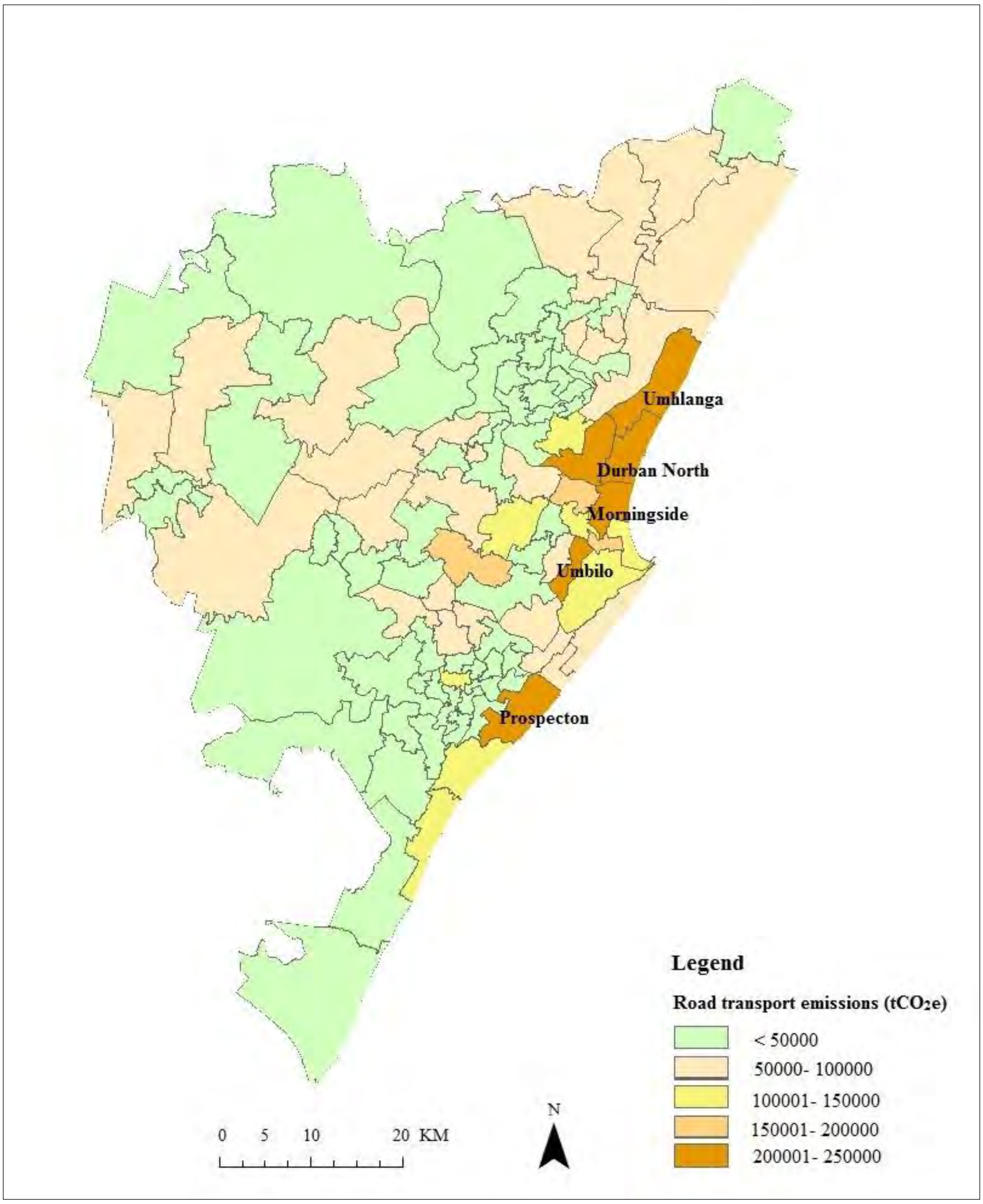


Figure 4.4 Total GHG emissions (tCO_2e) from road transport in the EM for the year 2013.

Overall, the dominant fuel type is diesel which is responsible for 57% of road emissions. This finding is similar to national trends, where diesel consumption has grown at a faster rate than petrol consumption (Merven *et al.*, 2012) and has overtaken petrol consumption (SAPIA, 2013). Heavy load vehicles make up 5% of the total vehicle population in Durban, yet contributes the most to emissions from road transport (Figure 4.5). Diesel is the dominant fuel used in heavy load trucks, which are the main transport mode used in the frequent haulage of goods, between Durban and Johannesburg. The second major contributor to road emissions is light passenger petrol vehicles. Another salient feature is that heavy passenger vehicles contribute the third most to emissions, yet are the least represented vehicle type (4% of total vehicle population). This is due to the high mileages of these vehicles due to the urban sprawl spatial form and as is the most accessible mode of public transport available to commuters, many of whom live considerable distances away from where they work (Merven *et al.*, 2012).

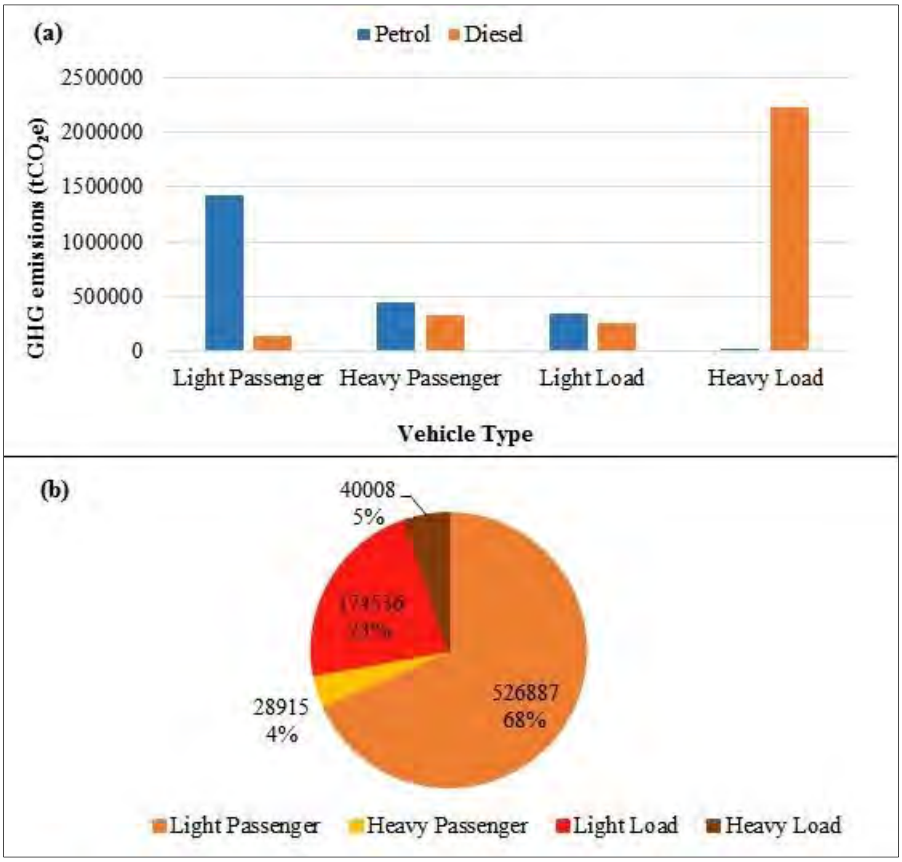


Figure 4.5 The GHG emissions (tCO_2e) from road transport, according to (a) vehicle class and fuel type, and (b) vehicle class composition (in figures and percentage) of the EM vehicle population for the year 2013.

Furthermore, the emissions are considered together with the passenger car vehicle ownership rate, which is expressed as the number of vehicles per capita (Table 4.4). Low car ownership rates indicate that the people do not have access to private transport and are reliant on public and other modes of transport, such as walking (Merven *et al.*, 2012). The South African average is 180 vehicles per capita, which is higher than the KZN average (117 vehicles per capita) (Merven *et al.*, 2012) and the Durban average of 157 vehicles per capita. However, within Durban, there are localized areas with high passenger car ownership. Generally, the wards with the highest emissions have the highest car ownership rates per capita, that range from 618-1030 vehicles per capita, and are similar to the private vehicle ownership rates of developed countries, which are 500-800 vehicles per capita (Merven *et al.*, 2012). However, the exception is Prospecton, which has a lowest passenger car ownership rate of the high emitters (25 vehicles per capita), which is the lowest vehicle ownership rate studied. Thus, this indicates the dominance of heavy trucks and freight transport in Prospecton.

Table 4.4 Passenger car ownership rates expressed in per capita.

Place	***Vehicle ownership per capita***
Developed countries average*	500-800
African average*	40
South African average	180
Gauteng average*	314
KZN average*	117
Durban average	157
Umhlanga	1030
Umbilo	785
Morningside	699
Durban North	791
Effingham	618
Prospecton	25

*Source: Merven *et al.* (2012)

4.3.2.2 Industry

The highest emissions from industry and commercial activities electricity consumption are the SDIB wards of Prospecton, Merebank, and Bluff and west of the SDIB which includes the Harbour and Clairwood (Figure 4.6; p. 116). There are 102 major manufacturing industries located in these wards which are fuel, petrochemicals, chemicals, and oil, paper production, transport equipment, food and beverages, metals and machinery, textiles, and non-metallic materials, such as plastics. These industries are responsible for approximately 45% of the total industry emissions and 13% of total GHG emissions calculated.

The major users of electricity are the paper mill located in Merebank, two petroleum refineries located in Prospecton and Bluff, and the port. These industrial activities are of local and national economic importance. For example, the port is the busiest in Africa (EM, 2014) and the two petrochemical refineries produce about 60% of the petrol in SA (Aylett, 2010). Other areas of interest are Pinetown and Umhlanga, which are associated with light industry and service industries respectively. Industrial process emissions are significant contributors to GHG emissions, however due to the lack of information on direct measurements of GHG emissions from industrial facilities in Durban (Thambiran and Diab, 2011b). Furthermore, this study only included emissions from electricity consumption and excluded other energy sources, such as coal and refinery gas, because this information is only available at the magisterial district scale and could not be disaggregated into sectors. Furthermore, industries are not mandated to provide data, nor is it in their competitive interest to make data available. However, the inclusion of energy emissions from electricity consumption is justified as it contributed 41% to total emissions from industry energy use in Durban, followed by coal (28%) and refinery gas (22%) (Thambiran and Diab, 2011b).

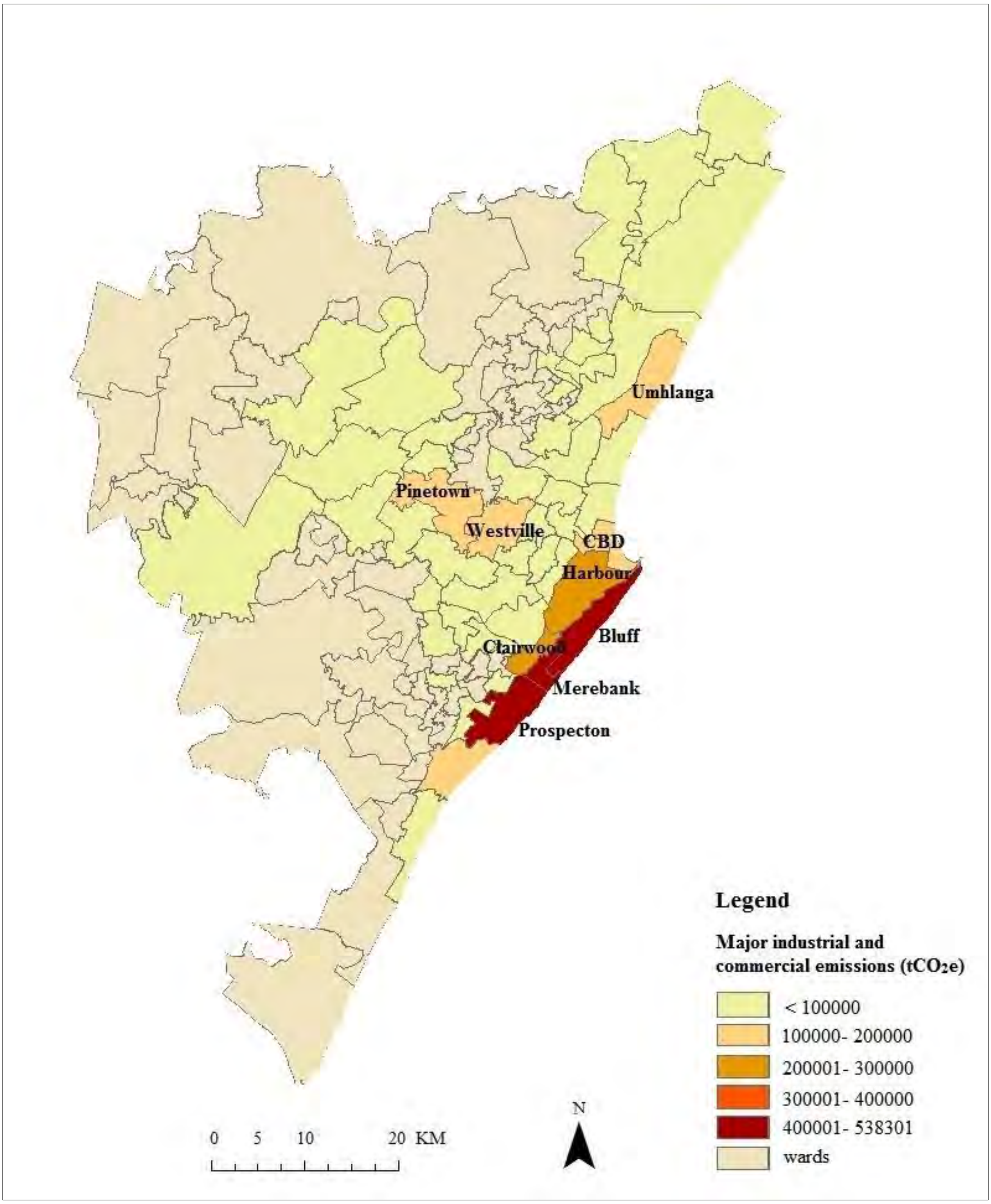


Figure 4.6 GHG emissions (tCO_2e) from major industrial and commercial electricity consumption in the EM for the year 2013.

