Transport Sector Greenhouse Gas Inventory for South Africa for the base year 2009

MPHETHE TONGWANE
STUDENT NO: 391005

SUPERVISOR:
PROF. STUART PIKETH

A research project submitted to the Faculty of Science, University of Witwatersrand, in fulfillment of the requirements for the degree of Masters of Science in Environmental Sciences.

February, 2013

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted for degree of Master of Science in the University of the Witwatersrand, Johannesburg. It has never been submitted for any degree or examination in any other university.

Mphethe Tongwane

26th day of February 2013

ABSTRACT

The transport sector is responsible for a quarter of global CO_2 emissions and the emissions continue to grow rapidly. The overall objective of this study was to calculate the following greenhouse gas emissions (GHG); CO_2, CH_4 and N_2O from the transport sector in South Africa in the base year 2009. However, in addition to the calculations of the emissions for this base year, emissions from road transport were recalculated since 2000. The available data allowed only Tier 1 method to calculate all the GHG emissions. Vehicles per type, province and distances they travelled were used to estimate the emissions, while fuel used at various airports in the country was used to determine aviation emissions. Emissions from other modes of the transport sector were calculated using the data from the national energy balances. It was estimated that 54,296 Giga grams (Gg) of CO_2 equivalent (CO_2-eq) emissions were emitted in 2009. Road, off- road, aviation and rail transports accounted for 80%, 13%, 6% and 1% of the emissions, respectively. Motorcars and trucks produced more than 70% of the road transport emissions. Road transport emissions increased at approximately 2.66% per year between 2000 and 2009. Gauteng province had the highest emissions. Minibus taxis were the most efficient transport mode on the basis of load carried.

PREFACE

Anthropogenic greenhouse gases (GHG) have increased at an alarming rate since industrial revolution centuries ago. GHGs absorb and emit long wave radiation (Ramanathan and Feng, 2009). This makes anthropogenic GHGs together with volcanic eruptions major sources of radiative forcing (Murphy *et al.,* 2009). Present anthropogenic radiative forcing causes planetary energy imbalance (Hansen *et al.*, 2005) which is primarily a catalyst to climate change. As a matter of fact, anthropogenic GHGs emissions top global environmental agendas.

Major producers of GHGs in South Africa and globally are the industrial processes and transport sector. These sources are predominant energy consumers whose major emission is CO_2. Several studies on GHG emissions in South Africa have been undertaken in the past. Major limitations of these studies were that the calculations were based on nationally aggregated energy balances. Emissions by province and vehicle type as well as associated indicators have not been developed before.

The aim of this study is to calculate GHG emissions for the transport sector in South Africa. The focus is on the year 2009, however, recalculations of the emissions since 2000 will be done where data allow. Mobility of vehicles has been used as a primary parameter to determine the emissions. Several emissions' indicators have been used to determine and compare the efficiency of the modes of transport in the country.

This study is divided into six chapters. **Chapter 1** presents the background of the GHGs and their association to global warming, climate change and the international engagements on the topic. **Chapter 2** discusses a literature review of the GHGs in relation to transport activities, the associated indicators and the factors that influence emissions. **Chapter 3** details the methodology and datasets employed in the study. The results are divided into two parts; the GHG emissions are discussed in **Chapter 4** and the indicators in **Chapter 5**. Lastly, **Chapter 6** presents the summary and conclusions of this research study.

Sections of this dissertation have been presented at the South African Society for Atmospheric Sciences conference in September 2011, and the National Association for Clean Air in October 2011.

I thank Prof. S.J. Piketh for his valuable supervision and guidance throughout this research. I am also grateful to Luanne Otter (PhD) for proof-reading this work. Assistance from the Department of Transport staff (Mr. N. Masondo, Mr. O. Khutswane, Ms. B. Jako, Mr. S. Mugeri, and Ms. H. Ngobeni) is highly appreciated.

If it were not for the support I got from my wife and son, this work would not have been done. I (we) can do all things through Christ who strengthens me (us) (Philippians 4:13).

TABLE OF CONTENTS

CHAPTER 1

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

CHAPTER 7

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACCRONYMS

Table 0.1: Administrative Provinces of South Africa

Name of province	**Abbreviation**
Gauteng	GA
KwaZulu Natal	KZ
Western Cape	WC
Eastern Cape	EC
Free State	FS
Mpumalanga	MP
North West	NW
Limpopo	LI
Northern Cape	NC

ACSA	Airport Company South Africa
BRICS	Brazil, Russia, India, China, South Africa
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon dioxide
CO_2-eq	Carbon dioxide equivalent
CSIR	Council for Scientific and Industrial Research
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
DOE	Department of Energy
DOT	Department of Transport
GDP	Gross Domestic Product
GHG	Greenhouse gas
ICAO	International Civil Aviation Organisation
IEA	International Energy Agency
IIED	International Institute for Environment and Development
IMF	International Monetary Fund

IPCC	InterGovernmental Panel on Climate Change
LDV	Light Duty Vehicles
NHTS	National Household Travel Survey
NIES	National Institute for Environmental Studies, Japan
N_2O	Nitrous oxide
OECD	Organisation for Economic Co-operation and Development
ppb	parts per billion
ppm	parts per million
RTMC	Road Traffic Management Corporation
SAPIA	South African Petroleum Industry Association
SARB	South African Reserve Bank
SARCC	South African Rail Commuter Corporation
SARS	South African Revenue Services
StatsSA	Statistics South Africa
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organisation

CHAPTER 1: BACKGROUND

This chapter presents the importance of studying GHGs and their relationship with climate change. It introduces a role that the transport sector should play in the GHG mitigation activities. It also outlines GHG source descriptions and characteristics of the transport sector in South Africa. Objectives of the study are also presented.

1.1.0 Introduction

It is observed that global mean temperatures are increasing with time. Natural factors alone fail to produce the warming observed in recent decades (Stott *et al.*, 2006a, 2006b; Ding *et al.*, 2007) suggesting that there are anthropogenic contributions involved. Radiative forcing provides means of comparing the influence of different perturbation mechanisms on climate since it affects both the long and short wave radiations (Collins *et al.*, 2006; Betts *et al.*, 2007; Forster *et al.*, 2007). Consequently, global mean temperatures follow the global mean radiative forcing fairly closely (Shindell and Faluvegi, 2009).

Radiative forcing alone cannot be used to assess the potential climate change associated with emissions, as it does not take into account the different atmospheric lifetimes of the forcing agents (Scheutz *et al.*, 2007). Each of the GHG has a unique average atmospheric lifetime over which it is an effective climate-forcing agent (Sharma *et al.*, 2006). Global warming potential of the GHGs is an index which expresses the ratio between the increase in infrared absorption due to the instantaneous emission of 1 kilogram of a given substance and that due to an equal emission of CO_2, both integrated over time

(Scheutz *et al.*, 2007; Vidal *et al.*, 2007). The InterGovernmental Panel on Climate Change (IPCC) has changed this index twice in less than two decades owing to improved scientific knowledge of GHGs and due to their continuous increase in concentration in the atmosphere (Scheutz *et al.*, 2007).

Concentrations of GHGs show a rapid increase from 278 parts per million (ppm) for CO_2, 722 parts per billion (ppb) for CH_4 and 273 ppb for N_2O in 1765 to 379 ppm, 1,774 ppb, 319 ppb respectively in 2005 (Figure 1.1) (Forster *et al.*, 2007; Scheutz *et al.*, 2007; Meinshausen *et al.*, 2011). These make a total CO_2 equivalent (CO_2-eq) concentration of all long-lived GHGs to be about 455 ppm (Rogner *et al.*, 2007).

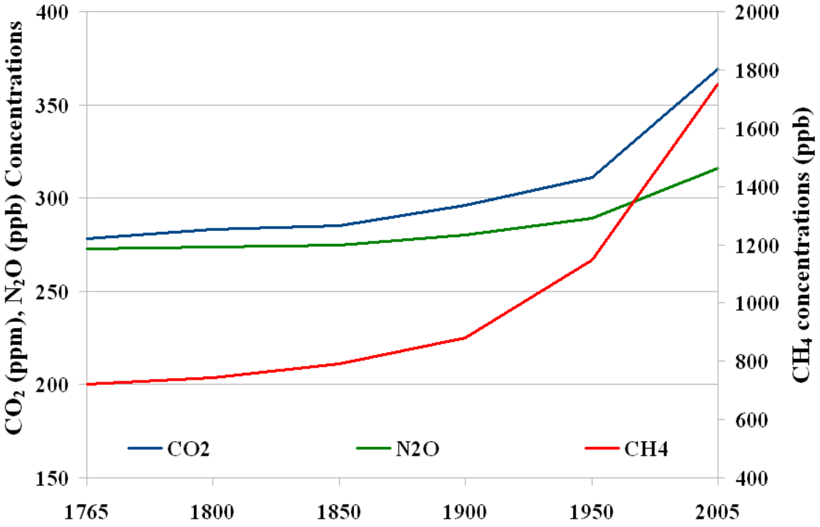

Figure 1.1: Historical global GHG concentrations from 1765 to 2005 (Forster *et al.*, 2007; Scheutz *et al.*, 2007; Meinshausen *et al.*, 2011)

Increase of CO_2 concentration in the atmosphere has caused the largest increase in radiative forcing since the industrial revolution (Forster *et al.,* 2007). They account for around 75-80% of the anthropogenic global warming effect (van Vuuren *et al.,* 2006; Quardrelli and Peterson, 2007; Stern, 2008). Today's atmospheric CO_2 level is higher than at any time in at least the past 420,000 years (King, 2004). Emission scenarios suggest that CO_2 concentrations will have exceeded 450 ppm by 2050 (Gregory *et al.,* 2004).

Increase of anthropogenic GHG concentrations in the atmosphere is not good for the climate. There is growing expectation that their increase to or above 550 ppm of CO_2-eq will lead to substantial changes in climate in the twenty first century (Johns *et al.,* 2003; van Vliet *et al.,* 2009; van Vuuren *et al.,* 2010). Climate change due to anthropogenic GHGs already in the atmosphere and future emissions are expected to be irreversible (Solomon *et al.,* 2009).

GHG emissions need to be stabilized at levels below 490 ppm CO_2-eq emissions before 2015 and to be further reduced to less than 50-80% of today's emissions by 2050 (Fisher *et al.,* 2007). This would assist to achieve a 2ºC above pre-industrial limit on global warming (Rogner *et al.,* 2007). Transport sector is among the key sectors that should mitigate their emissions in order to achieve the above requirements.

1.1.1. Climate change and policy development

Climate change discussions can be traced to have started in the nineteenth century (Thagard and Findlay, 2011). However, it was only in 1988 when the World Meteorological Organization and the United Nations formed a joint organization: the IPCC (Oosthoek, 2008). Few years later, the United Nations Framework Convention on Climate Change (UNFCCC) was formed in 1992. The objective of the convention is to stabilize GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (United Nations, 1992). The choice of a stabilization level implies the balancing of the risks of climate change against the risk of response measures that may threaten economic sustainability (Rogner *et al.,* 2007). However, to date there is no global agreement on a metric for delineating dangerous from acceptable climate change (Anderson and Bows, 2008).

A total of 195 countries including South Africa have ratified the UNFCCC. The Kyoto Protocol which makes the convention operational was adopted in 1997 but only came into force in 2005. Transport was one of the key sectors highlighted to be tackled by the protocol (Chapman, 2007). The protocol guides mitigation activities of the developed countries and it is to expire at the end of 2013 unless it is re-commissioned. However, mitigation of GHG is not only limited to developed countries alone. Article 4.1 of the UNFCCC requires that the countries signatory to the convention develop, periodically update and publish GHG by sources in their respective jurisdiction and to take appropriate mitigation actions. These mitigation actions can only be well informed when the developments of GHG are robust and incorporate all contributing factors.

1.1.2. InterGovernmental Panel on Climate Change

IPCC is a scientific body which uses emissions and climate scenarios as a central component of its work of assessing climate change research (Moss *et al.,* 2010). Its work is aiding to the understanding of climate science and the way that humans are changing the atmosphere (Oosthoek, 2008). The main IPCC work is divided into three working groups that deal with the physical science basis of climate change; the impacts, vulnerability and adaptation activities to climate change, and mitigation of climate change.

Mitigation of climate change is complex and therefore needs a systematic approach. The IPCC divides the mitigation work into seven themes; energy supply, transport, buildings, industry, agriculture, forestry and waste management (Barker *et al.,* 2007; Sims *et al.,* 2007). Energy is in the center of mitigation because historically, fossil fuels have been the main source of energy supply and have always served the human energy needs (Asif and Muneer 2007).

1.1.3. IPCC inventory guidelines

IPCC formulated homogeneous guidelines (IPCC, 1997, 2000, 2003, 2006) to harmonize scientific work on climate change. The underlying basis in the guidelines remained unchanged with time; however, the 2006 guidelines include new sources and gases as well as updates to the previously published methods whenever scientific and technical knowledge have improved (IPCC, 2006).

The 2006 IPCC guidelines disaggregate transport activities into different subsectors. The source description (Table 1.1) shows the diversity of mobile sources and the range of characteristics that affect emission factors (IPCC, 2006).

Table 1.1: Detailed sector split for the transport sector (IPCC, 2006)

Code and Name			**Explanation**
1 A 3	TRANSPORT		Emissions from the combustion and evaporation of fuel for all transport activity (excluding military transport), regardless of the sector, specified by sub-categories below. Emissions from fuel sold to any air or marine vessel engaged in international transport (1 A 3 a i and 1 A 3 d i) should as far as possible be excluded from the totals and subtotals in this
1 A 3	a	Civil Aviation	Emissions from international and domestic civil aviation, including takeoffs and landings. Comprises civil commercial use of airplanes, including: scheduled and charter traffic for passengers and freight, air taxiing, and general aviation. The international/domestic split should be determined on the basis of departure and landing locations for each flight stage and not by the nationality of the airline. Exclude use of fuel at airports for ground transport which is reported under 1 A 3 e Other Transportation. Also exclude fuel for stationary combustion at airports; report this information under the

1 A 3	a	i	*International Aviation (International Bunkers)*		Emissions from flights that depart in one country and arrive in a different country. Include take-offs and landings for these flight stages. Emissions from international military aviation can be included as a separate subcategory of international aviation provided that the same definitional distinction is applied and data are available to support the definition.
1 A 3	a	ii	*Domestic Aviation*		Emissions from civil domestic passenger and freight traffic that departs and arrives in the same country (commercial, private, agriculture, etc.), including take-offs and landings for these flight stages. Note that this may include journeys of considerable length between two airports in a country (e.g. San Francisco to Honolulu). Exclude military, which should be reported under 1 A 5 b.
1 A 3	b	Road Transportation			All combustion and evaporative emissions arising from fuel use in road vehicles, including the use of agricultural vehicles on paved roads.
1 A 3	b	i	*Cars*		Emissions from automobiles so designated in the vehicle registering country primarily for transport of persons and normally having a capacity of 12 persons or fewer.
1 A 3	b	i	1	Passenger cars with 3-way catalysts	Emissions from passenger car vehicles with 3-way catalysts.
1 A 3	b	i	2	Passenger cars without 3-way catalysts	Emissions from passenger car vehicles without 3-way catalysts.

1 A 3	b	ii	*Light duty trucks*		Emissions from vehicles so designated in the vehicle registering country primarily for transportation of light-weight cargo or which are equipped with special features such as four-wheel drive for off-road operation. The gross vehicle weight normally ranges up to 3500-3900 kg or less.
1 A 3	b	ii	1	Light duty trucks with 3-way catalysts	Emissions from light duty trucks with 3-way catalysts.
1 A 3	b	ii	2	Light duty trucks without 3-way catalysts	Emissions from light duty trucks without 3-way catalysts.
1 A 3	b	iii	*Heavy duty trucks and buses*		Emissions from any vehicles so designated in the vehicle registering country. Normally the gross vehicle weight ranges from 3500-3900 kg or more for heavy duty trucks and the buses are rated to carry more than 12 persons.
1 A 3	b	iv	*Motorcycles*		Emissions from any motor vehicle designed to travel with not more than three wheels in contact with the ground and weighing less than 680 kg.
1 A 3	b	v	Evaporative emissions from vehicles		Evaporative emissions from vehicles (e.g. hot soak, running losses) are included here. Emissions from loading fuel into vehicles are excluded.
1 A 3	b	vi	Urea-based catalysts		CO_2 emissions from use of urea-based additives in catalytic converters (non-combustive emissions).
1 A 3	c	*Railways*			Emissions from railway transport for both freight and passenger traffic routes.

1 A 3	d	Water-borne Navigation		Emissions from fuels used to propel water-borne vessels, including hovercraft and hydrofoils, but excluding fishing vessels. The international/domestic split should be determined on the basis of port of departure and port of arrival, and not by the flag or nationality of the ship.
1 A 3	d	i	*International waterborne navigation (International bunkers)*	Emissions from fuels used by vessels of all flags that are engaged in international water-borne navigation. The international navigation may take place at sea, on inland lakes and waterways and in coastal waters. Includes emissions from journeys that depart in one country and arrive in a different country. Exclude consumption by fishing vessels (see Other Sector - Fishing). Emissions from international military water-borne navigation can be included as a separate sub-category of international water-borne navigation provided that the same definitional distinction is applied and data are available to support the definition.
1 A 3	d	ii	*Domestic water-borne Navigation*	Emissions from fuels used by vessels of all flags that depart and arrive in the same country (exclude fishing, which should be reported under 1 A 4 c iii, and military, which should be reported under 1 A 5 b). Note that this may include journeys of considerable length between two ports in a country (e.g. San Francisco to Honolulu).

1 A 3	e	Other Transportation		Combustion emissions from all remaining transport activities including pipeline transportation, ground activities in airports and harbours, and off-road activities not otherwise reported under 1 A 4 c Agriculture or 1 A 2. Manufacturing Industries and Construction. Military transport should be reported under 1 A 5 (see 1 A 5 Non-specified).
1 A 3	e	i	*Pipeline Transport*	Combustion related emissions from the operation of pump stations and maintenance of pipelines. Transport via pipelines includes transport of gases, liquids, slurry and other commodities via pipelines. Distribution of natural or manufactured gas, water or steam from the distributor to final users is excluded and should be reported in 1 A 1 c ii or 1 A 4 a.
1 A 3	e	ii	*Off-road*	Combustion emissions from Other Transportation excluding Pipeline Transport.
1 A 4	c	iii	Fishing (mobile combustion)	Emissions from fuels combusted for inland, coastal and deep-sea fishing. Fishing should cover vessels of all flags that have refuelled in the country (include international fishing).
1 A 5	a		*Non specified stationary*	Emissions from fuel combustion in stationary sources that are not specified elsewhere.
1 A 5	b		*Non specified mobile*	Mobile Emissions from vehicles and other machinery, marine and aviation (not included in 1 A 4 c ii or elsewhere). Includes emissions from fuel delivered for aviation and water-borne navigation to the country's military as well as fuel delivered within that country but used by the militaries of other countries that are not engaged in.

			Multilateral Operations (Memo item)	Multilateral operations. Emissions from fuels used for aviation and waterborne navigation in multilateral operations pursuant to the Charter of the United Nations. Include emissions from fuel delivered to the military in the country and delivered to the military of other countries.

1.2.0. Transport sector

Growth of the transport sector is rapid and calls for urgent mitigation attention. Transport accounted close to 60% of emissions from oil combustion in 2004 (Quadrelli and Peterson, 2007). While global oil emissions from most sectors remained nearly steady in absolute terms since 1971, those of transport more than doubled (Quadrelli and Peterson, 2007; Yan and Crookes, 2009). The growth is due to the absence of policy actions in many parts of the world (Rogner *et al.,* 2007).

1.2.1. Transport sector in South Africa

Transportation is a huge and diverse sector in South Africa. Both land, sea and air transport modes are used in the country. Waterborne and aviation transports have both domestic and international components.

1.2.1.1. Road transport

There were over 8 million vehicles registered in South Africa in 2009 (RTMC, 2010). Population of motorcars was the largest of all motor vehicles' types. They made over 65% of the vehicles in 1998 (DEAT, 2003). Globally, the automobile market indicates a steady average annual growth above 3.5% (UNIDO, 2010). In South Africa, motor vehicle numbers increased on average by 4.1% per annum over the period 1970 to 1980 (DEAT, 2003). Similarly, during the period 2000 to 2009, annual growth of number of registered vehicles in the country was approximately 3.96%. The number increased by 2.6% between 2007/08 and 2008/09 (National Treasury, 2009).

Minibuses are important in public transportation in the country. Following their deregulation in the late 1980s, minibuses grew substantially to the extent that their market share surpassed that of buses (DEAT, 2003; Trans-Africa Consortium, 2010). However, the Government’s minibus recapitalization programme which was implemented in 2006/07 (DEAT, 2003; National Treasury, 2009) could reverse the situation. As at the end of the 2009/10, a total of 38,760 vehicles were scrapped and it was planned that 8669 vehicles would be destroyed in the following year (Ndebele, *Personal communication*).

1.2.1.2. Aviation

Aviation is one of the prominent modes of travel in South Africa. In 2008, South Africa registered 4,468 aeroplanes, 1,006 helicopters and 5,474 sports and recreational aircrafts (DOT, 2009a). Of more than 50 airlines operating in the country, six provide domestic flights (DOT, 2009b).

There was a significant reconfiguration of air links between South Africa and other countries in the period 1994–2003 (Pirie, 2006). OR Tambo International Airport serves as a link between southern Africa and the rest of the world.