The highest emitting wards are compared according to the emissions per floor space (Table 4.5), and expressed as emissions footprint (tCO_2e per hectare). Prospecton has the highest emissions, and the largest industry floor space area, due to 29 heavy industries, but has a low emissions footprint. Merebank has the lowest industrial extent and the highest emissions footprint, thus indicating the intensity of the industrial plants located, which are both owned by the paper mill. Jacobs is a major industrial area, and has the largest number of industrial plants located yet has the second lowest emissions footprint.

Table 4.5 Industrial emissions footprint of the highest emitting wards, expressed in tCO_2e per hectare (ha).

Ward	***Number of industrial plants***	***Floor space[7] (ha)***	***Emissions (tCO_2e)***	***Emissions footprint (tCO_2e/ha)***
Prospecton	29	190	536012	2821
Jacobs	37	118	202729	1718
Harbour	21	141	258309	1832
Bluff	13	18	410516	22806
Merebank	2	11	424081	38553

[7]Source: The Planning Initiative (2014).

Globally, the chemical and petrochemicals and paper pulp industry are the most energy intensive manufacturing industries (IEA, 2007), and amongst the largest GHG emitters due to process emissions (Huisingh *et al.*, 2015). Similarly in Durban, the fuel, petroleum and chemicals industry are the main users of electricity, followed by the paper and pulp industry, and transport equipment manufacturing (Figure 4.7; p. 118). These industries are almost exclusively located in the SDIB. Furthermore, the paper and pulp industry has the highest emissions intensity, followed by the transport equipment manufacture, and metal, machinery and appliances manufacture. Thus, the manufacturing industries are the most emissions intensive, based on electricity. From the rest of the manufacturing industry, the food and beverages is the least emissions intensive. The tertiary and service sectors, such as finance, health and social services and education are responsible for low emissions and are also the least emissions intense, from an electricity consumption perspective. However, exceptions in the tertiary and service sectors are retail and wholesale, which is the fifth largest contributor to emissions, but have emissions intensity from electricity consumption. Furthermore, the hotels and restaurants economic sub-sector has the highest emissions intensity, from electricity use, from the tertiary sector. However, this is expected as tourism is one of the main economic activities of the city. Therefore, from both a total emissions and emissions intensity reduction perspective, the SDIB is highlighted as a key area, as it is the location of the highest industry emissions from electricity consumption, due to the concentration of both high total emissions and emissions intensive sectors.

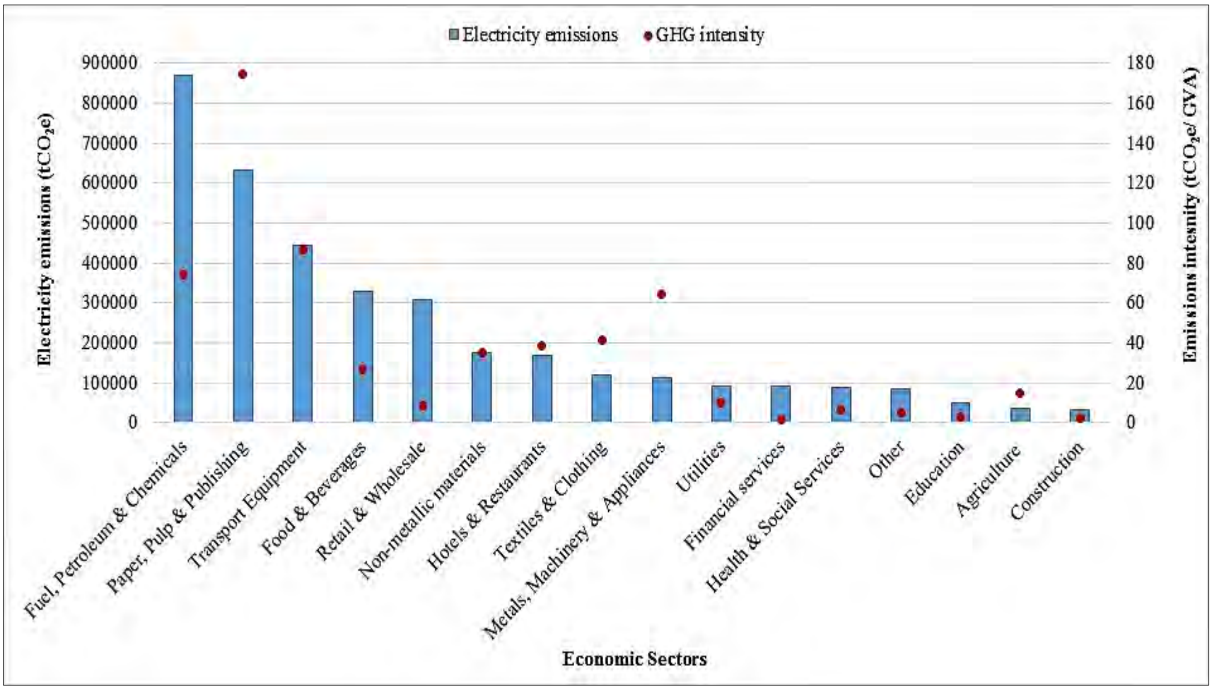


Figure 4.7 Electricity consumption emissions and emissions intensities of the economic sectors in the EM for the year 2013 (with GVA expressed in millions of rands).

4.3.2.3 Residential

The highest CO_2e emissions from residential electricity consumption (Figure 4.8; p. 121) were found in suburbs in the urban core. The specific suburbs are the Pinetown south, Hilary, Durban North, Umhlanga, and Illovu. These suburbs have middle to high income households and low population densities (EM IDP, 2015). The lower emissions are found in the rural periphery and the CBD, which is associated with business and commercial activities and more dense residences. This is consistent with studies in literature on the spatial distribution of carbon emissions from households, which have lower emissions from household energy use in the CBD and higher emissions in suburbs (VandeWeghe and Kennedy, 2007; Dodman, 2009a; Satterthwaite, 2010; Hoornweg *et al.*, 2011; Hillmer-Pegram *et al.*, 2012; Jones and Kammen, 2014). There are patches of low emissions in between areas of high emissions which are the former townships. Furthermore, the majority of emissions from the former township areas are below 30 000 tCO_2e, which is close to the city average of 29916 tCO_2e. Although there are about 956 000 households in Durban, the focus was on formal households, as ~34% of households are considered informal and 11% are rural households, which lack access or have limited access to electricity (Taylor *et al.*, 2014; EM IDP, 2015).

Household electricity consumption is the main target of national governments electricity saving campaigns and also subjected to electricity load shedding and electricity price increases. However, information from the EM Electricity (2014) indicated that, overall, total electricity consumption of households has decreased. Household electricity emissions (and thus consumption) from the major residential households, which are credit customers, decreased from 2008 to 2011 due to load shedding, followed by a slight increase from 2011 to 2013, when load shedding was re-introduced. The slight increase in household electricity consumption emissions could be due to load shedding and electricity saving campaigns initiated by the EM, such as changing of lightbulbs, which could have mitigated a large increase in electricity consumption. Although it is positive that emissions are decreasing, it is still problematic as the source of electricity generation is still fossil fuel-based. If Eskom did not implement load shedding to reduce supply, emissions would be higher.

However, it is important to note that the number of credit customers are decreasing, thus indicating that a fewer number of households are responsible for major electricity consumption. Prepaid customers are increasing, which indicates that more households are using less electricity, due to increasing electricity prices, and are also becoming reliant on other forms of energy to meet their needs. This is informed by the DoE (2012) National Household Energy Survey which indicated that prepaid electricity households also use other energy sources such as candles, paraffin, firewood, and gas. Furthermore, 323000 households are not electrified, and it is expected to take 32 years to address this backlog (EM SDF, 2014). The backlogs represent the future energy demand, which will increase GHG emissions in the future. Therefore, it is important to provide these communities with low carbon solar energy, generated on-site, so that they are not reliant on the unreliable national grid, and not subjected to electricity price increases. This will ensure that the future provision of electricity will not increase emissions.

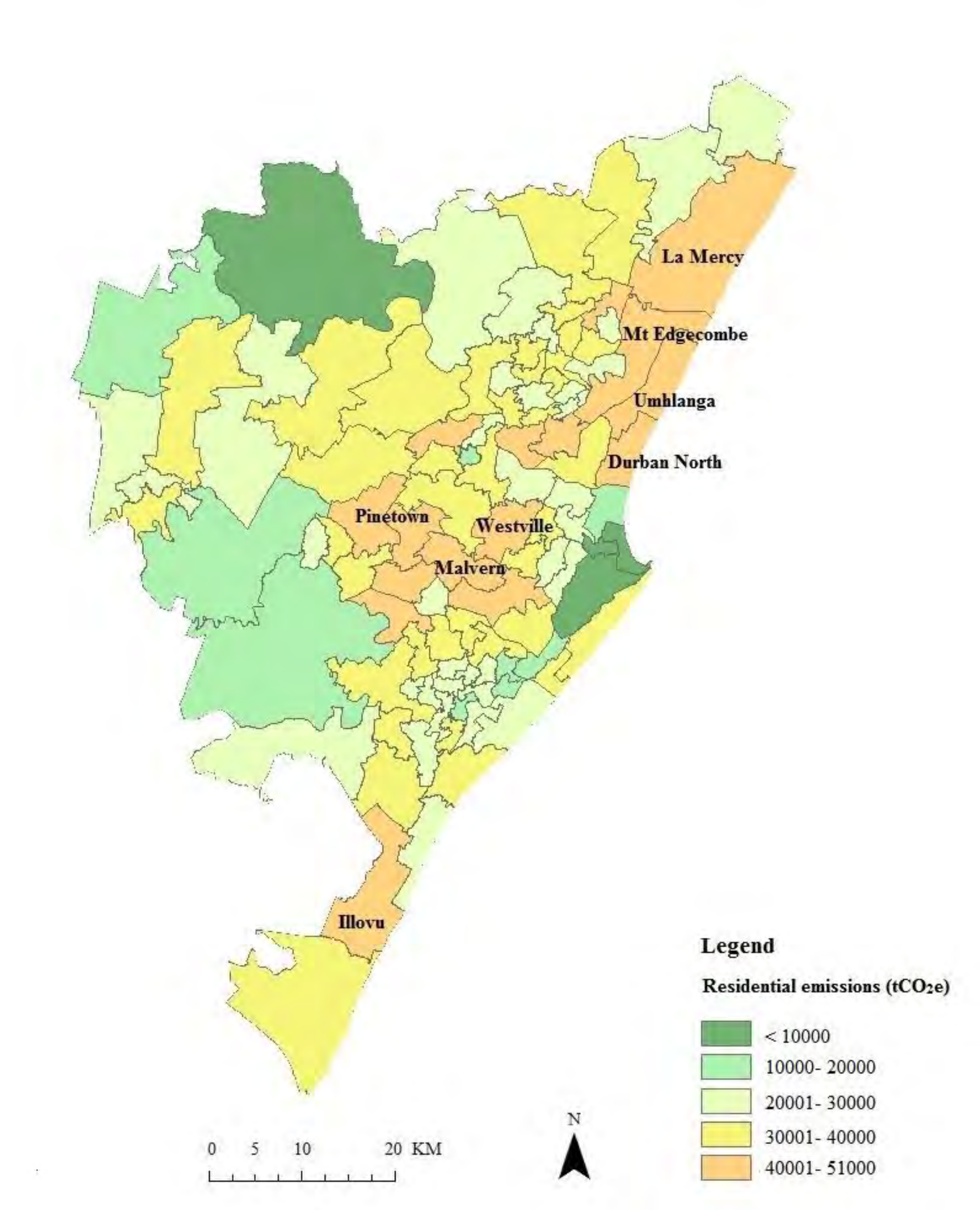


Figure 4.8 GHG emissions (in tCO_2e) from household electricity consumption in the EM for the year 2013.

4.3.2.4 Waste

Emissions from waste, such as solid waste disposal and wastewater treatment plants, contribute the least to total emissions as shown in Figure 4.1 (p. 95). Further disaggregation of the waste sector revealed that solid waste emissions contributed 91% to the sectoral emissions (Figure 4.9). Solid waste emissions were estimated from the landfills mentioned in section 3.6.4. Wastewater treatment emissions were calculated from the municipal owned and operated plants only. Further analysis of emissions from solid waste disposal in landfills and WWTPs will be discussed.

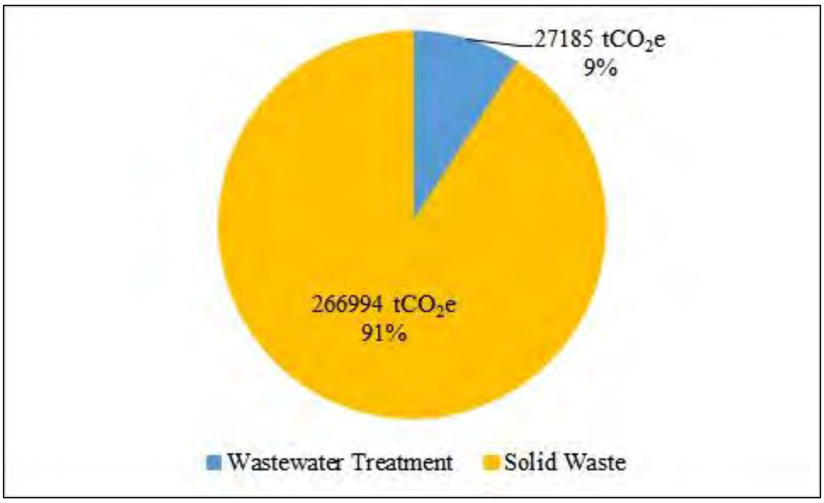


Figure 4.9 GHG emissions from waste emissions (in tCO_2e and percentage) in the EM for the year 2013.

Solid Waste

The emissions inventory for solid waste disposal at landfills in the for 2013 (Figure 4.10; p. 125) established that the two private landfills, Bulbul and Shongweni were the highest emitters, contributing 36% and 35% respectively, to total solid waste emissions. The Bisasar landfill was responsible for 20% of solid waste emissions, and Mariannhill contributed the least emissions (2%) in this sector.