Air passenger movements have been increasing over the last decade at all major airports in South Africa (Adam and Vanderschuren, 2009). Passenger traffic grew by more 9% annually between 2004 and 2007 in the airports controlled by Airports Company South Africa (ACSA) (DOT, 2008a). Domestic air travel in South Africa grew by about 14% per year over the three years prior to 2007 and by 70% over the period 2003 to 2007 (Campbell and Vigar-Ellis, 2012).

Passenger trips at OR Tambo International Airport have increased by 10% per year recently (Vanderschuren, 2010). The airport accounted for more than 37% of all aircraft departures at the national airports in 2009 (ACSA, 2011). Average daily flight capacity of 76,337 people and an actual daily trip generation of 54,861 people occur at the airport (Vanderschuren, 2010). Other major airports in the country are Cape Town International Airport and King Shaka International Aiport

1.2.1.3. Railways

Rail transport has potential to ferry bulk loads for long distances. However, in many markets and cities of the world including in South Africa, rail transport's role has been declining (SARCC, 2006; CSIR, 2008). South African rail freight transport's current core competence is the transport of high volume export minerals (CSIR, 2008; Van Eeden and Havenga, 2010).

The deregulation of freight transport led to an increase in the number of freight vehicles, especially long distance trucks (DEAT, 2003).

Moreover, decreased funding from the government for rail transport and increasing inaccessibility of the system contributed to the decline in rail services in the country (SARCC, 2006). Development of rail infrastructure has been stagnant and now lags the growth of settlement areas. Moreover, the current old fleet of trains makes traveling by rail to be unattractive.

1.2.1.4. Waterborne

South Africa serves as a southern African regional hub for seaborne trade. About 96% of the country's exports are transported by sea (Letete *et al.*, 2010). There are 18 ports along the coastline of the country (DOT, 2009b). These include eight multi-purpose commercial ports, fishing harbours and other government and private port facilities. Despite all these, South Africa is not a significant ship owning nation (Chasomeris, 2006).

Operations in the South Africa’s ports include compulsory pilotage services which may include guidance of a ship using a helicopter. Pilotage broadly refers to the finding of one’s way both into and out of a port, often within relatively shallow waters (Chapman and Chapman, 2005). These services are anticipated to use large volumes of aviation fuel and diesel for boats. Durban has the busiest port in Africa (eThekwini, 2006), therefore it can be anticipated that the port has pilotage activities larger than other ports in the country can be expected.

1.2.1.5. Off-road transport

Off-road transportation activities are broad. For this category to be investigated, detailed data are required. This category incorporates all forms of mobile vehicles that may not be licensed to travel on major public roads. These vehicles are usually used in various activities other than transportation of people and goods. Limited data about these vehicles are available and that makes it difficult to determine the off-road emission's profile.

Off-road category vehicles usually uses the same petroleum products used by road transport. This brings about a challenge where fuel points are shared between road, off-road and in some cases stationary combustion systems. This is critical as energy statistics in South Africa do not explicitly separate fuel consumption between road and off-road transports. They do not show energy used by transportation activities other than road transport. It is therefore highly likely that this energy is included in the road transport amounts.

1.2.1.6. Pipeline transport

Pipeline transport is another mode of transportation used in South Africa. Pipelines have established their place in the transportation system as the most efficient and cost effective means of transporting large quantities of liquids and gases over long distances (DOT, 2008b). Pipeline infrastructure is owned by the state pipeline company Petronet (part of the larger state-owned transport conglomerate Transnet), and the rest of the industry is vertically integrated (Winler and Marquard, 2007).

The existing pipeline systems in South Africa link Gauteng, Durban, Secunda and Mozambique (Mwanasonda and Winkler, 2005; DOT, 2008b). The Transnet network in the country spans more than at least 3,000 km (van den Berg and Mbara, 2011). Sasol Gas operates and maintains a gas supply network through 2,265 kilometres in Mpumalanga and Gauteng including the 865 kms crossborder pipeline linking the gas fields of Temane central processing facility in Mozambique to the Sasol Gas network at Secunda in South Africa (DOT, 2008b).

Transnet currently transports approximately 17 billion litres of petroleum products and 14 million gigajoules of gas annually, which is 50% of South African consumption (DOT, 2008b). The pipeline between Durban and Gauteng is already operating at its full capacity, and does not meet fuel demand any longer (DOT, 2008a).

Pipelines transportation involves energy intensive pumping process. National energy balances show electricity is the only energy used to do the pumping. Hence there are not direct GHG emissions from this mode of transport.

1.3.0. Rationale

GHGs have become a key policy consideration at all spheres of governance. All countries in the world are required to develop and implement appropriate measures to mitigate GHG emissions. Emissions from the transport sector are the fastest growing of all sectors (Wang *et al.,* 2007). Large numbers of researchers have used aggregated fuel sales to quantify GHG emissions from this sector. However, disaggregated bottom-up emission inventories are crucial to identify and implement robust mitigation plans. Disaggregated emissions are transparent and can be refined with more detailed data without affecting the methodology (Hoogwijk *et al.,* 2010).

1.4.0. Aims and objectives

The aim of the study is to quantify GHG emissions from the transport sector in each province of South Africa. In this study, GHG emissions from the transport sector will be based on data obtained for the base year 2009. Moreover, emissions for years starting in 2000 will also be recalculated. This work is anticipated to provide disaggregated information necessary to guide mitigation plans at the provincial and national levels.

The objectives are;

a) To quantify GHG emissions of each transport sub-sector in South Africa for 2009.

b) To determine provincial and total GHG emissions from the transport sector in South Africa for 2009.

c) To determine how much South Africa's transport sector contributes to total global transport sector GHG emissions

d) To determine efficiency of each mode of transport in the country

****

The chapter showed the relationship between climate change and GHGs. It further discussed international platforms coordinating activities associated with climate change and the GHG emissions. Different sources of GHGs and transport sector source descriptions were presented. Aims and objectives of this study were also given.

CHAPTER 2: LITERATURE REVIEW

This chapter will review GHG emitted by the transport sector in the world and in South Africa. Source apportionment of each mode of transport will be discussed. Factors that affect transport emissions will be presented.

2.0. Demography and macroeconomics in South Africa

Transportation energy consumption and related GHG emissions depend on the geographical population density (Kennedy *et al.*, 2009). Different subgroups in the population, described by various socio-economic, demographic and other personal characteristics, have different levels of emissions from motorised transportation (Brand and Boardman, 2008; Liddle, 2011).

South Africa is a country with approximately 50 million people. Gauteng is the largest populated province, followed by KwaZulu Natal and the Eastern Cape. Between 2000 and 2009, Statistics South Africa publications indicate that Gauteng and the Northern Cape experienced highest growths of human population. The growths in each of these provinces exceeded 30%. Limpopo, the North West and the Eastern Cape had a slight decrease in population.

South Africa is one of the most industrialized countries in Africa (Akiboade *et al.,* 2008). However, industrial activities are concentrated to few parts of the country. Gauteng province is the leading economic region of not only South Africa but also of Africa as it generates 10% and 33.8% of the continent's and South Africa’s gross domestic product (GDP), respectively (Pejout, 2004; Joubert and Axhausen, 2011). Other provinces which have good GDP per capita ratings are the Western Cape and KwaZulu Natal (Bosker and Krugell, 2008). These two provinces have ports that link trade in South Africa with the rest of the world (Joubert and Axhausen, 2011).

South Africa experienced an economic recession in 2008/2009. No sector of the economy had a growth above 1% in 2009 except for construction which grew by 7.8% (SARB, 2012).

2.1. Economic conditions and transport emissions

Transport GHG emission mitigation strategies can be grouped into three areas – vehicles, fuels, and travel demand (Lutsey and Sperling, 2009; McCollum and Yang, 2009). Transport demand is closely linked to economic growth (Zachariadis, 2007; Zhang *et al.*, 2009). Similarly, economic activities are the primary determinants of energy demand and thereby influence energy prices; yet energy prices, in turn, influence energy demand and economic performance (IEA, 2006). Consequently, dependence of economy on transport makes it a major source of global GHG emissions (Zegras, 2007).

Demand for transport fuels has continued to grow in an almost linear fashion with GDP since the 1970s (IEA, 2006). Retail fuel prices in South Africa (StatsSA, 2010a; SAPIA, 2010) have increased nearly linearly with time (Figure 2.1).

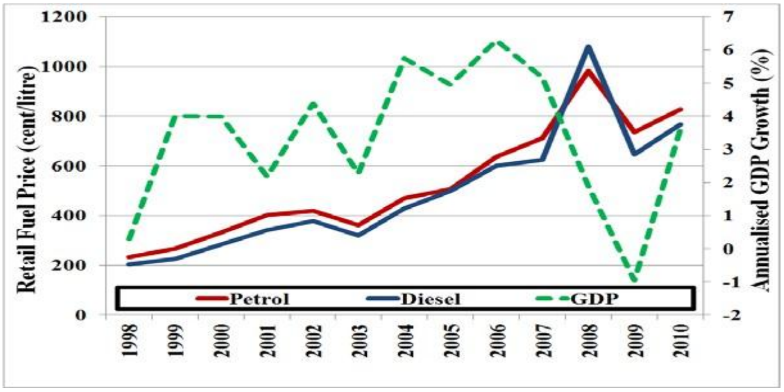

Figure 2.1: Retail fuel price and GDP growth trends in South Africa (SAPIA, 2010; StatsSA, 2010a)

Negative relationship between oil volatility and GDP is widely accepted in the literature (Awerbuch and Sauter, 2006). This relationship is important in South Africa as the country uses imported crude oil to provide for over 60% of its liquid fuel demand (DOE, 2010). As a result, the area of the economy most directly susceptible to oil shocks in South Africa is the transport sector as it is highly reliant on imported fuels (Wakeford, 2006).

High fuel prices normally reduce vehicle mobility through behavioral changes (McKinsey Global Institute, 2009). In such conditions, people prefer not to travel or they use mass transport rather than private vehicles. As a result of reduced mobility, global oil demand fell back by 3% over the first semester of 2008 and by 1.5% over the second semester (European Union, 2010).

2.2. Transport sector energy economics

Transport primarily depends on a single fuel source. Petroleum products supply about 95% of the total energy used by world transport (Ribeiro *et al.,* 2007). Globally, road transport accounts for 80% of total energy use by the transport sector (Bond *et al.,* 2007; Chapman, 2007). In South Africa and around the world, transport accounts for more than 20% of the final energy consumption (Haw and Hughes, 2007; Ziramba, 2009; DOE, 2010; IEA, 2011). Road transport is responsible for about 20% of the South Africa's final energy demand (Haw and Hughes, 2007).

Compared to other middle-income developing countries, South Africa's economy is heavily energy intensive (Winkler, 2007; Akiboade *et al.,* 2008). High energy intensities indicate a high price or cost of converting energy into gross domestic product (DOE, 2010).

The dominant fuel used by transport sector in South Africa is petrol with 53.3%, followed by diesel with 34% and then jet fuel with 10.9% and the lowest is electricity with 1.8% (DOE, 2010). Diesel use in road transport has been increasing over the past few years (Haw and Hughes, 2007; Rayner, *personal communication*). In South Africa, long-term forecasting and trend modeling estimated that the average annual growth of fuel consumption would be 2.1% for petrol and 2.4% for diesel (DEAT, 2003).

2.3. Past transport sector GHG emissions in South Africa

Energy consumption by transport directly translates into GHG emissions. Transport accounts for 14.3% of world total GHG emissions and about 25% of world GHG emissions from fossil fuels (Wright, 2004; Ribeiro *et al.*, 2007; Zegras, 2007; Hensher, 2008).

GHG inventories for the transport sector have been developed in South Africa before. The studies of Scholes and van der Merwe (1996), DEAT (2003), DEA (2009b) and Cruz *et al.*, (2011) used energy balance data and their results are nationally aggregated (Figure 2.2). They do not show modal, provincial and trend analysis.

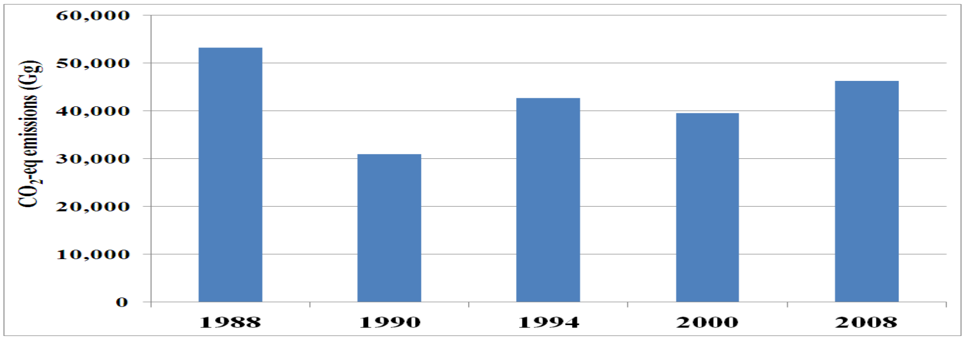

Figure 2.2: Transport sector CO_2 equivalent emissions in South Africa (Scholes and van der Merwe, 1996; DEAT, 2003; DEA, 2009b; Cruz *et al.*, 2011)

In 1994, the transport sector accounted for about one tenth of South Africa's GHG emissions (DEAT, 2003). However, in 2000, transport emissions contributed 9% of the total emissions (DEA, 2009b; 2011). The decrease in emissions between 1994 and 2000 was related more to improper allocation of fuel consumption in this sector rather than to an actual decrease in the emission (DEA, 2011).

GHG emissions from the transport sector were expected to increase with time in South Africa. Nearly a decade ago, transport CO_2-eq emissions were projected to be around 45,000 Gg in 2010 (DEAT, 2003). This is consistent with the global anticipation where the contribution is forecasted to grow to between 45% and 58% of energy related emissions by 2030 (IEA, 2009; Quadrelli and Peterson, 2007).

Some previous studies combined GHG emissions from domestic and international bunkers. For example, the emissions in 1988 included international bunkers as it was not possible to separate the fuel between the domestic and international consumptions (Scholes and van der Merwe, 1996). International bunkers emitted approximately 18% and 19% of total transport emissions in South Africa in 1990 and 1994 (DEAT, 2003). Waterborne transport accounts for over 75% of the international emissions (DEAT, 2003; DEA, 2009b).

Globally, about three quarters of GHG emissions from transport sector came from road vehicles in 2004 (Ribeiro *et al.*, 2007). In South Africa, this subsector contributed to more than half of the transport sector emissions in 1994, which was 36% over the 1990 value (DEAT, 2003). It accounted for over 90% of the sector's emissions in 2000 (DEA, 2009b) showing a worrying and unsustainable trend.

Passenger transport in South Africa is dominated by the energy intensive private transport. Annual CO_2 emissions from passenger cars are estimated to be approximately 4.13 million tonnes in Johannesburg (Goyns, 2008) and 2.14 million tonnes in Durban (Thambiran and Diab, 2011).

2.4. Characteristics of transportation loads in South Africa

The most used motorised travel mode in South Africa is the minibus-taxi (DOT, 2005). For the period 1980-2000, minibus taxis captured more than 60% of the commuter market (DEAT, 2003). Vast majority

(76%) of households reported that they do not have access to train services in contrast to minibus taxis which are much more accessible especially for short time trips (DOT, 2005).

Around 230 thousands aircraft landings carrying about 33-million passengers move through South Africa's 10 principal airports in a year (Letete *et al.,* 2010). In 2008, more than 12 million passengers embarked on domestic aircrafts (DOT, 2009a). Number of international passengers arriving and leaving South Africa is usually less than half of their domestic counterparts.

Railways transport largest number of passengers in the country. In 2009, it transported about 644 million people compared to 288 million people transported by road transport (StatsSA, 2010). Both figures were higher than the respective numbers in 2008.

Freight transportation is dominated by road transport. During 2009, more than 426 million tons of payloads were transported by road compared to about 183 million tons moved by rail (StatsSA, 2010). On the other hand, freight transported by aviation was about 360 thousand tons in 2008 (DOT, 2009a).

One of the commonly used factors to determine efficiency of transport vehicles is the load the vehicles carry for each distance unit they travel. Passengers or tonnes transported for each vehicle kilometre is the frequently used indicator. This indicator is a product of number of passengers/tonne a vehicle transported for each kilometre in its trip.

Passenger- kilometres vary between modes of transport and provinces in South Africa (StatsSA, 2003; DOT, 2005; RTMC, 2010). Based on assumed vehicle occupancy rates Haw and Hughes (2007) estimate that 52% of the road passenger-kilometres in South Africa are met by public transport and 48% are met by private vehicles. Road transport and passenger rail produced 21 billion and 16 billion passenger-kilometres in 2008 respectively (DOT, 2009a).

Globally the aviation sector, which is an energy-intensive mode, has seen a tremendous increase in the volume of its traffic during the last three decades (Grazi and van den Bergh, 2008). Between 1990 and 2006, total scheduled world revenue passenger-kilometres and cargo revenue tonne-kilometres traffic rose by 108 and 140%, respectively (Macintosh and Wallace, 2009).

Air traffic experienced depression in 2009 because of the global financial crisis (ICAO, 2010). Global statistics for that year show that overall passenger/freight freight tonne-kilometres performed in 2009 decreased by 4.3% over 2008, and international tonne-kilometres reduced by about 5.9% (ICAO, 2009). The situation improved in 2010 whereby world passenger-kilometres performed on total scheduled services increased by about 8.0% (8.5% international and 7.1% domestic) over 2009 (ICAO, 2010; 2011). Domestic passenger-kilometres and tonne-kilometres decreased by 3.45% and 4.36% in 2009 over 2008 respectively in South Africa (ICAO, 2009).

2.5. Modal intensities

Energy services may have broader attributes that may be combined with useful energy outputs in a variety of ways (Sorrell *et al.*, 2009). One of the useful indicators is energy or CO_2 modal intensity expressed in mega joules or grams of CO_2 emissions per passenger- or tonne-kilometres respectively. This indicator provides a measure of the energy or carbon intensity associated with transporting various loads (Becken and Patterson, 2006; Zheng *et al.*, 2011; Zhou *et al.*, 2011).

Passenger-kilometres and tonne-kilometres are the two main determinants of energy consumption (IEA, 2011). In fact, energy use per passenger kilometre is the most important indicator of energy intensity for collective modes of transport (Reddy, 2000). It provides a platform to analyze flexibility for modal shifting (Haw and Hughes, 2007). Most importantly, there is linear dependence between the emission of CO_2 and fuel consumption (Mickūnaitis *et al.*, 2007).

Private passenger vehicles have highest energy intensities in South Africa (Table 2.1) (Haw and Hughes, 2007). They also consume largest amounts of energy. For freight vehicles, medium commercial vehicles have highest intensity while heavy commercial vehicles use largest amounts of energy after private vehicles.

Table 2.1: Intensities of road passenger and freight transport (Haw and Hughes, 2007)

Passenger transport	**Intensity (MJ/pass-km)**	**Total mileage (billion vehicle-km)**	**Total fuel (PJ)**
Diesel buses	0.39	0.92	12.66
Petrol taxis (minibus)	0.44	8.82	38.46
Diesel taxis (minibus)	0.29	0.00	0.00
Petrol cars	1.51	62.00	197.23
Diesel cars	1.40	1.82	5.36
Hybrid cars (diesel)	0.59	0.00	0.00
Hybrid cars (petrol)	0.70	0.00	0.00
SUV (diesel)	2.04	0.21	0.88
SUV (petrol)	2.39	0.23	1.14
Motorcycles	1.80	1.58	2.84
Freight	**(MJ/tonne-km)**		
Light commercial vehicles	1.59	11.34	54.00
Medium commercial vehicles	7.00	6.89	47.92
Heavy commercial vehicles	0.84	5.28	66.62

Modal intensities can also be expressed as a function of economic or demographic indicators. The ratio of both the energy and carbon emissions to GDP is used to measure energy and CO_2 intensities of national economies (Zhou *et al.*, 2011). In fact, carbon intensity is a mixed indicator mainly subjected to energy and economic structures (Romano, 2011; Zhou *et al.*, 2011). Alternatively, because CO_2 emissions can be strongly influenced by the size of the population, per capita indicators provide better and more equitable basis for comparison across designated geographical areas (Zhou *et al.*, 2011).

In the early 1990s, South Africa ranked among the top 10 and 20 countries in the world respectively, regarding the tons of carbon emitted per unit of GDP annually and tons of carbon emitted per capita per year (Scholes and van der Merwe, 1996). In 1995, South Africa's emissions intensity was about 240 per cent above world average, and in terms of emissions per capita, South Africa was 189 per cent above the world average of 1.07 tons of carbon per person (Blignaut *et al.* 2005).

Energy and CO_2 efficiency have become a highly important global goal during past few years (Liimatainen and Pollanen, 2010). This indicator expressed as MJ/km for energy and CO_2/km for CO_2 emissions provides a measure of the average fleet efficiency of all vehicles (Zheng *et al.*, 2011; Zhou *et al.*, 2011). Road transport's fuel consumption and emissions per km traveled are much higher than that of the other transport modes (Soylu, 2007).

The Government and the automobile industry in South Africa recently agreed on the efficiency rates of some of the country's vehicle types. The CO_2 emissions threshold for new passenger cars and light duty double cabs are set at 120 g/km and 175 g/km respectively (National Treasury, 2010; SARS, 2010). Rates beyond these are taxed.

2.6. Vehicle ownership and occupancy rates

Ownership rates and the use of vehicles influence energy consumption (Goyns, 2008; Mohammed and Venter, 2009). Compared to other developing countries, South Africa has a relatively high rate of car ownership. Cities in South Africa have the highest motorcar ownership rates in Africa with 189 and 241.3 motorcars per 1,000 people in

Durban and Johannesburg respectively (Naude *et al.,* 2000; Akinboade *et al.,* 2008; UITP, 2010; Thambiran and Diab, 2011). The ratio of passengers to vehicles varies from province to province (Table 2.2).