Bulbul landfill, is a privately owned and operated by Wasteman waste services company, is surrounded by Indian and African communities of Chatsworth and Umlazi, located in close proximity to households. The landfill, which accepted low hazardous level industrial waste (Friedrich and Trois, 2010), closed in 2011, meaning that it stopped receiving waste, after numerous community protests and campaigns (Cole, 2011). However Bulbul landfill is still the highest emitter in this sub-sector, as it does not have a LFG collection system (EM Energy Office, 2012). The Shongweni landfill is located on the peri-urban fringe of the EM, near Shongweni nature reserve and KwaNdengezi community, is privately owned and operated by EnviroServ waste management company. The landfill which also does not have an LFG collection system and this has contributed to high emissions in this sub-sector. Furthermore, Shongweni landfill is the only currently operating landfill that accepts low to moderate hazardous level industrial waste (Friedrich and Trois, 2010).

The Bisasar landfill is the most important landfill in the EM, and also the largest and busiest landfill in SA (Parkin *et al.*, 2006; Friedrich and Trois, 2013). The landfill caters for central Durban and received the most volume of waste, but is not the largest emitter due to the CDM project which is LFG collection and electricity generation, which has significantly mitigated emissions so that it was the third highest emitter in the EM. However, the Bisasar landfill is associated with conflict and community protests due to its location within the residential area (Parkin *et al.*, 2006; Leonard, 2012). Another example of the CDM LFG collection and electricity generation project is Mariannhill landfill, which is located about 20 km from the city centre, and receives waste from the western areas of the EM (Moodley *et al.*, 2011) Mariannhill landfill received the second least amount of waste but is the lowest GHG emitter due to emissions mitigation. Furthermore, the Mariannhill landfill is SA's first landfill conservancy, and is considered a textbook example due to its location hidden from public view, by the natural topography and vegetation, although it is located near communities (Parkin *et al.*, 2006; Moodley *et al.*, 2011).

Buffelsdraai landfill was established in 2009 to cater for northern EM (Moodley *et al.*, 2011), and is hidden from public view and away from communities. The Buffelsdraai landfill has low emissions because it receives the lowest volume of waste. However, the landfill does not have the LFG collection system in place (Friedrich and Trois, 2015). Furthermore, the closure of the Bisasar landfill at the end of 2015 will increase the amount of waste received at Buffelsdraai, which is located ~40 km from Bisasar. Furthermore, Mariannhill landfill will also close and be replaced by new site in Shongweni in 2022, and a new landfill is planned in Illovu, although the date is unknown (EM IDP, 2015). Thus, solid waste will be transported further north, west and south to landfills which do not have LFG collection systems and electricity generation (and plans are unclear if it will be in place), which will increase emissions from solid waste disposal, as well as life cycle emissions from the collection and transportation of solid waste (Friedrich and Trois, 2015).

Furthermore landfill emissions must be noted in the context of solid waste disposal in EM, where 88% of total households have their refuse removed by the local authority or private contractors (StatsSA, 2013). The remaining households (12%) do not have their refuse removed, and subsequently dump waste on their own, in a communal dump, or do not have a specific method, and thus cause the most environmental damage (Manfredi *et al.*, 2009). The wards associated with these activities are the peri-urban tribal authority areas, which experience non-refuse removal service rates of 52-83% (StatsSA, 2013). The medium term (20 year) target of the EM LTDF is a zero waste city (Imagine Durban, 2010), which does not need landfill sites, yet more landfill sites are being planned, whereas municipal resources should be targeted at diverting waste away from landfills and encouraging citizens to reduce consumption, recycle, and compost organic waste (Friedrich and Trois, 2015).

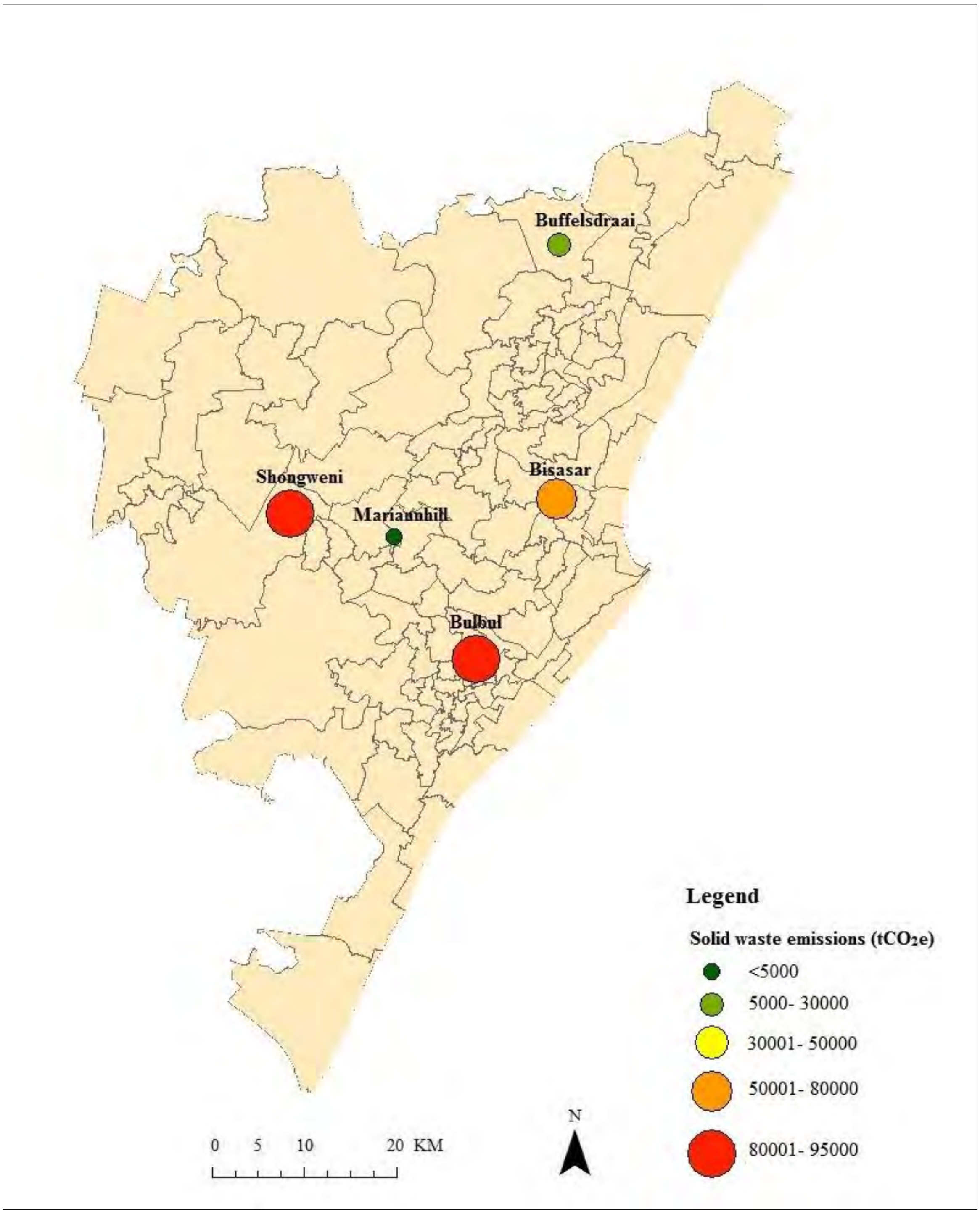


Figure 4.10 GHG emissions (tCO_2e) from solid waste disposal at landfills in the EM for the year 2013.

An analysis of the waste composition received by the landfills, which are represented by average values (Figure 4.11), are important to understand the contribution to emissions. The municipal landfills received solid waste mostly from households, garden, business, and industry, thus the majority of the waste were organic waste. The private landfills received the highest contribution of general solid waste from businesses and industry. The highest emissions were from Bulbul landfill, which received high contributions of both general solid waste from businesses and industry, and household waste, which has high organic content, and building rubble. The waste composition from Shongweni landfill differs from the other landfills, as it does not receive household or garden waste but received waste mainly from business and industry, as well as the high makeup of sludge and liquid, and ash, which are considered low to moderate hazardous industrial waste.

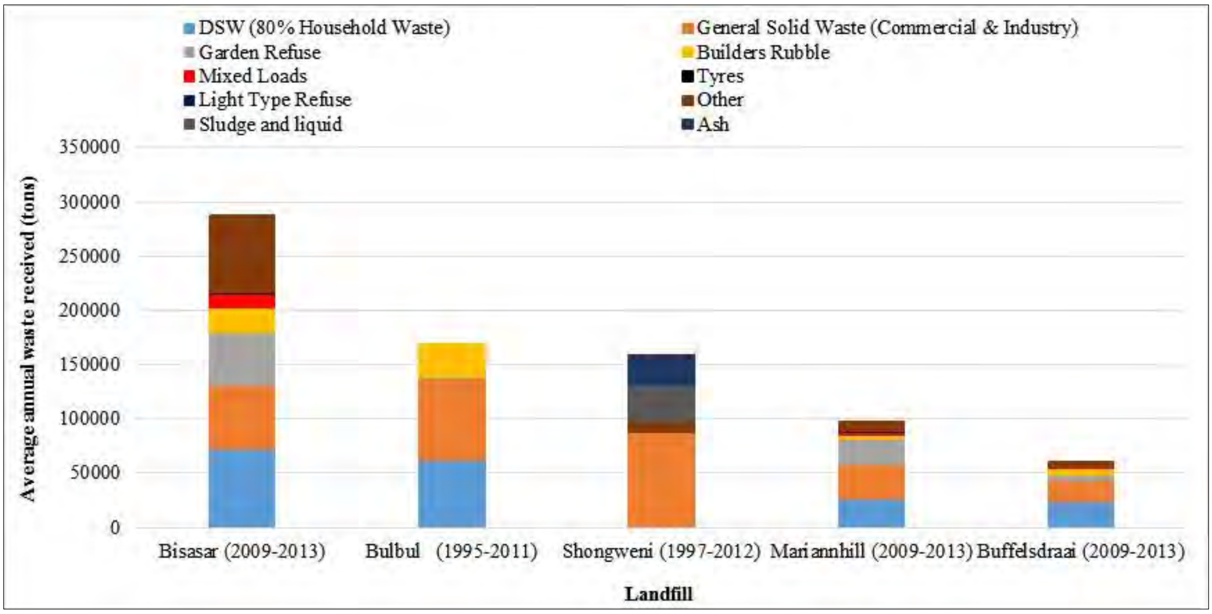


Figure 4.11 Average annual amount and composition of waste received at the landfills studied. The years used to calculate averages are in brackets.

Wastewater Treatment

Emissions from the Central, Isipingo, and Umbilo wastewater treatment plants were responsible for nearly half of the emissions from the wastewater treatment sector

(Figure 4.12). However, this is expected as these three plants serve the most population. Furthermore, the waterborne WWT network in the EM is limited by the UDL, which is based on the areas served by the current water-borne municipal sanitation network infrastructure (Breetzke, 2009). The intention of this was an attempt to limit urban sprawl, specifically the increasing westward growth of the Umhlanga development, which was in competition with the CDB development and revitalization (Breetzke, 2009).

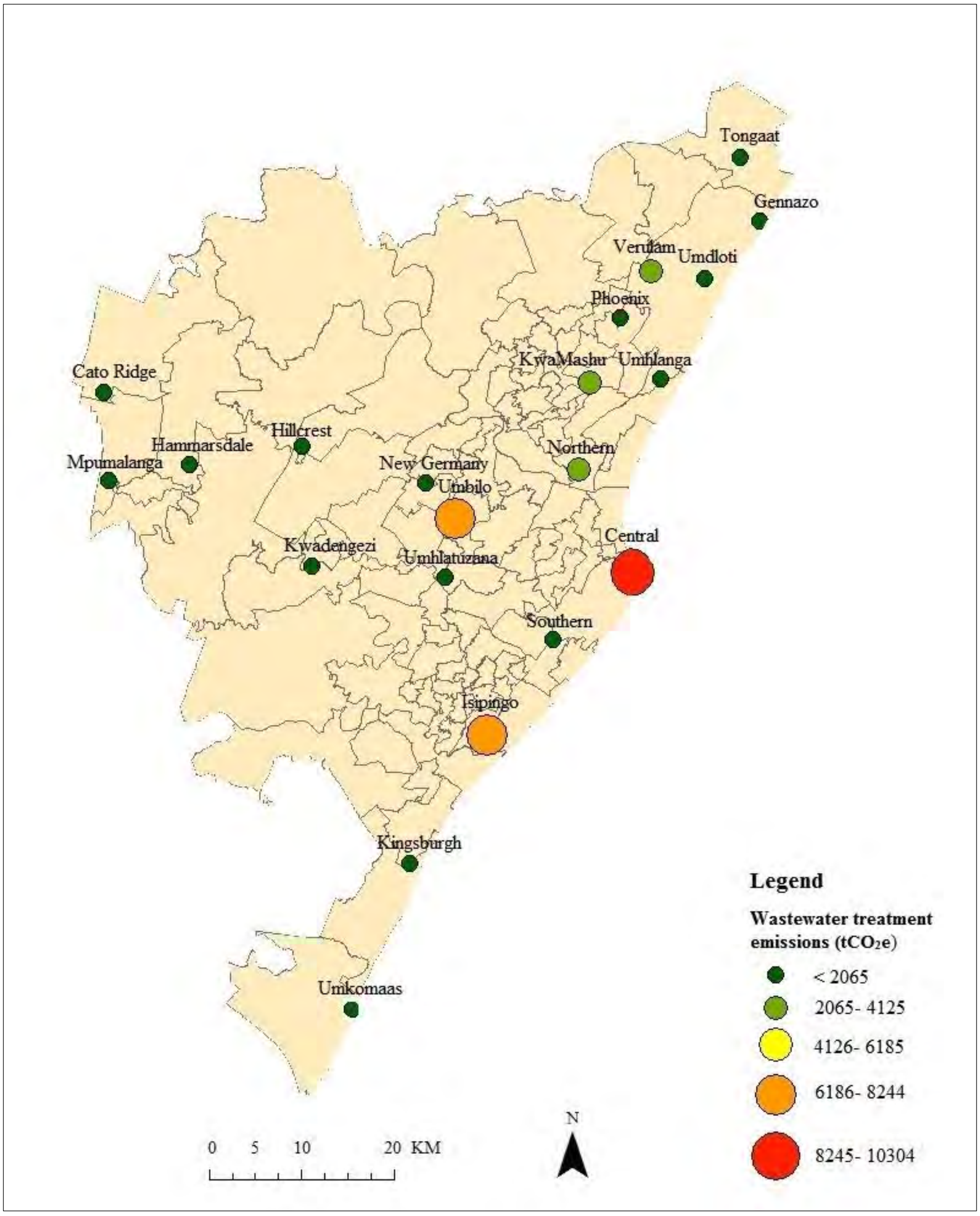


Figure 4.12 GHG emissions (tCO_2e) from wastewater treatment plants in EM for the year 2013.