Table 2.2: Number of passengers per vehicle type per province in South Africa in 2003 (DOT 2005, RTMC, 2010; StatsSA, 2003)

Province	Motorcars	Minibuses	Buses
Gauteng (GA)	1.4	33.79	40.08
KwaZulu Natal (KZ)	2.2	55.24	189.68
Western Cape (WC)	1.9	26.35	58.28
Eastern Cape (EC)	2.5	57.44	120.03
Free State (FS)	1.9	53.94	68.93
Mpumalanga (MP)	2.2	40.05	117.30
North West (NW)	2.6	48.62	106.88
Limpopo (LI)	3.5	61.39	153.42
Northern Cape (NC)	2.0	33.13	29.24
Republic of South Africa (RSA)	2.3	45.55	98.20

High ownership rates affect the occupancy rates of the vehicles and the ultimate energy consumption. Lower vehicle occupancy rates result in more energy consumption for travel on a per capita basis (Flamm, 2009). Thus, reduction of energy and GHG intensity per passenger-kilometer can be achieved by increasing vehicle occupancy rates (de Haan *et al*., 2007; Moriarty and Honnery, 2008).

2.7. Emission factors and vehicle technology

CO_2 estimates from combustion of fossil fuels basically require three input parameters which are; CO_2 emission factor, energy content of the fuel, and carbon stored or unoxidized during its utilization (Winiwarter and Rydpal, 2001; Limmeechokchai and Suksuntornsiri, 2007; Weisser, 2007; Roy *et al.,* 2009). CO_2 emission factors are based on the carbon content of the fuel and they are a good basis to compare pollutant emission from combustion of different fuels (Oannh *et al*., 1999; IPCC, 2006).

A calorific value or energy content of a fuel is predominantly a function of the carbon content (Roy *et al.,* 2009). Gross calorific value differs from net calorific value because it also includes the energy that is carried away in the water vapour resulting from the oxidation of the hydrogen in the fuel (Pulles and Yang, 2011). The carbon content increases with a decrease in net calorific value (Weisser, 2007). Moreover, it heavily depends upon various parameters involved in the combustion process (Bhattacharya and Salam, 2002).

Methane and nitrous oxide emissions depend more on driving cycle of the vehicles, fuel properties and technology than on fuel consumption (Graham *et al.,* 2009). Specifically, the distance based emission rates for CH_4 vary both by driving cycle and by vehicle technology while the distance based emission rates for N_2O vary more by driving cycle than by vehicle technology (Graham, 2006). Fuel-based emission factors that do not specify vehicle technology are highly uncertain (IPCC, 2006).

Catalytic converters are the post-combustion control devices which reduce CH_4 emissions from vehicles (Beer *et al.,* 2002). However, N_2O emissions from motor vehicles equipped with the converters are greater than those without (Beer *et al.,* 2002; Behrentz *et al.,* 2004).

Emission factors can also be described in mass of an emission per unit distance. Distance based emission factors (g/km), though environmentally more meaningful, are subjected to greater variability than the mass of emissions per unit energy (g/MJ) (Beer and Grant, 2007). Their variability depends on a large number of factors such as technology, driving conditions, and maintenance (Hueglin *et al.*, 2006). As such, it is preferred that CO_2 emissions are calculated using emission factors in grams per unit energy than the grams per kilometre (IPCC, 2006).

Distance based emissions factors have been calculated before in South Africa (Table 2.3) (Stone and Bennett, 1998; Scorgie *et al.*, 2004). These studies classified emission factors into two main regions, i.e. Coastal and Highveld.

Table 2.3: Selected road transport distance based emission factors in South Africa (Scorgie *et al.*, 2004)

Pollutant	**Units**	**COASTAL**		**HIGHVELD**	
		Leaded petrol	**Unleaded petrol**	**Leaded Petrol**	**Unleaded petrol**
		Petrol-driven vehicles (Non-catalytic converter equipped)			
CO_2	g/km	214.00	213.50	188.00	190.00
CH_4	g/km	0.05	0.06	0.06	0.04
N_2O	mg/km	5.00	5.00	5.00	5.00
		Petrol-driven vehicles (Catalytic converter equipped)			
CO_2	g/km	267.50	268.00	257.00	243.00
CH_4	g/km	0.03	0.03	0.03	0.05
N_2O	mg/km	5.00	5.00	5.00	5.00
		***Diesel-driven vehicles**			
		LCVs	**M&H**	**LCVs**	**M&H**
CO_2	g/km	245.00	739.00	245.00	739.00
CH_4	g/km	0.01	0.15	0.01	0.09
N_2O	mg/km	17.00	30.00	17.00	30.00

*LCV – Light commercial vehicles

*M&H – Medium and heavy vehicles

Determination of especially CH_4 and N_2O emissions from mobile sources requires consideration of transportation technology (Hankey and Marshall, 2010). Fuel-efficient technology is an essential component of a comprehensive strategy for GHG emissions abatement (Schafer and Jacoby, 2006; Yang *et al.*, 2009). In this case, technologies include improvement of fuel economy of the vehicles (Samaras and Meisterling, 2008) and usage of alternative fuels (Yang *et al.*, 2009) and hybrid vehicles.

****

The chapter presented energy economics and the relationship between fossil fuel and GHG emissions in the transport sector. It showed results of past inventories in the transport sector in South Africa. Factors that affect the emissions were discussed. Emissions indicators were investigated.

CHAPTER 3: METHODOLOGY

This chapter provides background on approaches and methodologies used to calculate GHG emissions. It outlines how GHG emissions for each transport category are calculated. It also presents details on how modal intensities and uncertainties associated with emissions were calculated. Data used in this study are described.

3.0. IPCC methodology

The 2006 IPCC Guidelines provide a detailed methodological framework to accomplish preparation of regular reports on inventories of anthropogenic GHG emissions (IIED, 2009). This method relies on a territorial approach which varies from national to lower levels of governance (D'Avignon *et al.,* 2010; Li *et al.,* 2010).

IPCC uses the tiered approach to estimate GHG emissions. A choice of a tier depends on the availability of relevant activity data and indigenous emission factors (NIES, 2006; Kis-Kovacs *et al.,* 2010). Higher tier methodologies are more demanding in terms of complexity and data requirements as they require country-specific information (Bader and Bleischwitz, 2009; Kis-Kovacs *et al.*, 2010). Only two tiers are usually used to calculate CO_2 emissions in the transport sector as it is not possible to produce significantly better results than by Tier 2 (IPCC, 2006).

Tier 1 is the basic method, where activity data are usually aggregated national statistics and the emission factors are default values representing typical process conditions (IPCC, 2006: NIES, 2006;

Miyoshi and Mason, 2009: Kis-Kovacs *et al.,* 2010). For Tier 1, CO_2 emission factor takes account of all the carbon in the fuel including that emitted as CO_2, CH_4, CO, non-methane volatile organic compounds and particulate matter (IPCC, 2006).

Tier 2 approach is the same as Tier 1 except that country-specific carbon contents of the fuel sold in road transport as well as associated emission factors are used (IPCC, 2006; NIES, 2006). For this tier, the CO_2 emission factors may be adjusted to take account of un-oxidised carbon or carbon emitted as a non-CO_2 gas (IPCC, 2006). For aviation, this approach is based on information of the number of landings and take-offs (Miyoshi and Mason, 2009). For CH_4 and N_2O, Tier 2 approach uses fuel-based emission factors specific to vehicle subcategories (IPCC, 2006).

For key categories that have a significant influence on a total inventory of GHG, it is required to apply higher-tier methods (IPCC, 2006; Cruz-Nunez *et al.,* 2008; Kis-Kovacs *et al.,* 2010). In the case of transport's emissions, greater priority has been attached to the development of emission models and inventories for road vehicles and aircrafts (IPCC, 2006).

Methane and nitrous oxide emissions from motor vehicles may also be determined using Tier 3 approach. On top of the detailed emission factors required, this approach depends on robust vehicle activity levels for each vehicle subcategory and possible road type (IPCC, 2006). However, it is usually difficult to obtain these detailed data. As a result, calculations of CH_4 and N_2O emissions may use this approach if it is not possible to estimate fuel consumption by vehicle type (IPCC, 2006).

Tier 1 was used to calculate all transport emissions in this study. Details on modal emissions differed depending on activity data available.

3.1. Energy consumed by road transportation

Energy consumed by road transport was estimated for each of the nine provinces of South Africa by fuel type and vehicle category. The calculations were done for the base year 2009. Moreover, the energy for each of the years since 2000 were recalculated.

Number of vehicles and distances travelled annually were used to calculate the energy used by each transportation subsector. Numbers of vehicles and distances travelled (Table 3.1) were obtained from the National Traffic Information System dataset (RTMC, 2010).

Table 3.1: Number of vehicles in South Africa as on 31 December 2009 (RTMC, 2010)

	Motor cars	Mini buses	Buses	Motor cycles	*LDVs	Trucks	Other
GA	2,256,780	110,845	14,916	141,423	626,637	121,769	36,706
KZ	754,048	43,394	6,958	33,526	281,554	50,441	31,615
WC	969,006	35,458	5,107	74,669	271,920	34,586	33,278
EC	346,880	20,715	3,714	24,281	161,633	24,470	13,929
FS	253,701	12,035	2,025	23,266	110,215	19,227	39,522
MP	282,341	19,781	4,406	22,925	151,718	24,978	25,533
NW	255,514	18,090	3,118	20,681	128,660	17,976	27,259
LI	200,662	18,781	3,846	12,637	153,258	19,504	14,740
NC	92,161	3,842	1,127	8,992	60,697	8,653	7,904
RSA	5,411,093	282,941	45,217	362,400	1,946,292	321,604	230,484

*LDVs: Light Duty Vehicles

Distances travelled by each vehicle category were obtained from (RTMC, 2010). The data had statistics for all the years except 2009 where only first eight months of data were available. As a result, the total vehicle kilometres travelled in 2009 were estimated using the eight months of data and 2008 statistics. Changes in kilometres travelled between each month of 2009 and its corresponding month in 2008 were determined. Averages of the changes in the data for the eight months were estimated and it was assumed that they were valid during the last four months of 2009. On average, 2009 distances were a factor of 0.97 of the distances travelled in 2008; however, the changes vary between vehicle categories and provinces. Annual distances travelled in 2008 were then multiplied by these averages to estimate distances travelled in 2009 (Table 3.2). It was assumed that petrol and diesel vehicles travelled the same distances in a year.