Additionally, the rural areas are important green spaces which need to be preserved, thus waterborne sanitation infrastructure will be detrimental and also unfeasible, due to the low sparse densities and the under-development of those areas (EM IDP, 2015). To overcome these barriers and also to ensure basic service provision to those areas which were non-serviced during Apartheid, the EM sanitation department provided alternative services of on-site sewage treatment to the peri-urban, rural and also informal settlements. The alternative services include ventilated improved pit latrines for dense settlements and urine diversion toilets for less dense areas (EM IDP, 2015). Thus, the emissions from wastewater treatment from those areas are significantly lower, due to the lack of waterborne wastewater.

The wastewater treatment processes which contribute the most to emissions are the plants with effluent discharge into streams, rivers, and oceans (43%), followed by the stationary combustion of the biogas with anaerobic digestion of biosolids (40%) (Figure 4.13; p. 129). The only WWT types that contributed CH_4 emissions were the stationary combustion of biogas with anaerobic digestion of biosolids, and anaerobic lagoons whilst the rest of the processes contributed N_2O only. However, a single plant employs various methods; for example, Central WWTP employs treatment without nitirification or denitrification and also effluent discharge into aquatic body, which is the Indian Ocean.

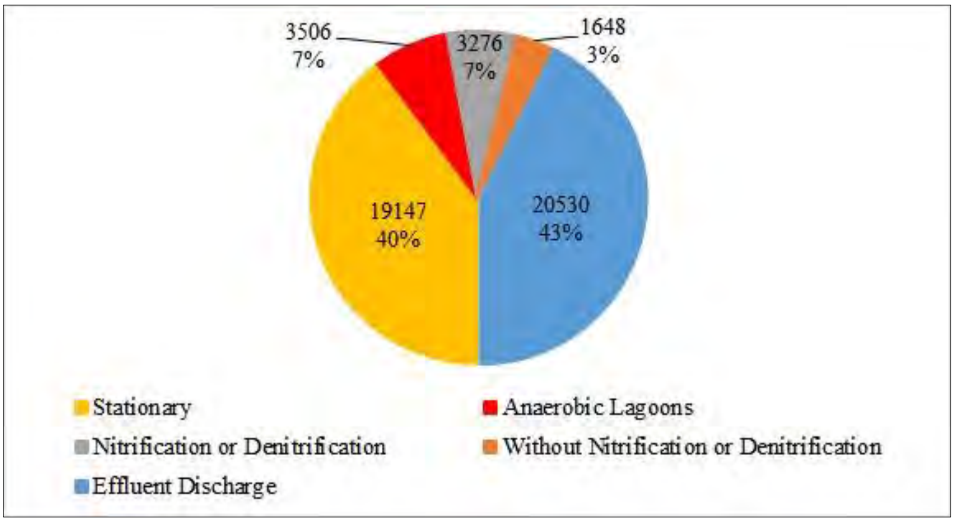


Figure 4.13 GHG emissions (in tCO_2e and percentage) from wastewater treatment plants in the EM for the year 2013.

4.3.3 Emissions Inventory Uncertainties

The major uncertainty is related to the lack of coverage of other sources and sectors which limits the completeness and comprehensiveness of the emissions inventory and emissions profiles. Specifically, the emissions inventory lacks emissions from industry process, residential on-site burning of biofuel and other energy sources, and energy consumption from the marine, and aviation transport sectors. The inclusion of this information is expected to change the emissions profile at the ward scale. For example, the inclusion of industrial process emissions and other energy sources will change the emissions profile of SDIB wards. Likewise, the inclusion of residential burning and other energy sources can change the emissions profile of the rural fringes. The implication of this is that the mitigation strategies will need to be modified.

Despite these gaps, the study presented is a first attempt which is focused on key sectors and sources of emissions, which were highlighted in similar studies for Durban. Furthermore, there is increasing motivation for reducing emissions from the activities which contribute the most to emissions, especially in cities from developing nations, as local government has limited resources to focus on emissions reductions from all activities. However, future sectoral studies and data availability and access could work towards improving the representation of emissions.

4.4 Spatial Analysis of Emissions in Durban

Following from the qualitative analysis of the municipal strategic planning documents, the key development areas in Durban were identified, which were industrial and logistics expansion in the SDIB and in the western fringe of the city (Cato Ridge and Hammarsdale). Furthermore, commercial development is expected to increase in north Durban, and development of former township areas and CBD revitalization were highlighted.

The areas identified as high emission zones will be discussed in detail in section 4.5. Similarly to air pollution priority areas, the highest emitting activities located in the high emissions zones must be considered priority areas where interventions are required to reduce emissions. The emission profiles of the highest emission zones will be discussed in conjunction with the development plans identified in the qualitative analysis of municipal strategic plans.

The spatial analysis of emissions revealed significant emissions along the coast, and low emissions from the adjacent hinterlands (Figure 4.14; p. 132). The highest emissions are from the SDIB, specifically from Prospecton, (767172 tCO_2e), which is ~6.5 times more than the Durban ward average (118632 tCO_2e). A spatial trend of high emissions zone running parallel along the coast, and the national N2 road, is identified from Umbongtwini through the CBD and the north to Umhlanga. Another spatial trend of relatively lower emissions is identified from east to west, along the national road which is the N3, from central Durban to the west and includes Westville, Pinetown, and Cato Ridge. Both emission trends are attributed to historical city growth trends from the port outwards, and infrastructure focus on the two national roads (Breetzke, 2009). The least emissions are from rural and the former township areas. The lowest emissions are found in Shangase Ta (9985 tCO_2e), which is about 11.9 times less than the Durban average.

This indicates the disparity in emissions contribution which exists in the city. To further highlight emissions inequality, the 10 highest emission wards (between 300001-770000 tCO_2e) are responsible for 35% of total emissions, of which 15% is attributed to the three highest emitting wards, whilst the rest of Durban contributed 65% to total emissions.

Prospecton, Merebank and Bluff, found in south Durban, are the three highest emitters in eThekwini. This is followed by Umhlanga in the north and the Harbour. The majority of South Durban emissions are associated with the manufacturing industries, and the port, and related activities, specifically road freight which uses heavy trucks that consume diesel. Residential and private car and public transport, from the residential suburbs of Isipingo, Clairwood, Merebank, and Bluff, makes minimal contributions to emissions, when compared to the magnitude of industry emissions.

Central Durban wards (CBD west and north such as Morningside) wards are similar to other studies due to the low sectoral contribution of residential energy to emissions. However, contrary to other studies (VandeWeghe and Kennedy, 2007; Jones and Kammen, 2014), the high total and per capita emissions are associated with the city centre, due to the high contribution of road transport because of urban sprawl which has impacted on the lack of efficient and reliable public transport. This has led to a reliance on private transport as well as heavy trucks for haulage. Furthermore, the energy intensive tourism service industry is also located in central Durban wards. The north Durban suburbs of Umhlanga and Durban North are characterized by the high contribution of road transport, specifically private cars (both petrol and diesel) to their total emissions. Therefore the high emissions zones identified broadly are south Durban, central Durban, and north Durban. These places are highlighted for further private housing, commercial office parks and industrial development. Thus, these zones and their context, together with the municipalities' development plans will be discussed in detail in section 4.5.

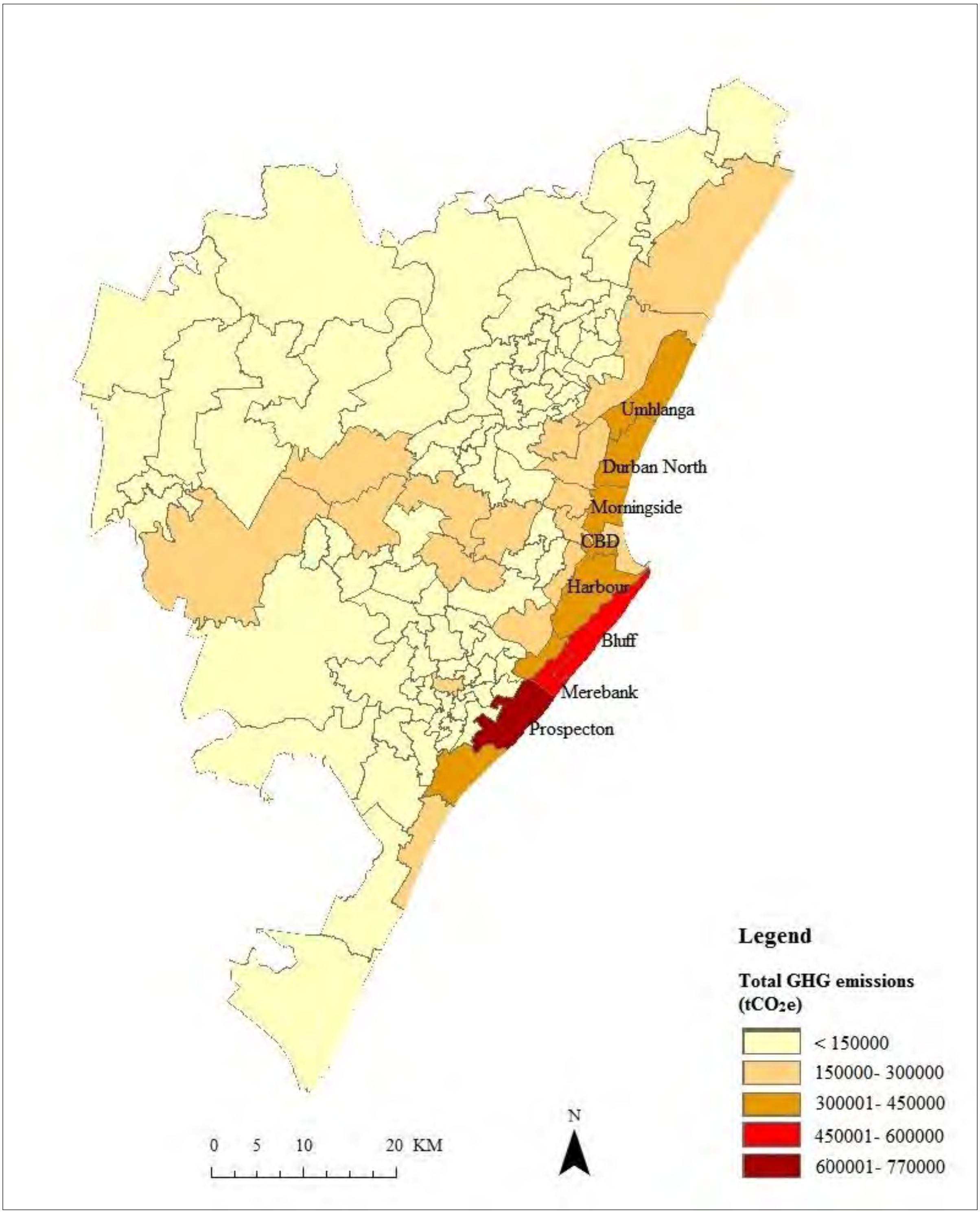


Figure 4.14 Total GHG emissions (in tCO_2e) in the EM for the year 2013.

The intra-ward comparison of the populations GHG intensity (tCO_2e per capita) is in agreement with total emissions, thus, the wards with the highest emissions are highest per capita emitters and the wards with the lowest per capita emissions are the lowest emitters (Table 4.6; p. 135). Furthermore, the GHG intensity of these wards is above the South African average carbon intensity (9.90 tCO_2e per capita). This differs from the situation in Chinese and American cities, where China contributes the most to emissions, yet their per capita emissions are low when compared to the lifestyles of American citizens (Moghaddam *et al.*, 2013).

When compared to Oslo (Norway) per capita emission of 2.19 tCO_2e per capita, which was chosen by Zhou *et al.* (2014) as the benchmark indicator to assess low carbon development, the average per capita emissions calculate for this study (3.43 tCO_2e per capita) are high. Furthermore, the GHG intensity of the majority of the wards in Durban is below the average for this study. Therefore this indicates the inequality in emissions intensity in Durban. Furthermore, the only wards which are lower than the Oslo benchmark, are the rural tribal authorities, which correspond the most deprived areas in the EM, and are characterized as poverty stricken and lack formal housing, and basic services, such as sanitation and electricity (EM IDP, 2015), thus providing further evidence to highlight the emissions disparity within Durban.

Due to the overwhelming contribution of industry emissions in Prospecton, the per capita emissions are comparable to Chinese cities, such as Lanzhou (21.04 tCO_2e per capita), where industry accounts for the bulk of emissions (Wang *et al.*, 2012). Additionally, Ramsay and Naidoo (2012) found that the emissions intensity of Tara Road in the SDIB are comparable to Asian cities, and recorded a value of 73.26 tCO_2 per capita, due to the energy consumption of industry and buildings. Furthermore, the emissions are also comparable to developed nations, such as USA, where the city of Denver has emissions of 20.12 tCO_2e per capita which are related to lifestyle emissions (Wang *et al.*, 2012). However, south Durban communities not affluent and are exposed to various environmental and health risk due to the proximity to industry.