Table 3.2: Estimated distances (km) travelled by vehicles in 2009

	Motor cars	**Mini buses**	**Buses**	**Motor cycles**	**LDV**	**HDV**	**Other**
GA	11,878	23,996	24,753	4,910	16,892	26,568	2,230
KZ	15,659	27,431	35,378	9,288	19,978	44,014	1,777
WC	12,002	32,060	38,606	3,942	18,386	52,853	1,396
EC	16,070	26,349	24,640	5,777	14,638	33,735	1,528
FS	18,292	38,585	63,469	5,368	22,555	58,354	712
MP	20,765	29,460	43,089	7,692	22,537	66,636	1,701
NW	15,897	21,921	30,677	5,450	15,642	47,386	793
LI	17,836	18,618	18,379	7,657	10,672	32,608	1,094
NC	14,400	35,375	45,140	4,286	13,981	52,209	1,444

Fuel economies which were available in the literature were inconsistent. They were obtained from Taviv *et al.* (2008), Goyns (2008), Mohammed and Venter (2009), Mopani and Capricorn Districts (2010) and Otter *et al.* (*in press*) from which average fuel economies and their associated standard deviations were estimated (Table 3.3). Few motorcycles use diesel, therefore it was generally assumed that all motorcycles used petrol only. These average fuel economy rates were used in this study under the assumption that they were the same in all the provinces.

Table 3.3: Estimated fuel economies per vehicle based on various sources

	Fuel economy (litres/100 km)	
	Petrol	Diesel
Motorcars	9.91	8.44
LDV	10.35	8.20
Minibuses	13.17	12.00
Buses	48.75	44.48
Trucks	20.00	35.50
Motorcycles	4.07	3.75

Motor vehicles usually use either petrol or diesel as their fuel. Numbers of vehicles per province using either fuel were obtained from DOT (2010). The dataset contained number of motor vehicles registered from 2007 to 2009. National averages for 2009 are shown in Figure 3.1.

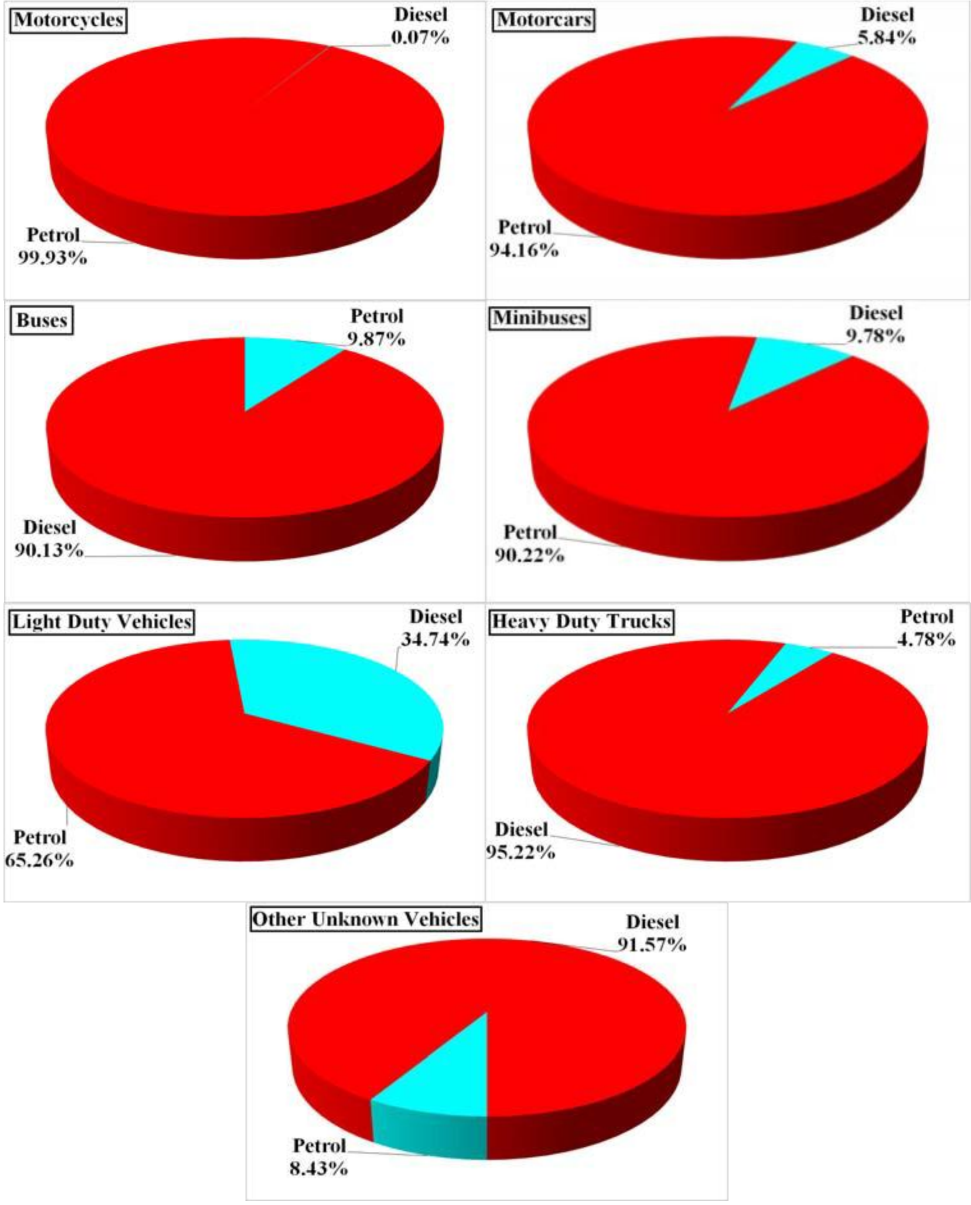

Figure 3.1: Average fuel shares of motor vehicles by type in South Africa in 2009

Fuel profiles of vehicles during the years 2000-2006 were estimated using data from DOT (2010). Numbers of vehicles by fuel type first registered in each of these years were used as proxies to determine profiles in respective years. Averages of the fuel profiles for the years 2007 to 2009 together with the proxies were used to estimate the profiles during the years 2000-2006 using Equation 3.1.

The first years of vehicle registrations were obtained from DOT (2010).

$$N_{i,j,k} = A_{i,j} + (P_{i,j,k}) / (A_{i,j}) \tag{3.1}$$

Where;

N; were the estimated percentages of vehicles using either one of the fuels during the years 2000-2006
A; was the average number of vehicles using either fuel in 2007-2009
P; were the proxies for each year from 2000-2006
i; was the fuel type
j; was the vehicle type
k; was the first year of registration of a vehicle

Conversion of fuel from units of volume to those of energy was done using the averages 34.01 MJ/L for petrol and 37.43 MJ/L for diesel (DME, 2002; 2005; eThekwini, 2006; Lamprecht, 2007; City of Johannesburg, 2008; StatsSA, 2009; DOE, 2009b; 2010a; Leckel, 2009; 2010; Smith *et al.*, 2012; Swart *et al.*, 2012). The same conversion factors were used in all the provinces.

Road transport used other energy types other than petrol and diesel. The other energy types which included residual fuel and other kerosene were obtained from the energy balances DOE (2010b). They contributed very small amounts to the total energy. These energy types were included in the overall quantities of energy and the resulting emissions.

3.2. Energy consumed by off-road transportation

Little statistics were available to calculate off-road energy. Energy consumed by this subsector was estimated using the energy balance data and the results of road transport energy consumption obtained using distances travelled. An approach was selected from the possible two principles suggested by the IPCC (2006);

(1) For each major fuel type, estimate the fuel used by each road vehicle type from vehicle kilometres travelled data. The difference between this road vehicle total and the apparent consumption is attributed to the off-road sector; or

(2) The same fuel-specific estimate in (1) is supplemented by a similarly structured bottom-up estimate of off-road fuel use from knowledge of the off-road equipment types and their usage. The apparent consumption in the transportation sector is then disaggregated according to each vehicle type and the off-road sector in proportion to the bottom-up estimates.

The first approach was adopted in this study. The differences between the energy data generated from the road transport calculations and the energy data obtained from DOE (2010b) were allocated to the off-road category. The analysis was extended to determine the contribution of this category since 2000.

3.3. Energy used for aviation transportation

Fuel consumed by aircrafts (Table 3.4) was used to calculate the emissions from the aviation subsector. Monthly fuel statistics per airport in 2009 were obtained from DOE, (2009a). These data were classified in litres sold to various licensed districts in the country.

Table 3.4: Fuel consumed by aircrafts for each province in 2009 (DOE, 2009a)

Province	**Fuel**		
	Gasoline	**Jet**	
	Domestic		**International**
EC	774,945	153,625,104	6,491,460
FS	1,366,519	7,539,834	
GA	2,844,751	879,997,522	744,894,208
KZ	10,253,003	95,697,068	7,081,487
LI	188,273	3,952,839	20,5
MP	561,191	3,755,092	378,398
NC	747,952	6,034,257	
NW	518,509	301,475	
WC	2,114,422	149,551,936	289,722,507

Jet fuel was separated into fuel used for both domestic and international flights. However, aviation gasoline data were not separated into domestic or international consumption, so it was assumed that the fuel was used by small domestic aircrafts based on IPCC (1997), Geels (2005), Nygren *et al.,* (2009) and Weber *et al.*, (2012). The fuel was converted to energy units using average calorific values of 33.9 MJ/L for aviation gasoline and 34.3 MJ/L for jet fuel (DOE, 2005; 2009b; eThekwini, 2006; City of Johannesburg, 2008).

3.4. Energy used for railways and waterborne transportations

Disaggregated energy data used by railways and waterborne transportations were not available. As a result, energy balances data DOE (2010b) was used. The 2009 national energy balance reported that rail transport consumed various types of energy (Table 3.5). Energy types used were petrol, diesel, other kerosene, hard and bituminous coal. All these data were aggregated. The national energy balance classified the energy used by waterborne activities under the ‘internal navigation’ category. This would suggest that the energy was used by the ships within the jurisdiction of South Africa and not for the international shipping. The energy was approximately 14.56% of the energy used by the entire transport sector and it was comparable to the energy reported by Olivier and Peters (1999) that was used by international ships in South Africa in 1990. It was concluded here that the ‘internal navigation’ energy was used for international shipping.

Table 3.5: Energy used by rail in 2009 in South Africa (DOE, 2009b)

	Energy (TJ)
Hard Coal	2,035.48
Bituminous coal	2,035.48
Motor gasoline	8.25
Other kerosene	0.12
Gas diesel	1685.06

3.5. GHG emissions from road transport in 2009

Carbon dioxide emissions were calculated using Tier 1 approach only. On the other hand, Tiers 1 and 2 were used to calculate CH_4 and N_2O emissions.

3.5.1. CO$_2$ emissions

Greenhouse gas emissions from road transport were calculated for each year starting from 2000 to 2009. Total CO$_2$ emissions by vehicle's mode and fuel type for each of the years were determined. The emissions from road transport were based on the energy calculated in section 3.2 above and were calculated using Equation 3.2 (IPCC, 1997; 2006; Singh *et al.*, 2008; Liao *et al.*, 2011).

$$CO_2 \ (Kg) = \sum S_{a,b} * D_{a,b} * FE_{a,b} * NCV_{a,b} * CEF_{a,b} * 10^{-3} * (1-CS_{a,b}) * FCO_{a,b} * 44/12 \qquad (3.2)$$

Where:

S is the number of vehicles;
D is distance (km);
FE is the fuel efficiency rates (L/km);
NCV is the net calorific value of the fuel (MJ/L);
CEF is the carbon emission factor (kg/MJ);
CS is the carbon stored;
FCO is the fraction of carbon oxidized;
a is the fuel type; and
b is the vehicle type;

The carbon emission factor for diesel and petrol, carbon stored and fraction of carbon oxidized (%) were 20.2 ton of C/TJ, 18.9 tonne of C/TJ, 0 and 0.99, respectively (IPCC, 1997, 2006; Liao *et al.*, 2011). To express the results as CO$_2$, total carbon oxidized was multiplied by 44/12 which is the molecular weight ratio of CO$_2$ to carbon (IPCC, 1997; Singh *et al.*, 2008; Liao *et al.*, 2011).

Default IPCC emission factors were used to calculate the emissions from fuel types; other kerosene and residual fuel oil. Carbon emission factors for these fuels were 19.6 and 21.1 ton/TJ respectively.

3.5.2. CH_4 and N_2O emissions

Two approaches were used to calculate CH_4 and N_2O emissions. The first approach was Tier 1. It used default energy-based emissions factors while the second approach was Tier 2 which applied estimates of locally derived distance-based emission factors.

3.5.2.1. CH_4 and N_2O emissions based on energy emission factors

Emissions of CH_4 and N_2O were calculated using energy-based emission factors (Tier 1 approach) (Equation 3.3). Thus a similar approach to that of CO_2 was used to calculate these emissions. The emission factors of CH_4 were 33.0 and 3.9 kg/TJ for petrol and diesel respectively (IPCC, 2006). And the similar emission factors for N_2O were 3.2 and 3.9 kg/TJ for each of the respective fuels.

$$CH_4, N_2O \text{ emissions (kg)} = \sum S_{a,b} * D_{a,b} * FE_{a,b} * NCV_{a,b} * EF_{a,b} \quad (3.3)$$

Where:

S is the number of vehicles;
D is the distance (km);
FE is the fuel efficiency rates (L/km);
NCV is the net calorific value of the fuel (TJ/L);
EF is the emission factor (kg/TJ);
a is the fuel type; and

b is the vehicle type;

3.5.2.2. CH_4 and N_2O emissions based on distance emission factors

Emissions of CH_4 and N_2O were also calculated using distance based emission factors (Equation 3.4). The recalculation was used to validate the energy-based emissions. These emission factors were based on the use of catalytic converters technology on the vehicles. Other information and data that affect these emissions were not available.

$$CH_4, N_2O \text{ emissions (kg)} = \Sigma S_{a,b} * D_{a,b} * EF_{a,b} \quad (3.4)$$

Where;

S is the number of vehicles;
D is the distance (km);
EF is the emission factor (kg/km);
a is the fuel type; and
b is the vehicle type;

The emission factors and technology information were based on Scorgie *et al.,* (2004), who reported that in 2002 percentage of vehicles fitted with catalytic converters was 7.3% and that a growth rate of the use of catalytic converters in new vehicles was 47.3% of the new cars purchased in 2002, with an annual average growth rate of 3.9% based on the 1990-2002 data.

The 2002 data from RTMC (2010) was used as the basis for number of vehicles employing catalysts technology. Estimated fractions of vehicles using either petrol or diesel in 2002 were employed. Distances travelled by each vehicle per province in 2002 were also used. These data together with the technology information outlined above were used to calculate emissions in 2002.

Difference between number of vehicles in 2002 and 2009 was taken as new vehicles brought into the national fleet during the years up to 2009. The increase of vehicles between 2003 and 2009 was separated into vehicles equipped with catalytic converters (using Equation 3.5) and the vehicles not equipped with the converters. Fraction (%) of vehicles not equipped with converters would therefore be a percentage difference between 100% and M.

$$M = P*(1+A)^n \tag{3.5}$$

Where;

M is the final (cumulative) percentage of vehicles equipped with catalytic converters in 2009 (%);

P is the principal or initial value in 2002 (47.3%); A is the annual growth rate (3.9%); and

N is the number of years (n = 7 for the years 2003 to 2009).

Emission factors found in Scorgie *et al,* (2004) were averaged (Table 3.6). The first reason for the averaging was that vehicles in the Scorgie *et al* report used different classification to the one adopted in this study. They used classifications like light commercial vehicles, and medium and heavy vehicles. Secondly, the emission factors in the report were according to the Coastal and Highveld regions. The regions do not perfectly fit to the provincial disaggregation used in this study.

Table 3.6: Distance based emission factors (adjusted from Scorgie *et al.,* 2004)

	Petrol vehicles	
	CH_4 (g/km)	**N_2O (mg/km)**
Equipped with catalytic converters	0.04[a]	5
Not equipped with catalytic converters	0.05[b]	5
	Diesel Vehicles	
	CH_4	**N_2O**
	0.0806[c]	23.5[d]

[a] Emission factor was the average of 0.03 g/km for coastal areas and 0.05 g/km for the Highveld;

[b] Emission factor was the average of 0.06 g/km for coastal areas and 0.04 g/km for the Highveld;

[c] Emission factor was the average of 0.007 g/km for light commercial vehicles, 0.147 g/km for medium and heavy vehicles in the coastal areas, and 0.088 g/km for medium and heavy vehicles in the Highveld;

[d] Emission factor was the average of 17 g/km for light commercial vehicles and 30 g/km for medium and heavy vehicles

Separate CH_4 and N_2O emissions were determined for vehicles registered in 2002 and those registered from 2003 to 2009. The two calculations were then added together to give the total emissions in 2009. Both emissions in 2002 and the total in 2009 were compared with the calculations obtained using fuel based emission factors.

3.6. GHG emissions from other modes of transport

GHG emissions from off-road, aviation and rail transportation were calculated using Equations 3.6. The quantities in the equation depend on each subsector as described below. However, values for carbon stored, fraction of carbon oxidized and emission factors for petrol and diesel in all these other transport subsectors were the same to those of road transport described above.

$$\text{Emissions (Gg)} = \sum E_a * EF_a \qquad (3.6)$$

where;

E is the energy (TJ);

EF is the emission factor (ton C/TJ for CO_2, kg/TJ for CH_4 and N_2O);

a is the fuel type

3.6.1. Off-road GHG emissions

Emissions from off-road transport were estimated using petrol and diesel as the energy sources. Emissions could not be disaggregated into provinces due to data limitations.

3.6.2. Aviation GHG emissions

To calculate CO_2 emissions from aviation, carbon emission factors for aviation gasoline were 18.9 ton C/TJ and 19.5 ton C/TJ for jet kerosene (IPCC, 1997; 2006). Emission factors for CH_4 were 0.5 kg/TJ for both aviation gasoline and jet fuel. Similarly, N_2O emission factors were 2.0 kg/TJ for both fuels. Factors 0 (zero) and 0.99 were put for carbon stored and fraction of carbon oxidized respectively.

Separate calculations were conducted for both domestic and international flights. Emissions from domestic flights were attributed to South Africa as per the IPCC Guidelines. However, emissions from international flights were not added to the national emissions and they were attributed to the international bunkers.

3.6.3. Rail and waterborne GHG emissions

Emissions from rail transport were based on the nationally aggregated data. Emission factors (Table 3.7) were applied to calculate the emissions. The carbon oxidized fraction was 0.98 for coal IPCC (2006) was used.

Table 3.7: GHG emission factors for rail transport (IPCC, 2006)

	Emission Factors		
	Carbon (ton C/TJ)	**CH_4 (kg/TJ)**	**N_2O (kg/TJ)**
Hard Coal	25.8	2	1.5
Bituminous coal	25.8	2	1.5
Motor gasoline	18.9	3.2	33
Other kerosene	19.6	3	0.6
Gas diesel	20.2	4.15	28.6

Emissions from waterborne transport were calculated for international ships only. Thus the emissions were not added to South Africa's total emissions but to international bunkers. The emissions were developed at the national level. Values for carbon stored, fraction of carbon oxidized and emission factors for diesel were used to calculate the emissions.

3.7. Trends in GHG emissions in South Africa since 2000

Road transport GHG emissions were recalculated for the years since 2000. Tier 1 approach was used for all emissions and updated conversion factors were used where applicable. The results were used to determine change of rates of emissions with time.

3.7.1. Trend in road transport GHG emissions

Trend in road transport GHG emissions was done using annual numbers of vehicles and their associated mobility. The rest of the steps were similar to the descriptions for road transport outlined earlier in the chapter.

As mentioned in section 3.1, annual numbers of vehicles per province were obtained from RTMC (2010). Annual changes since 2000 were determined to investigate the effect of vehicle population on the emissions (Figure 3.2).