Furthermore, when the emissions from industry electricity consumption are excluded from the emissions intensity calculation (Appendix C), the new GHG emissions intensity of Prospecton is 8.49 tCO_2e per capita, due to fuel consumption emissions from freight vehicles, as the private passenger car ownership rates of this ward is low. Other south Durban wards emissions intensity also decreases to 3.90tCO_2e per capita for Bluff and 3.21 tCO_2e per capita for Merebank, which can be compared to cities in developing nations, such as Kolkata (3.29 tCO_2e per capita), Amman (3.3 tCO_2e per capita), and European cities such as Barcelona (4.0 tCO_2e per capita) (Feng *et al.*, 2015). Morningside then becomes the emissions intense ward, with 10.83 tCO_2e per capita, followed by Umhlanga (8.88tCO_2e per capita) and Durban North (8.07 tCO_2e per capita), which are still comparable to cities in USA and Canada, such as New York (7.96 tCO_2e per capita), Seattle (11.47 tCO_2e per capita), and Toronto (8.81 tCO_2e per capita) (Kennedy *et al.*, 2012). This underlined the impact of structural influence on emissions intensity in SDIB, which are outside the control of citizens, due to the concentration of industries. Furthermore, the significance of lifestyles emissions in Morningside, Umhlanga, and Durban North neighbourhoods are emphasized, especially the contribution of road transport and passenger cars, because these wards recorded high passenger car ownership rates which are comparable to developed countries.

Table 4.6 GHG emissions intensity (in tCO_2e per capita) of the EM wards for the year 2013.

Ward Name	*GHG emissions intensity*	*Ward Name*	*GHG emissions intensity*
Prospecton	28.17	Hilary	2.08
Bluff	16.73	New Germany	1.95
Harbour	16.43	Waterfall	1.56
CBD	14.48	Newtown	1.48
Clairwood	13.76	KwaMashu F	1.47
Merebank	13.36	Umlazi V	1.45
Umhlanga Rocks	13.16	Pinetown South	1.32
Morningside	13.00	Maidstone	1.28
Durban North	10.41	Umlazi U	1.19
South African average[8]	**9.90**	Umlazi C	1.16
Pinetown Central	9.73	Shastri Park	1.15
Durban average[9]	**8.53**	KwaNdengezi	1.13
Umbogintwini	8.46	Savannah Park	1.11
Umbilo	8.43	Isipingo	1.09
Malvern	7.62	Westville- Pitlochry	1.06
Westville	7.46	Newlands West	1.03
Springfield	7.41	Umlazi	1.03
Effingham	7.41	Umlazi Q	1.01
Amanzimtoti	7.31	Dassenhoek	1.01
South Beach	6.93	eMathole	1.01
Kloof	6.76	KwaMashu	1.01
Shongweni	6.06	Umlazi S	1.00
Umlazi R	5.56	Umlazi K	0.97
Westmead	5.44	Ntuzuma F and H	0.95
Musgrave	5.25	Umlazi E	0.94
World average[10]	**4.90**	KwaMashu M	0.94
Mt Edgecombe	4.73	Mpumalanga	0.94
La Mercy	4.56	Illovu	0.93
Yellowwood Park	4.22	Kwadabeka	0.93
University of Natal	4.17	Umlazi G	0.91
Havenside	3.83	Umkomaas	0.90
Newlands	3.75	KwaNdengezi	0.89
Tongaat	3.72	Amaoti	0.89
Reservoir Hills	3.61	KwaMashu K	0.89
Clermont	3.51	Umlazi L	0.88
Georgedale	3.47	Mpumalanga Complex	0.88
Durban average (this study)	**3.42**	Kwamashu B	0.88
Westcliff	3.41	Qadi	0.85
Verulam	3.38	eMachobeni	0.83
Forest Haven	3.36	Umlazi H	0.82
Chatsworth	3.22	Inanda	0.80
Hillcrest	3.15	Lindelani	0.78
Verulam	3.00	Ntuzuma E	0.77
Hammarsdale	2.93	Ntuzuma B	0.77
Westham	2.86	Folweni	0.76
Phoenix Industrial	2.84	Folweni	0.75
Phoenix	2.79	Folweni	0.74
Wyebank	2.67	Adam's Mission	0.73
Shallcross	2.66	Isimahla Ta	0.69
Risecliff	2.58	eMatikwe	0.68
Chesterville	2.43	Inanda	0.62
Sherwood	2.28	Inanda Farm	0.49
Oslo average[11]	**2.20**	Ximba	0.44
Lamontville	2.16	Shangase Ta	0.32

Sources: [8] Winkler *et al* . (2009), [9]EM Energy Office (2012), [10]Singer *et al* . (2014), [11]Zhou *et al* . (2014)

4.5 High Emission Zones

The high emission zones are discussed in the context of three zones: (i) south Durban- from the harbour south along the coast to Umbogintwini, (ii) central Durban (iii) north Durban- north of the CBD along the coast to Umhlanga. The wards in these zones constitute the ten highest emitters and the nine highest emissions intense neighbourhoods (which are all above the South African average GHG emissions intensity) in Durban. Many of the wards which fall under south Durban in this study are considered central Durban in the EM spatial planning. However, the use of south Durban to describe these wards is due to the common use of SDIB to describe the strip of land from the Harbour which extends southwards to Prospecton. The socio-economic context of the high emitting wards are first discussed, followed by the GHG emissions profiles with the relative sectoral contributions to total emissions which are then discussed together with future development implications and mitigation options.

4.5.1 South Durban

The SDIB is the second largest industrial hub in South Africa, due to its proximity to the port. Prior to 1950, south Durban was a multicultural area (Nurick and Johnson, 1998). However the current make of the south Durban communities is the legacy of racial segregation of the Group Areas Act of 1953. Thus, the wards of SDIB are predominantly made up of historically marginalized and disenfranchised black communities, such as Bluff, Merebank, Isipingo and Clairwood. The exception is the Bluff, which was considered a white area.

During Apartheid, heavy industrial development of the area was prioritized due to economic sanctions, port proximity, and the availability of cheap labour from the surrounding marginalized communities (Scott *et al.*, 2002). Therefore, the large industries in the SDIB, such as the petrochemical refineries, were considered national strategic interests, and operated with little restriction in terms of air pollution and also were given special electricity pricing deals. Although there is progress in stricter air pollution laws than those that existed in the past, and the development of Air Quality Management Plans and the SDB Multi-Point Plan (SDB-MPP) to improve air quality, the special electricity pricing rates and the significance of petrochemical and oil refineries as National Key Points, and the prohibition of disclosure of information to third parties have yet to be withdrawn (Nurick and Johnson, 1998; Scott and Barnett, 2009). There are strong civil society organizations and community resistance against the poor air quality and climate change issues related to industries and heavy trucks (Nurick and Johnson, 1998; Scott and Barnett, 2009; Aylett, 2011; Sutherland *et al.*, 2013; Bond, 2014b; Mottiar, 2014).

The current GHG emissions profiles of the wards in south Durban shows the high contribution of industry emissions (Figure 4.15; p. 138) followed by road transport. Household electricity use was generally low, however the highest contribution were from Bluff and Umbogintwini. About 57% of the households in south Durban are considered low to middle income, earning between less than R38200 to R614400 annually (StatsSA, 2013). The exception is Umbogintwini, where 70% of households have no income or earn less than R38200 annually (StatsSA, 2013). Furthermore, the emissions profile for south Durban is comparable to Singapore, where energy emissions (dominated by electricity consumption) from industry, commercial and residential buildings contributed 83% to total emissions, followed by road transport emissions (17%) (Sovacool and Brown, 2010). A further similarity is the economic activities in Singapore, such as petroleum and oil refineries and the port (Sovacool and Brown, 2010).

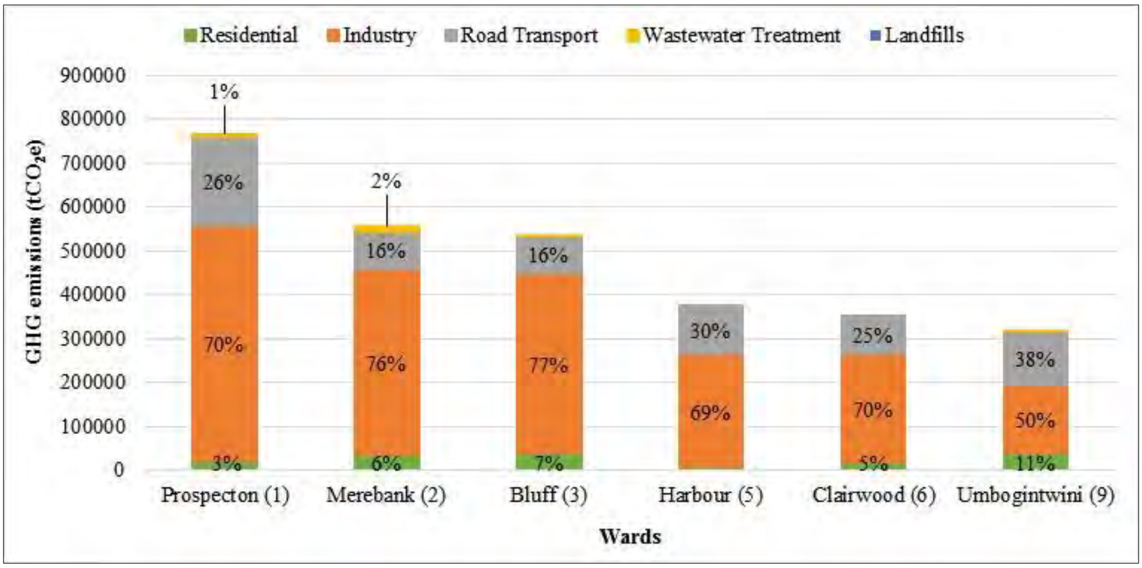


Figure 4.15 The GHG emissions profile (in tCO_2e) of south Durban wards for the year 2013. The emission rankings of wards are in brackets (1= highest emitter in the EM).

Specifically, the chemicals manufacturing industries contributed the most to emissions. Nationally, Hallowes (2015) reported that the Chemical and Allied Industries Association (CAIA) does not support further development of government's climate change policy including the carbon tax, and the DEA's plans to set a national carbon budget applicable to sectors to limit emissions, as they view SA's national emissions are insignificant and government's carbon reduction targets were met. This indicates the perceptions of major industry towards emissions mitigation in South Africa, which is a clear contrast from what the DEA and citizens' demand, and further indicative of structural influences beyond the control of the municipality.

The emissions profile of the harbour shows the high contribution of industry electricity consumption to total emissions (69%), followed by road transport (30%), especially private vehicles as ownership rates are high and heavy trucks, due to port-related activities. Specifically, the port is one of the highest electricity consumers in the city. Other major economic activities are the manufacturing of chemicals and rubber, food and beverages, electrical appliances, and transport equipment, specifically shipbuilding and repairs.

A major future development in South Durban is the Durban Dig-Out Port (DDOP) and the petrochemical sector. Furthermore, other major infrastructural developments are hinged on the DDOP development. The development of the DDOP at the former Durban airport site in Prospecton arose to increase port performance. The current port is considered inefficient as a container port due to high tariffs thus making it one of the most expensive in the world (EM, 2014). This is further indicated by the loss of rankings in logistics performance by the World Bank (EM, 2014).

The DDOP is expected to increase port capacity by eight-fold. The increase in container handling capacity and efficiency, plus the increase in the existing port capacity, and the expansion of the petrochemical complex in south Durban.is the second mega-project priority of the National Development Plan (NDPs) Strategic Infrastructure Projects (SIP). This is in conjunction with Operation Phakisa, which aims to create economic growth and job creation in the maritime sector. However, the increase in port size by the extreme eight-fold multiple due to projected increase in shipping is considered unwarranted, since there is lack of major growth in shipping volumes, the increased attention on GHG emissions from ships, proposed carbon taxes and emission limitations, and the global economic market risk (Bond, 2014b; Hutson, 2014). There is an overwhelming focus on freight transport and logistics, especially heavy trucks, which are expected to increase due to the potential development of a logistics park in Clairwood on former green space land. Furthermore, the EM expects that heavy vehicles will double by 2030, even despite plans for improvements in air and rail transport (Maharaj, 2013).

According to Maharaj (2013) the highest sea level rise projected will not pose a challenge as the port infrastructure will be adequate. However, the link between increasing ocean temperature, wind speeds and already projected sea level rise, and the impact of coastal storms on the port and ships is not considered. Furthermore, the Durban Climate Change Strategy (DCCS, 2014), considers the rising sea level and the increased intensity of coastal storms a threat to the port expansion, thus there is a need to adopt a risk-averse approach to land use, infrastructure planning, and development. However, this lack of climate change considerations resulted in the DEA (2013) rejecting the ports' EIA. The EIA also claimed that emissions from the DDOP will be reduced due to larger ships which will result in lower GHG emissions per container. However, a reduction in emissions intensity is not equivalent to a reduction in actual emissions because an increase in emissions efficiency can still lead to increase in total emissions, due to increased shipping activities.

More manufacturing industries are expected to be developed and/or expanded in the areas adjacent to the DDOP. Presently, the proposed location for the DDOP is the highest emitting ward in eThekwini. An example of proposed industry is the expansion of transport equipment manufacturing. The transport manufacturing sector is already located in the highest emitting zone and is the third highest emitting and emissions intense sector. However, it represents an opportunity to reduce both emissions intensity and total emissions.

The industrial and road upgrades and developments of other key development areas, which are directly linked to the site or in other parts of eThekwini are based on the DDOP. Thus, if climate change impacts are not considered, Durban will be left behind as only the economic aspect is considered, and the social and environmental are ignored. However, the DDOP development is incompatible with a low carbon strategy as it will increase emissions directly and through related activities, such as increase in road freight. Even though technology can play a role in emissions decrease, any benefits will be offset by the increase in number of calls at port and increasing demand. The current port is already a high electricity user and the new DDOP will also use more electricity, thereby increasing emissions in the already highest emitting south Durban zone. The increase in petrochemical manufacturing shows the increasing reliance on fossil fuel for SA. Furthermore, the Durban estuarine bay, which is threatened by the port expansion, provides vital ecosystem services including carbon sinks (DEA, 2013).

An alternative development for south Durban, recommended by South Durban Community Environmental Alliance (SDCEA), entailed local economic development based on labour intensive industry, agriculture, public transport accessibility and efficiency, less consumerism, and zero-waste generation, and investment in social infrastructure to provide and improve access and efficiency of basic services (Bond, 2014).

4.5.1.1 Recommendations for Mitigation Strategies in South Durban

Industrial electricity consumption emissions from the chemicals, paper, and transport manufacturing industries are the highest, therefore it is important for these industries to upgrade their structure and move towards improved and cleaner production (Feng *et al.*, 2015; Zhao *et al.*, 2015). Since industries of the same sector in the same space can adopt renewable energy generation on site (DEA, 2014b) to achieve industrial symbiosis, which is the effective use of energy and resources (Huisingh *et al.*, 2015). However, large scale infrastructural projects for renewable energy generation are limited in cities (Moriarty 2015), even more so in Durban, due to the topography and green space protection, but also in the SDIB as it is prime industrial land.

Furthermore, there are limits to technological measures to mitigation emissions, as demonstrated in China, where increasing energy efficiency resulted in increasing production, thus resulting in no net reductions in emissions. Moreover, Feng *et al.* (2015) recommended limiting and even eliminating the development of industries with high energy consumption, emissions and low-value added. Similarly, restricting and limiting the development of industries which are not low carbon, or do not have a low carbon strategies are recommended. However, the municipality needs to be cautious of imposing limiting regulations as this can be offset by leakage by increasing emissions and non-low carbon development in less stringent areas, or areas with low emissions (Bushnell *et al.*, 2008). Although this structural reduction is recommended for industries which emit significant pollutants (Bushnell *et al.*, 2008; Wang *et al.*, 2014b) of which the majority are in SDIB, it is unsuitable for GHG emissions.

Therefore, a viable option for industries in SDIB to reduce emissions is through carbon offsets with developmental co-benefits, as recommended by the National Treasury (2014). Specifically, the industries in South Durban can invest in renewable energy projects, ecosystem rehabilitation, and food security in the rural periphery, which are also the lowest emitting areas in the municipal, thereby ensuring that the development of those areas are not associated with increasing emissions.

4.5.2 Central Durban

Since the 1900's the area which is referred to as central Durban was an important location for residences and businesses which led to a racially diverse community. In 1963 the area was designated for whites; however Africans and Indians remained in some locations, which led to local authorities neglecting these locations which resulted in urban degradation (Nomico and Sanders, 2003). Thus, the Durban CBD and inner city is characterized by decentralization since the 1980's due the impacts of neglect by the then local government, which led to the relocation of many major corporates to office parks in mixed land use areas, such as Umhlanga (Nomico and Sanders, 2003; Michel and Scott, 2005). However, currently there are plans for urban renewal in the inner city to attract investors (EM IDP, 2015). Morningside, north of the CBD, is a generally affluent area, formerly designated for whites. The main economic activities are tertiary services such as retail, entertainment and corporate offices.

The western CBD profile shows that road transport dominates (54%), followed by the commercial sectors (Figure 4.16; p. 143). This part of the CBD hosts the Warwick Junction, which is a major transport node and is the main gateway into the city for commuters (Nomico and Sanders, 2003). Furthermore, the majority of economic activities are wholesale and retail, financial services and commercial office parks. Similarly, the emissions profile of Morningside shows the high contribution of road transport (77%) to the total ward emissions. This is due to the large number of petrol and diesel private passenger car ownership rates. Furthermore, Morningside has the highest residential emissions in central Durban. Morningside is considered middle income as 50% of households earn an annual income of more than R153801. In contrast, the CBD is the one of the lowest residential emitters in eThekwini and households in the CBD are considered low income, because ~70% of households earn less than R76400 annually (StatsSA, 2013). The high contribution of road transport emission to the emissions profile is comparable to developing cities such as Delhi and Sao Paulo, where road transport contributed 66% and 51% respectively (Sovacool and Brown, 2010), of which the dominant source of CO_2 emissions were private cars. Therefore, Morningside is more similar to those cities than the rest of the CBD.

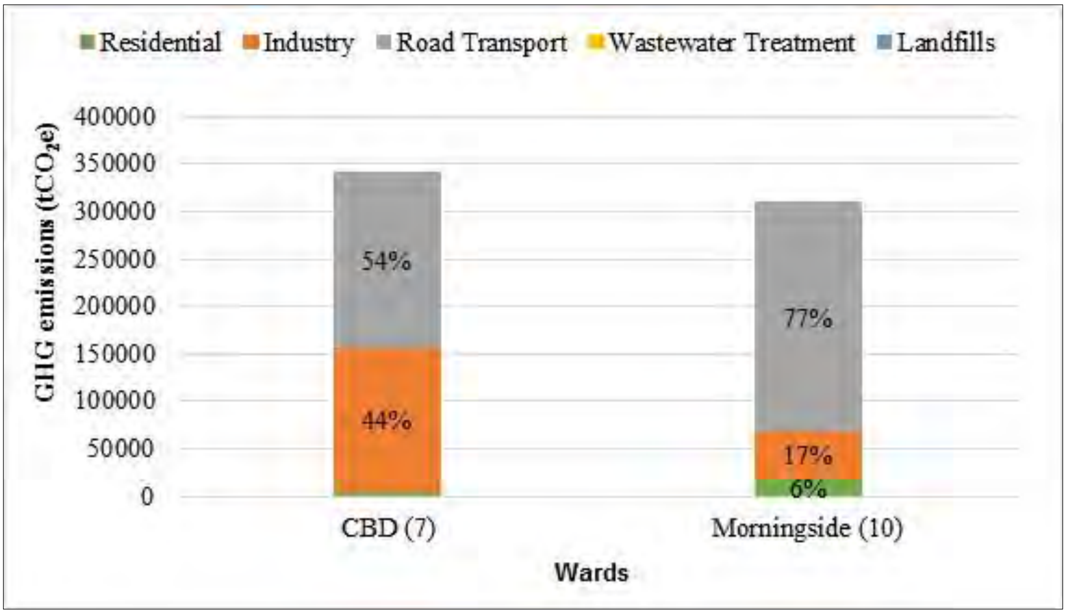


Figure 4.16 The GHG emissions profile (in tCO_2e) of central Durban wards for the year 2013. The emission rankings of wards are in brackets (1= highest emitter in the EM).

4.5.2.1 Recommendations for Mitigation Strategies in central Durban

The road transport sector is recommended to be the focus of mitigation strategies, with the specific focus on minibus taxis in the CBD and private passenger cars in Morningside. The mitigation strategy which achieves the most reductions in road transport emissions in SA is reducing vehicle mileages and the vehicle population (Thambiran and Diab, 2011b; Tongwane *et al.*, 2015) and modal shift from private cars to public transport (DEA, 2014b). Furthermore, there are concerns about the limits of technological improvements in motor vehicles, because increasing vehicle energy efficiency and the encouraging of taking up these vehicles may result in the rebound effect, where increased energy efficiency is offset by increased driving (Larson *et al.*, 2012; Muniz *et al.*, 2013; Moriarty and Honnery, 2015). Therefore, the strategy to reduce mileages and the number of motor vehicles on the road are vital and are applicable to both minibus taxis and cars. Furthermore, the revitalization of the CBD is focused on improving infrastructure to create a walkable and accessible inner city. This ties in with the concept of eco-mobility, which are sustainable transport systems, that have recently gained impetus amongst cities worldwide (Gota, 2015; Lah *et al.*, 2015).

EM should provide financial incentives and subsidies for minibus taxi owner's purchase more fuel efficient vehicles (Gota, 2015; Lah *et al.*, 2015). The vehicle population and the distance travelled by private vehicles need to be reduced in Morningside. Furthermore, the reduction of car mileages can be achieved by providing incentives for companies that apply car sharing schemes for their employees. Companies can provide incentives for employees residing in the same neighbourhoods to carpool. These incentives can also be supported by the EM. Furthermore, the EM should implement vehicle restrictions and limits on specific major roads to create a low emissions zone (DEFRA, 2010) within the CBD and Morningside; for example, the restriction of cars on major roads will need to be mandatory so that it would be a car-free zone, and commuters would need to use public transport, walk or cycle. This strategy is in alignment with the DEA (2014b) MPA, which stated that the successful implementation and effectiveness of modal shift from private passenger cars to public transport is site-specific therefore the role of local government is vital. This will ensure greater use of public transport in the IRPTN, especially as the CBD is one of the main corridors in the network.

The success and uptake of mass transit is vital for emissions mitigation, sustainability, and social cohesiveness especially in developing cities due to increasing populations and limited space for transport infrastructure (Lah *et al.*, 2015). These socio-economic and physical factors are particularly relevant to the EM, as the inequalities in emitting activities are evident and spatial planning is limited by dissected topography and green spaces (Breetzke, 2009; Turok, 2012). However, with these eco-mobility strategies and the IRPTN, the EM needs to ensure the reliability and efficiency of public transport, and the safety of commuters.

4.5.3 North Durban

Umhlanga and Durban North have always been generally high income, low density residential suburbs, associated with holiday makers due to the coastline (Michel and Scott, 2005; Ahmed, 2008). The Apartheid context of Umhlanga and Durban North were designated "white" suburbs buffered against former tribal areas and African townships, such as INK, by the designated Indian areas of Newlands, Tongaat, and Verulam (Michel and Scott, 2005). Umhlanga is located about 20 kilometres from the city centre, and was bordered by large areas of undeveloped land, used for sugarcane farming. The undeveloped land was ideal for the development of gated residential suburbs, large retail spaces and office parks for tertiary economic activities and corporate headquarters (Michel and Scott, 2005). Presently, this situation is still occurring due to more former agricultural land being released by the Tongaat-Hulett Sugar Company to be transformed into urban land use, thus increasing the western expansion of Umhlanga (Michel and Scott, 2005; Ahmed, 2008; EM IDP, 2015).

The key contributor to emissions in the north is road transport in Umhlanga (57%) and Durban North (64%), (Figure 4.17; p. 146), which is dominated by private passenger car ownership rates, which are even higher than rates in developed countries, due to the affluent inhabitants. The industry emissions are related to the tertiary sector, such as retail, and commercial office parks and increased development is expected in those sub-sectors. The emissions profiles of Durban North and Umhlanga are comparable to Morningside, and internationally with Delhi and Sao Paulo (Sovacool and Brown, 2010), due to the dominance of road transport emissions, especially from cars.

This area has the highest residential electricity emissions of the three zones. The private car ownership and high residential electricity consumption emissions are due to the affluent lifestyles of the inhabitants. According to the StatsSA (2013), about 47% of households in Umhlanga and Durban North earn between R307601- 2457601 and more annually, and are thus classified as upper middle to high income households. Furthermore, Umhlanga has the highest number of households (24%) in Durban which earn R2457601 or more annually. The increase in upmarket gated residential housing estates, commercial developments, such as retail and office parks, and tourist facilities (Michel and Scott, 2005; Ahmed, 2008; EM IDP, 2015) are expected to increase affluence. Although there is development of low cost housing in Cornubia, which is west of Umhlanga, the majority of developments are aimed at the wealthy. However, important infrastructure developments such as sewerage and roads have lagged behind the residential and commercial development growth (Ahmed, 2008; ASSAf, 2011).

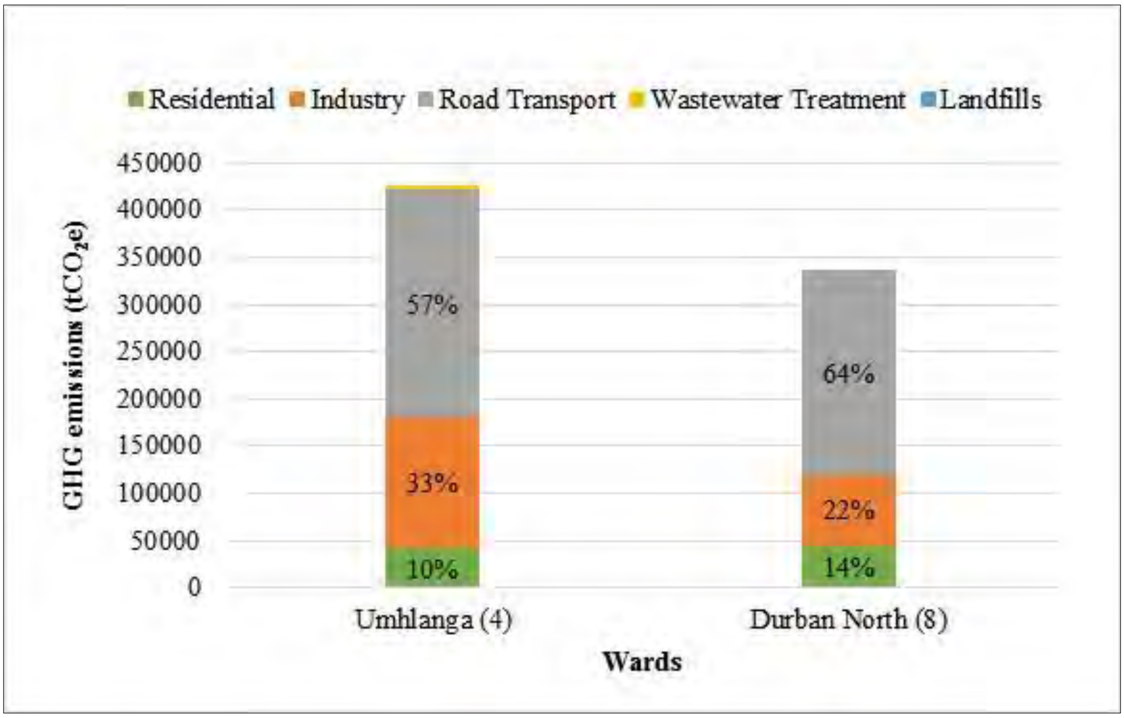


Figure 4.17 The GHG emissions profile (in tCO_2e) of north Durban wards for the year 2013. The emission rankings of wards are in brackets (1= highest emitter in the EM).

4.5.3.1 Recommendations for Mitigation Strategies in North Durban

Similar to central Durban, the road transport sector is recommended to be the focus of mitigation strategies. However since the emissions profile of Umhlanga and Durban North are similar to Morningside, the specific measure recommended is on reducing the number of private cars and the distance travelled (Thambiran and Diab, 2011b; Tongwane *et al.*, 2015). This strategy should be prioritized in the form of vehicle restrictions, such as a car-free road, which is in agreement with the DEA (2014b) MPA recommendation for modal shift from private passenger cars to public transport. Furthermore, the inhabitants of these wards can afford energy efficient cars, which will be driven more, hence emissions can still increase as energy efficiency is offset (Larson *et al.*, 2012; Muniz *et al.*, 2013; Moriarty and Honnery, 2015). Furthermore, major multinational companies have their headquarters in Umhlanga (Michel and Scott, 2005), therefore these companies can provide incentives for employees to carpool and use public transport. This will ensure greater use of public transport in the IRPTN, especially as Umhlanga is one of the main corridors in the network.

Michel and Scott (2005) revealed that the majority of people that work in Umhlanga are from the surrounding wards of Durban North, Verulam, KwaMashu and Phoenix, which is about 30 minutes travel to work, and also inner Durban suburbs, such as Morningside, Overport, Berea, Musgrave, Umbilo and CBD, and outer Durban suburbs, such as Pinetown, which is about 30- 60 minutes travelling time to work. Therefore, the employees are less affluent, since most of them do not live in Umhlanga because they cannot afford to live near to where they work, thus commuters rely on public transport or private passenger vehicles (Michel and Scott, 2005). Furthermore, with the increasing attention on eco-mobility and social cohesiveness (Gota, 2015; Lah *et al.*, 2015), the IRPTN is vital in delivering these goals, as Umhlanga is characterised by upmarket, gated residential estates (Scott *et al.*, 2002).

Another pertinent issue is reducing electricity consumption from households in in Umhlanga and Durban North. Currently there are plans for the further expansion of commercial office spaces and upmarket residential developments. These EM needs to limit the developments which are not green infrastructure and lack energy efficiency. The EM also needs to encourage residences in these areas to install photovoltaic installation on roofs, which is a municipal initiative (EM, 2015), especially as these residents can afford this technology.

Furthermore, socio-economic transformation is required to move away from a luxurious to a sustainable lifestyle, to reduce energy and waste emissions. This is especially applicable to affluent neighbourhoods. The EM needs to place more emphasis, encouragement and provide incentives for low carbon lifestyles, as within Durban (demonstrated by the disparate distribution of emission emitting activities), SA, and globally, there is increasing inequality and rising consumption of resources by the affluent.

4.6 Synthesis and Conclusion

The EM does demonstrate climate change mitigation strategies, yet the majority of developmental decisions planned for economic growth are from national government through the NDP and SIPs, are in conflict with climate change strategies. This limits the mitigation actions of the EM, even with development co-benefits, as the projects are nationally mandated. Furthermore urban sprawl is both motivated for and against in the municipal plans, due to the conflict between national, provincial, and local visions of spatial development. Therefore, there is greater need for multi-level governance in development, which also needs to include the implications for emissions mitigation, as the incorrect developmental decisions and projects will have devastating implications for future emissions.

The major emission zones are parallel to the coastline, which are south Durban, central Durban, and north Durban. South Durban, has the majority of highest emitting wards and are characterized by emissions from industry electricity use. The majority of emissions from central Durban are due to road transport, specifically passenger cars and the emission profile of north Durban reveals the significance of road transport emissions from private passenger cars. The areas with the lowest emissions are under traditional authority and former townships, especially to the west and north, and are highlighted for regeneration and development as they have low levels of access to services and economic opportunities. Furthermore, many households in Durban do not have access, or have limited access to electricity; therefore other sources of energy are used, such as candles, paraffin, firewood, and gas, which have carbon emissions, health and safety implications in the form of outdoor and indoor air pollution, and fires. Therefore these areas represent ideal opportunities to run pilot programmes for low carbon resilient development and for government and the high emitting manufacturing companies to invest in carbon, air pollution, and other environmental offsets, so that quality of life of the inhabitants can be increased without the associated increase in emissions.

The specific mitigation measures recommended for south Durban were that the manufacturing industries which use the most electricity and also the most intensive (petrochemical and chemicals, paper, and transport equipment manufacturers) invest in renewable energy projects, ecosystem rehabilitation, and food security in the rural periphery and former townships, which are also the lowest emitting areas in the municipal, thereby ensuring that the development of those areas are not associated with increasing emissions. Furthermore, the EM should limit the expansion of industries which do not have a low carbon development plan. Road transport emissions are the focus of central and north Durban, specifically the reduction of cars and distance travelled is recommended, as these areas have car ownership rates which are comparable and even higher than developed nations. It is recommended that the reduction of both mileages and vehicle be achieved by vehicle restrictions on roads, which will also ensure the uptake of the IRPRN in Durban, which is currently under construction, as well as other eco-mobility options.

Thus, with the integration of emission inventories, the suitable development based on place (an area or region) or sector can be identified. The emission profiles generated from emissions inventories can identify the strategies for the transition to a low carbon city, with development co-benefits, and also assess the capacity of those responsible for emissions to implement the change that is required. Moreover, the emissions profiles can be presented to citizens, so that they can be actively involved in place-based mitigation, as shown in Hillmer-Pegram *et al.* (2012).

However, a major barrier experienced was the lack of availability and access to data, especially from industry. This limits the compilation of the emissions inventory.

Another barrier identified is the scepticism of new initiatives (Burch, 2010), and the lack of mechanisms in place for interdepartmental collaboration and innovation, which are vital for emissions inventory compilation and mitigation measures. This is due to different municipal departments with their individual mandates and different goals, such as the central way municipality generates income is through services such as electricity provision. In the EM, electricity sales contributed the most, which is 37%, to municipality revenue (EM IDP, 2015) thus it is a challenge for electricity department to instruct consumers to use less electricity as it will impact on their revenue.

Emissions inventories can be used in EIA and Strategic Environmental Assessments (SEAs) (Sookun *et al.*, 2014), which requires simplified methodologies and analysis, and also in the IDP, which is drawn up every five years and the IDP reviews, which are published annually. EIA's are applied at the project level therefore it is recommended to move towards SEA, which assess and informs plans, policies and programmes at the proposal early stage so that it can have an important influence on the proposed development (Ahmed, 2008). Thus, the use of emission inventories, which can be compiled annually, can be used in conjunction with the annual IDP review. This is vital as the EM cannot afford to follow old development paths, especially with increasing attention and responsibility on emissions reductions. Thus, the EM needs to show that it is innovative and a leader in climate change actions by developing place-based mitigation measures.

CHAPTER 5: CONCLUSION

5.1 Introduction

Cities are key sources of GHG emissions, and this is expected to increase as urban development increases. Thus, cities have a key role to play in emissions reductions, specifically cities in developing countries, as they will experience the most urban growth, which represents an ideal opportunity for transitioning into a low carbon city. The successful implementation of mitigation strategies requires alignment with the development goals of local government. There are spatial variations in the distribution of emission activities and sources. Thus, a spatially resolved emission inventory is vital to identify the quantity of GHG emissions and the associated spatial distribution from the various sectors in the city. This information will enable decision-makers to find the high emission hotspots within the city, and develop specific place-based mitigation strategies.

The aim of this study, which as motivated for in Chapter 1, was to identify the spatial distribution of anthropogenic GHG emissions in Durban to identify high carbon emission zones. Once the high emission zones are identified, strategies can be introduced, based on emissions profiles, to ensure the spatial planning and development of low emissions zones, to achieve the goal of a low carbon city. Thus, the information from this study was used to assess the opportunity for using emissions inventory in spatial planning for a low carbon city.

5.2 Summary of Study

A literature review, detailed in Chapter 2, was undertaken on the current state of knowledge on the use of emissions inventories in spatial planning. The review identified gaps such as the lack of emissions inventory methods for developing countries. Furthermore, the use of emissions inventories in spatial planning is an emerging concept, thus few studies were undertaken, of which the majority were from developed nations and China. Moreover, many of the studies focused on a single sector, such as households or road transport.

The first objective of this study was to develop a conceptual framework to attribute GHG emissions. Based on the major emitting activity data identified from previous studies, a conceptual framework was developed to spatially attribute emissions. A method was developed, based on the ICLEI emission inventory principles, to account for the spatial location of activity data and related emissions, as well as the South African city context. The achievement of this objective was presented in Chapter 3.

The second objective of this study entailed the creation of GHG emissions inventories for the energy, road transport, and waste sectors. The third objective of this study was to explore the spatial distribution of emissions using GIS. Both of the objectives were achieved in Chapter 4, where the emissions inventory results, and maps for sectoral and total emissions, were presented. The spatially resolved emissions inventory, in conjunction with the municipality's spatial development plans, was used to identify high emission areas and areas of priority development, as per objective 4, which was also found in Chapter 4. South Durban, central Durban, and north Durban were identified as the areas of high total and sectoral emissions, as well as the areas which are the most developed areas in the city, and the areas highlighted for future development and expansion. The fifth objective was to provide recommendations to reduce emissions to facilitate the planning of a low carbon city. This was accomplished in Chapter 4, where the emission profile of the high emitting areas presented the sectors which contributed the most to emissions, thus recommendations were provided for targeted emission reductions, specific to a place.

South Durban, which has the majority of highest emitting wards, is characterized by industrial and heavy truck emissions. Furthermore, the most emission intense industries, such as petrochemical, paper, and transport equipment manufacturing are concentrated in this area. Therefore, it is recommended that industries work towards becoming more energy efficient and also invest in renewable energy, and also reduce dependency on heavy trucks to transport freight by switching to rail. However, this does not seem likely as the EM development plans are geared towards increasing production of petrochemicals and transport equipment manufacture, and increasing road freight due to the development of the port and expansion of the pier. This is evident of the limited role of the EM in development, as many of these plans are driven by provincial or national government, thus highlighting the structural influence. Therefore, it was recommended that the EM encourage these manufacturing industries use the opportunity to offset their carbon emissions by investing in low carbon resilient development of areas in the Durban which are the most deprived and also associated with the lowest emissions, thereby fulfilling the goal of emissions reductions and developmental co-benefits.

The majority of emissions from central and north Durban were due to road transport, specifically passenger cars. Thus, the IRPTN is vital in reducing passenger car emissions by reducing the distance travelled and the need for cars, especially in the CBD and Umhlanga, which are also the main corridors of the network. Furthermore, development north of Durban is expected to increase, which will increase urban sprawl and thus transport emissions. This is also further evident of the conflicting municipal plans, which plan to limit urban sprawl but edge developments are driven by private developers.

In summary, a three-pronged approach is recommended to simultaneously reduce emissions and achieve development: (i) energy audits of already existing industrial and commercial spaces in south, central, and north Durban must be mandatory to encourage technological improvements and renewable energy and further development and expansion should only be approved if they are energy efficient and low carbon, and do not rely on road transport, (ii) the implementation of car-free roads in central and north Durban to reduce distances travelled and the light passenger vehicle population, and also to ensure the widespread use of the IRPTN and other eco-mobility options (iii) areas with the most development needs, such as rural and former township areas, are the lowest emitters, for example up to 11.9 times less than the Durban average, which is an ideal opportunity for climate resilient development and for industries to offset their emissions by investing in the low carbon development of these areas.

This study is the first attempt in the identification of locations that contribute the most to emissions and their specific development needs, so that the most gains in emissions reductions and development co-benefits can be achieved. The concept of sustainable development, is by default, integrated, and is still viewed solely as an environmental issue. Sustainable development is not practiced strongly in local developmental decisions in the EM, and other local governments, both in South Africa and internationally. Emissions inventories at the neighbourhood scale are vital in identifying place-based mitigation opportunities. However, since municipalities lack strong sustainability in local development projects, it does not give confidence to the applicability of emissions inventory integration in local development. Therefore, what is required is more research and innovation into the application and value of emissions inventories in cities as planning and policy tools to facilitate low carbon development.

5.3 Recommendations for Future Research

This study quantified emissions from a spatial perspective to identify the place-based contribution to GHG emissions, and thus responsibility for emissions mitigation. However, this study will be further improved by more research and improved data availability and collection in the future. Thus, the following additional research is recommended to improve and apply the wide-scale use of emissions inventories:

- Detailed sector specific studies, based on main sectors highlighted in this research.
- The road transport emissions and passenger car ownership rates can be used in future studies; to compare the emissions profile and spatial distribution of the current vehicle classes and fuel types to the status of the future vehicle population after the IRPTN has been utilized.
- In-depth place-based research to capture variations within wards.
- Studies on the lifestyles of the affluent communities and their contribution to emissions.

- Building on this inventory and projecting GHG emissions in conjunction with future development scenarios.

Although not extensive and inclusive, this research was the first attempt in identifying the main local contributors to global emissions, so that place-based mitigation strategies can be put in place to achieve the most emissions reductions, based on the specific emission profile. Therefore, this work aims to contribute to the growing body of research in emissions inventories and their application, as GHG emissions considerations need to be integrated in local development.

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APPENDIX A– INFORMATION AND EQUATION FOR THE CALCULATION OF LANDFILL EMISSIONS

Average annual rainfall and CH_4 generation rate constant (k) value

Average Rainfall (Inches/Year)		
<20	**20-40**	**>40**
k = 0.02	k = 0.038	k = 0.057

ICLEI Equation 9.1 Landfills with Comprehensive LFG Collection Systems

$$CH_4\ emitted\ (tCO_2e) = LFG\ collected\ \times\ CH_4\%\ \times \{(1\ - DE)\ + [((1\ - CE) \div CE) \times (1 - OX)]\}\ \times unit\ conversion\ \times GWP$$

Where,

LFG collected = Annual LFG collected by the collection system, in million standard cubic feet (MMSCF)

CH_4% = Amount of CH_4 in LFG (percentage)

DE = $CH_{4\ \mathrm{Destruction}}$ efficiency of (percentage)

CE = Collection efficiency (percentage)

OX = Oxidation factor (percentage)

Unit conversion = used to convert MMSCF into tonnes

GWP = Global warming potential of CH_4

APPENDIX B- EQUATIONS FOR THE CALCULATION OF EMISSIONS FROM WASTEWATER TREATMENT

ICLEI Equation 10.2 Stationary CH_4 from Incomplete Combustion of Digester Gas

$$\begin{aligned} &Annual\ CH_4\ emissions\ (tCO_2e) \\ &\qquad = P\ \times Digester\ gas\ \times\ F_{CH_4}\ \times\ \rho(CH_4)\ \times (1\ - DE)\ \times 0.0283 \\ &\qquad \times 365.25\ \times\ 10^{-6})\ \times GWP \end{aligned}$$

Where,

P = Population served by the WWTP with anaerobic digesters

Digester gas = Cubic feet of digester gas produced per person per day (default value = 1 ft^3/ person/ day)

F_{CH4} = Fraction of CH_4 in biogas (default value = 65%)

DE = CH_4 Destruction efficiency (default value = 99%)

GWP = Global warming potential of CH_4.

ICLEI Equation 10.4 Process CH_4 from Wastewater Treatment Lagoons

$$\begin{aligned} &Annual\ CH_4\ emissions\ (tCO_2e) \\ &\qquad = \Big((P\ \times\ F_{ind\ -com})\ \times\ BOD_5\ load\ \times \big(1\ -\ F_p\big)\ \times Bo \\ &\qquad \times\ MCF_{anaerobic}\ \times 365.25\ \times\ 10^{-3}\Big)\ \times GWP \end{aligned}$$

Where,

P = Population served by the lagoons

$F_{ind-com}$ = Factor for industrial and commercial co-discharge (default value = 1.25)

BOD_5 load = Amount of BOD_5 produced per person per day (default value = 0.09 $kgBOD_5$/ person/ day)

F_p = Fraction of BOD_5 removed in primary treatment (default value = 32.5%)

Bo = Maximum CH_4 producing capacity for domestic wastewater (default value = 0.6 $kgCH_4$/ $kgBOD_5$ removed)
$MCF_{anaerobic}$ = CH_4 correction factor for anaerobic systems (default value= 0.8)
GWP = Global warming potential of CH_4.

ICLEI Equation 10.7 Process Emissions from WWTP with Nitrification/ Denitrification

$$Annual\ N_2O\ emissions\ (tCO_2e) = \left((P_{total}\ \times\ EF_{ind-com}) \times EF\ nit\ or\ denit\ \times\ 10^{-6}\right)\ \times GWP$$

Where,

P_{total} = Total population served by the WWTP
$F_{ind\text{-}com}$ = Factor for industrial and commercial co-discharge (default value = 1.25)
EF = Emission factor for the WWTP with nitrification or denitrification (default value = 7g N_2O/ person/ year)
GWP = Global warming potential of N_2O.

ICLEI Equation 10.8 Process Emissions from WWTP without Nitrification/ Denitrification

$$Annual\ N_2O\ emissions\ (tCO_2e) = \left((P_{total}\ \times\ EF_{ind-com}) \times EF\ without\ nit\ or\ denit\ \times\ 10^{-6}\right) \times GWP$$

Where,

P_{total} = Total population served by the WWTP
$F_{ind\text{-}com}$ = Factor for industrial and commercial co-discharge (default value = 1.25)

EF = Emission factor for the WWTP without nitrification or denitrification (default value = 3.2g N_2O/ person/ year)
GWP = Global warming potential of N_2O.

ICLEI Equation 10.10 Process N_2O Emissions from Effluent Discharge

$$\begin{aligned} Annual\ N_2O\ emissions\ (tCO_2e) &= ((P_{total}\ \times\ F_{ind-com}) \\ &\times (Total\ N\ load\ -\ N\ uptake\ \times\ BOD_5\ load) \times EF\ effluent\ \times \frac{44}{28} \\ &\times (1 - F\ plant\ nit\ or\ denit) \times 365.24\ \times GWP \end{aligned}$$

Where,

P_{total} = population served
$F_{ind\text{-}com}$ = Factor for industrial and commercial co-discharge (default value = 1.25)
Total N load = total nitrogen load (default value = 0.026 kg N/ person/ day)
N uptake = Nitrogen uptake for cell growth in aerobic system (default value = 0.05 kg N/ kg BOD_5)
BOD_5 load = Amount of BOD_5 produced per person per day (default value = 0.09 kgBOD_5/ person/ day)
EF effluent = Emission factor (default value = 0.005 kg N_2O - N/ kg sewage - N produced)
F plant nit/denit = Fraction of nitrogen removed for the centralized WWTP with nitrification/denitrification (default value = 70%)
GWP = Global warming potential of N_2O.

APPENDIX C- SECTORAL AND TOTAL EMISSIONS, AND EMISSIONS INTENSITY OF DURBAN WARDS

Ward No	Ward Name	Resident-ial electricity use emissions (tCO_2e)	Industry electricity use emissions (tCO_2e)	Road Transport fuel use emissions (tCO_2e)	Wastewater Treatment emissions (tCO_2e)	Solid Waste disposal emissions (tCO_2e)	Total emissions (tCO_2e)	Population	GHG intensity (tCO_2e/ capita)	Total emissions exlc industry (tCO_2e)	GHG intensity exlc. Industry (tCO_2e/ capita)
1	Ximba	12916	0	507	781	0	14204	31923	0.44	14204	0.44
2	Shangase Ta	9985	0	0	0	0	9985	31525	0.32	9985	0.32
3	Inanda Farm	21204	0	367	0	0	21571	43926	0.49	21571	0.49
4	Hammarsdale	30812	0	83979	308	0	115098	39325	2.93	115098	2.93
5	Georgedale	20135	0	81558	1067	0	102760	29625	3.47	102760	3.47
6	Mpumalanga	26953	0	0	0	0	26953	28801	0.94	26953	0.94

7	Shongweni	18269	530	73006	0	94248	186053	30711	6.06	185523	6.04
8	Hillcrest	36750	5441	73852	0	0	116043	36813	3.15	110602	3.00
9	Waterfall	37654	13340	669	0	0	51663	33066	1.56	38323	1.16
10	Kloof	36257	45513	74024	0	0	155793	23046	6.76	110280	4.79
11	Newlands	46034	11716	131201	0	0	188951	50449	3.75	177235	3.51
12	KwaNdengezi	24158	0	0	919	0	25077	28024	0.89	25077	0.89
13	Dassenhoek	36247	0	1036	0	0	37283	36987	1.01	37283	1.01
14	KwaNdengezi	31266	0	0	0	0	31266	27790	1.13	31266	1.13
15	Westmead	47185	94919	75201	0	4318	221623	40753	5.44	126704	3.11
16	Pinetown South	47320	2122	531	0	0	49974	37886	1.32	47852	1.26
17	Savannah Park	42054	0	0	0	0	42054	38047	1.11	42054	1.11
18	Pinetown Central	33181	168118	82008	3620	0	286928	29479	9.73	118810	4.03
19	Wyebank	46160	1245	73006	0	0	120411	45079	2.67	119166	2.64
20	Kwadabeka	22606	0	0	0	0	22606	24380	0.93	22606	0.93
21	New	35913	10613	8027	0	0	54553	27947	1.95	43940	1.57

	Germany										
22	Clermont	19913	0	73006	0	0	92919	26449	3.51	92919	3.51
23	Reservoir Hills	28085	11868	74284	0	0	114236	31686	3.61	102368	3.23
24	Westville	40376	114622	103444	0	0	258442	34653	7.46	143820	4.15
25	Springfield	25870	20117	198373	781	54470	299610	40422	7.41	279494	6.91
26	South Beach	4400	114808	129095	0	0	248303	35840	6.93	133495	3.72
27	Morningside	18520	51562	239204	0	0	309286	23796	13.00	257725	10.83
28	CBD	5909	150761	184009	6857	0	347537	24000	14.48	196776	8.20
29	Chesterville	33858	1850	49593	0	0	85301	35043	2.43	83451	2.38
30	Sherwood	38302	854	49593	0	0	88749	38890	2.28	87895	2.26
31	Musgrave	24830	25982	129257	0	0	180069	34297	5.25	154088	4.49
32	Harbour	5232	258309	113019	0	0	376560	22918	16.43	118251	5.16
33	Umbilo	26179	11999	240620	0	0	278799	33073	8.43	266799	8.07
34	Effingham	32253	43110	206715	3466	0	285543	38545	7.41	242433	6.29
35	Umhlanga	43486	137761	241264	1069	0	423580	32198	13.16	285819	8.88
36	Durban	45425	75289	215281	0	0	335995	32275	10.41	260706	8.08

	North										
37	Newlands West	43650	0	0	0	0	43650	42239	1.03	43650	1.03
38	Lindelani	31527	0	0	0	0	31527	40347	0.78	31527	0.78
39	KwaMashu	25667	0	0	0	0	25667	25496	1.01	25667	1.01
40	KwaMashu B	27325	0	0	0	0	27325	31119	0.88	27325	0.88
41	KwaMashu K	32437	0	251	0	0	32687	36598	0.89	32687	0.89
42	Ntuzuma F and H	38234	0	0	0	0	38234	40236	0.95	38234	0.95
43	Ntuzuma E	26658	0	0	0	0	26658	34402	0.77	26658	0.77
44	eMachobeni	36111	0	0	0	0	36111	43482	0.83	36111	0.83
45	Ntuzuma B	29564	0	1196	0	0	30760	40080	0.77	30760	0.77
46	KwaMashu F	24792	19992	0	0	0	44783	30514	1.47	24792	0.81
47	KwaMashu M	30086	0	0	0	0	30086	32032	0.94	30086	0.94
48	Phoenix Industrial	22553	66011	0	0	0	88564	31157	2.84	22553	0.72

49	Phoenix	30396	4695	69556	0	0	104647	37464	2.79	99952	2.67
50	Forest Haven	29791	57	69556	0	0	99404	29568	3.36	99348	3.36
51	Shastri Park	44438	0	3650	0	0	48089	41658	1.15	48089	1.15
52	Westham	35033	0	69556	0	0	104589	36558	2.86	104589	2.86
53	Amaoti	33176	0	0	0	0	33176	37141	0.89	33176	0.89
54	Newtown	32055	15804	0	0	0	47858	32296	1.48	32055	0.99
55	Inanda	35154	0	367	0	0	35521	44598	0.80	35521	0.80
56	eMatikwe	29651	0	0	0	0	29651	43748	0.68	29651	0.68
57	Inanda	23051	0	0	0	0	23051	36909	0.62	23051	0.62
58	La Mercy	41561	46739	86584	3055	0	177939	39016	4.56	131200	3.36
59	Verulam	36392	0	85445	0	19214	141051	46967	3.00	141051	3.00
60	Verulam	31895	12964	85445	0	0	130304	38570	3.38	117340	3.04
61	Tongaat	24719	17622	85859	0	0	128200	34461	3.72	110578	3.21
62	Maidstone	28060	11330	707	421	0	40519	31695	1.28	29189	0.92
63	Malvern	45014	69578	153354	523	0	268468	35242	7.62	198891	5.64
64	Yellowwood Park	38737	48412	69003	0	0	156152	37015	4.22	107740	2.91
65	Hilary	50603	37832	3667	0	0	92103	44338	2.08	54271	1.22
66	Bluff	37494	410516	86561	781	0	535353	31960	16.75	124837	3.91
67	Adam's Mission	34081	0	0	0	0	34081	46482	0.73	34081	0.73

68	Merebank	33723	424081	86958	10389	0	555151	40765	13.62	131070	3.22
69	Havenside	33418	729	304	0	94744	129195	33760	3.83	128466	3.81
70	Westcliff	31484	10157	64238	0	0	105880	31052	3.41	95722	3.08
71	Shallcross	29908	6088	64368	0	0	100363	37698	2.66	94275	2.50
72	Riseclif	40807	0	64238	0	0	105045	40734	2.58	105045	2.58
73	Chatsworth	36339	1365	67310	0	0	105014	32581	3.22	103648	3.18
74	Lamontville	16387	0	34892	0	0	51279	23699	2.16	51279	2.16
75	Clairwood	16692	202729	89400	0	0	308821	22446	13.76	106093	4.73
76	Umlazi V	12891	7414	8786	0	0	29091	20081	1.45	21677	1.08
77	Umlazi H	31063	0	8216	0	0	39279	47697	0.82	39279	0.82
78	Umlazi K	20193	0	8216	0	0	28409	29401	0.97	28409	0.97
79	Umlazi G	28597	0	8216	0	0	36813	40380	0.91	36813	0.91
80	Umlazi E	21663	0	8216	0	0	29879	31777	0.94	29879	0.94
81	Umlazi C	21445	0	8216	0	0	29662	25566	1.16	29662	1.16
82	Umlazi R	22973	1599	142742	0	0	167314	30270	5.53	165715	5.47
83	Umlazi L	24903	0	8216	0	0	33119	37549	0.88	33119	0.88
84	eMathole	32635	0	8216	0	0	40851	40579	1.01	40851	1.01
85	Umlazi	26121	0	8216	0	0	34338	33261	1.03	34338	1.03

86	Umlazi U	33907	0	8216	0	0	42123	35252	1.19	42123	1.19
87	Umlazi Q	19666	0	8216	0	0	27882	27574	1.01	27882	1.01
88	Umlazi S	28457	0	8216	0	0	36673	36821	1.00	36673	1.00
89	Isipingo	24700	2902	8216	0	0	35818	32899	1.09	32916	1.00
90	Prospecton	21760	536012	202344	7057	0	767172	27238	28.17	231161	8.49
91	Mpumalanga Complex	32146	0	0	0	0	32146	36520	0.88	32146	0.88
92	Westville - Pitlochry	30488	0	0	0	0	30488	28629	1.06	30488	1.06
93	Umbogintwini	35754	157132	121501	1274	0	315660	37316	8.46	158528	4.25
94	Folweni	22959	0	283	0	0	23242	31042	0.75	23242	0.75
95	Folweni	30328	0	0	0	0	30328	39927	0.76	30328	0.76
96	Folweni	26407	0	0	0	0	26407	35585	0.74	26407	0.74
97	Amanzimtoti	28191	28060	133331	186	0	189768	25970	7.31	161708	6.23
98	Illovu	44825	0	0	0	0	44825	48177	0.93	44825	0.93
99	Umkomaas	34506	0	516	0	0	35022	38918	0.90	35022	0.90
100	Isimahla Ta	10242	0	12770	0	0	23012	33486	0.69	23012	0.69

101	University of Natal	20014	36820	53248	0	0	110082	26372	4.17	73262	2.78
102	Mt Edgecombe	45604	85818	69627	1381	0	202429	42814	4.73	116611	2.72
103	Qadi	24545	0	0	0	0	24545	28777	0.85	24545	0.85
	Total	3081343	3634904	5191940	43937	266994	12219118	3565668	3.43	8584214	2.41