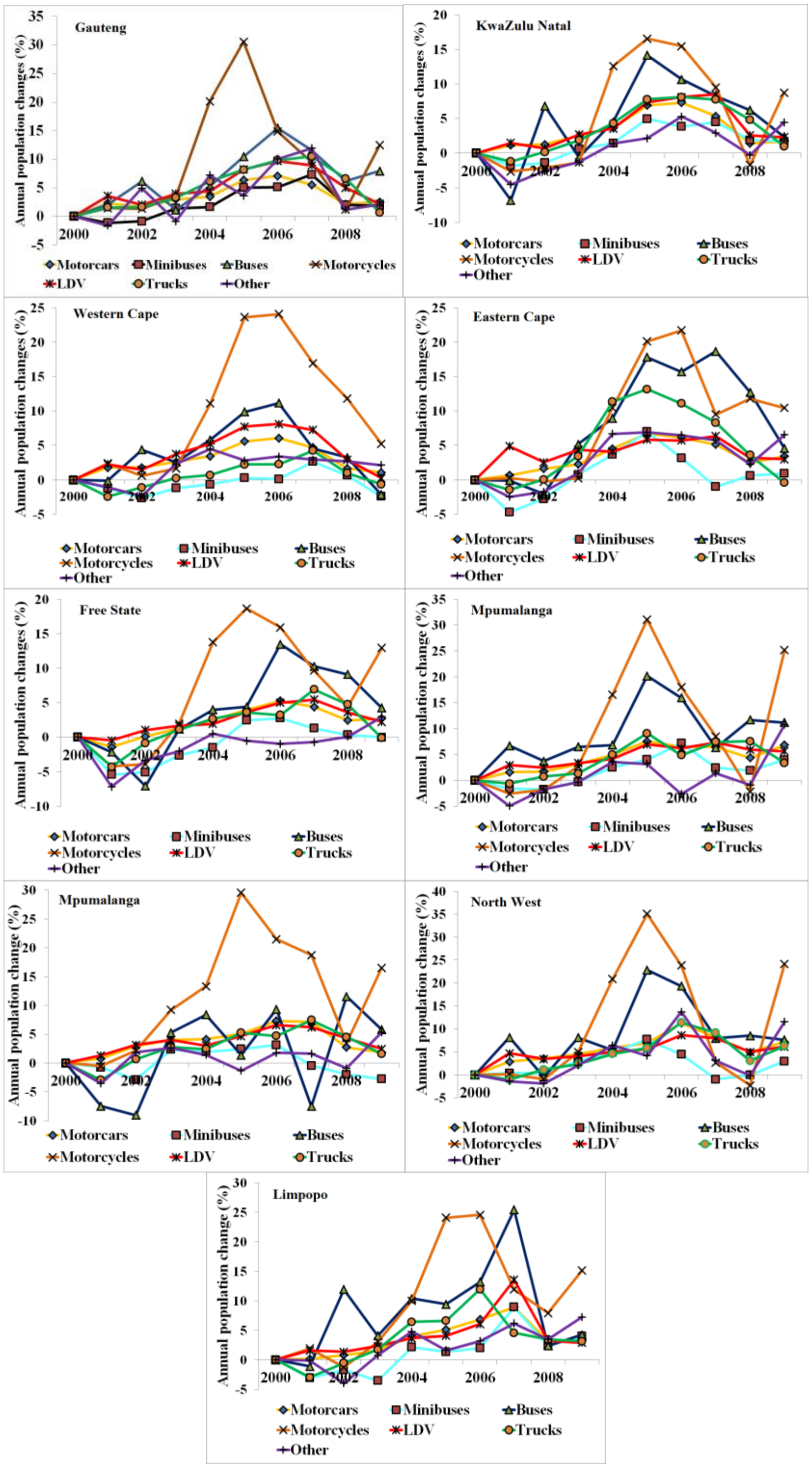

Figure 3.2: Vehicle population annual by province between 2000 and 2009

Data on the mobility of vehicles in the country since 2000 were obtained from RTMC (2010). Provincial trends in mobility of the type of vehicles (Figure 3.3) and their relation to emissions were also investigated.

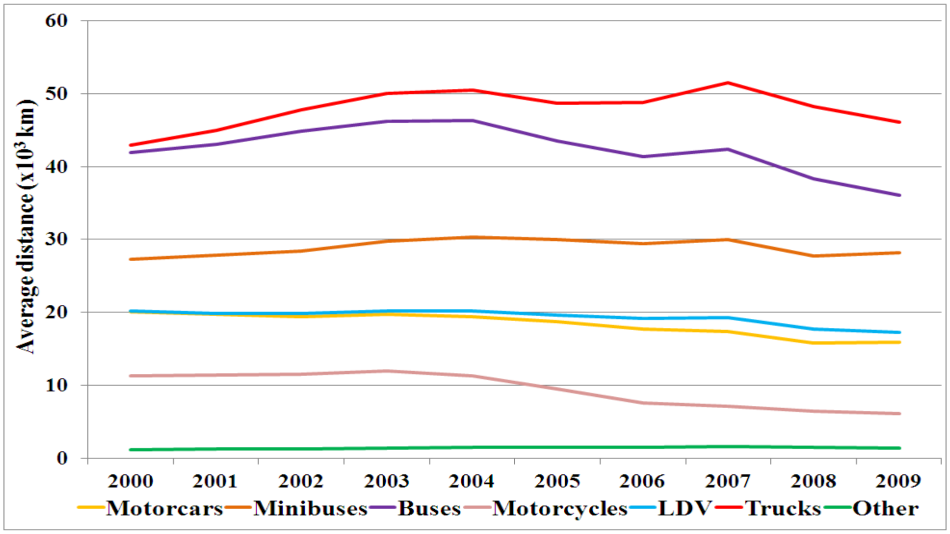

Figure 3.3: Average distances travelled by motor vehicles in South Africa between 2000 and 2009

3.8. CO_2 equivalent emissions

Calculated GHG emissions were converted to CO_2 equivalent emissions. The 100 years global warming potentials were used to change CH_4 and N_2O emissions into their CO_2 equivalents; 1 for CO_2, 25 for CH_4 and 298 for N_2O (Forster *et al.*, 2007; Scheutz *et al.*, 2009). They were based on the Fourth Assessment Report of the IPCC released in 2007.

3.9. Energy and GHG emissions modal intensities

Modal intensities were calculated for road and aviation transportations since other subsectors did not have sufficient data. Energy and CO_2 modal intensities for each vehicle category were calculated using Equation 3.7. Numbers of passengers using each road transport mode were estimated based on the 2003 national household travel survey statistics DOT (2005) and the 2009 midyear population statistics StatsSA (2009) (Table 3.8).

$$\text{Modal Energy } (CO_2) \text{ Intensity}_i = E_i\ (G_i)/(L_i{*}D_i) \qquad (3.7)$$

Where:

E is the energy used by vehicles of mode *i* (MJ); G is the CO_2 emissions (g);
L is the load (passengers or tonnes) carried by the vehicles;
D is the distance travelled (km); and
i is the mode of vehicle

Table 3.8: Percentage of people using each mode of transport and the 2009 population

	Provincial percentage of people[a]			**2009 midyear population**[b]
	Buses	**Motorcars**	**Minibus taxis**	
EC	3.3	10.3	15.9	6,648,600
FS	3.3	15	22.5	2,902,400
GA	3.7	27.3	31.8	10,531,300
KZ	8.7	13.7	20.5	10,449,300
LI	5.6	8.6	17.7	5,227,200
MP	8.1	13.8	19.7	3,606,800
NC	2.2	16.9	12.7	1,147,600
NW	6.7	13.3	22.7	3,450,400
WC	4.6	31.9	19.6	5,356,900

[a] Adjusted from DOT (2005);

[b] StatsSA (2009).

Percentages of people using motorcars, sedan and metred taxis in the survey were added together. Transported tonnes per vehicle were assumed to be 3.0 tons and 25 tons for each kilometre travelled by the light duty and heavy duty vehicles respectively based on Haw and Hughes (2007).

Provincial per capita CO_2 equivalent emissions in 2009 for road transport were calculated. Total CO_2 emissions per GDP were also established. This indicator for South Africa was compared with the rates of other countries and regions. CO_2 emissions for other countries were obtained from IEA (2010), while the corresponding GDPs and population values were sourced from International Monetary Fund (IMF, 2012).

Aviation intensities were calculated using the total modal energy and CO_2 emissions determined here and passenger kilometres obtained from ICAO (2010). ICAO reported that domestic flights in South Africa contributed to 8,896 million passenger-kilometres and 878 million tonne-kilometres in 2009. Domestic passenger and tonne kilometres were added together since the energy and the resulting emissions could not be separated into the usage of either passenger transport or freight.

Changes in modal intensities between 2003 and 2009 were calculated using Equation 3.2 where modal intensities for the former year were subtracted from the latter. The difference relation can be reduced to Equation 3.8 as all other parameters did not change during the years. It was however, assumed that vehicle fuel types would not necessarily influence modal intensities.

$$\text{Change in modal intensity} = 100\%*(S_{a,2009}/P_{a,2009}-S_{a,2003}/P_{a,2003})/(S_{a,2003}/P_{a,2003}) \quad (3.8)$$

Where:

S is the population of vehicle of type *a* in 2003 and 2009; and

P is the number of passengers using vehicles of type *a* in 2003 and 2009

3.10. Uncertainties associated with the 2009 GHG emissions

Primarily there are two methods to calculate uncertainties associated with the emissions. One of them is the error propagation method which is limited to normally distributed data only (Winiwarter and Rypdal, 2001). When data are significantly inaccurate and not normal, detailed statistical approaches which can be described by probability density functions are used (Winiwarter and Rypdal, 2001; Szemesova and Gera, 2010; Winiwarter and Muik, 2010).

Error propagation method was applied to calculate uncertainties in this study. Calculations were limited to CO_2 because distributions of uncertainties in emission factors of CH_4 and N_2O were lognormal (Monni and Syri, 2003; Monni, 2004; IPCC, 2006). Moreover, details of activity data were not comprehensive to allow applications of a robust statistical analysis. Modal uncertainties (U_T) were based on Equation 3.9 (IPCC, 1997; 2006).

$$U_T = (U_1^2 + U_2^2 + \ldots + U_n^2)^{1/2} \qquad (3.9)$$

Where:

U_i are the percentage uncertainties associated with each factor in the activity data (or the mean value) in Equations 3.1 and 3.6.

Uncertainties for road transport were done for each mode of transport and fuel. Aggregated but separate calculations were done for other modes of transport. Aggregation was in terms of uncertainties in the activity data and the emission factors. Modal uncertainties were combined to give total uncertainties in the CO_2 emissions of the transport sector (Equation 3.10) (IPCC, 1997; 2006).

$$U_{Total} = ((U_1 * X_1)^2 + (U_2 * X_2)^2 + \ldots + (U_n * X_n)^2)^{1/2} \; / \; | X_1 + X_2 + \ldots + X_n| \qquad (3.10)$$

Where; U_{Total} is the percentage uncertainty in the sum of the quantities;

X_i and U_i are the uncertain quantities and the percentage uncertainties associated with them, respectively.

Uncertainties in emission factors and the activity data for other subsectors were adopted from literature (Table 3.9). For road transport, uncertainties in the activity data were estimated based on the literature as described below. However, the uncertainties associated with other forms of energy used by road transport other than petrol and diesel were taken to be 5% based on IPCC (2006).

Table 3.9: Uncertainty values for different transport subsectors (Monni and Syri, 2003; Monni, 2004; IPCC, 2006)

Transport mode	**Activity data**	**Emission factor**
Road	See text	2
Civil aviation	5	2
Railways	5	2
Other unknown vehicles	3	2

Standard deviations in the road transport data were calculated and converted to the respective uncertainties. Uncertainties in the mean were estimated as ± 1.96 multiples of the standard error, where the standard error is the sample standard deviation divided by the square root of the sample size (IPCC, 2006). Very limited data were available in the literature.

Uncertainties in the number of vehicles were estimated using three data values. Two separate uncertainty calculations were based on total number of vehicles in 2004 and 2007. Standard error in the number of vehicles was calculated using population of vehicles in 2004 obtained from RTMC (2010) and Taviv *et al.* (2008); and the population in 2007 obtained from RTMC (2010) and SAPIA (2008). An average uncertainty of 3.07% of the two values was determined and used here.

Uncertainties in distances travelled by vehicles in South Africa were estimated as 25% (Kioutsioukis *et al.*, 2004) and 13% (Baidya and Borken-Kleefeld, 2009). The two were uncertainties in Italy and India respectively and they were the only values found in the literature. The average of the two was used in this study. It would include variations in the distances travelled in different road conditions in the country among others.

Uncertainties associated with fuel economy varied between vehicle modes (Table 3.10). They were estimated based on the fuel economy data obtained from Taviv *et al.,* (2008), Mohammed and Venter (2009), Mopani and Capricorn Districts (2010) and Otter *et al.* (*in press*) where means and standard deviations were calculated. Uncertainties in the petrol fuel economies for trucks were assumed to be equivalent to those of diesel. Uncertainties in the fuel economy of motorcycles were assumed to be approximately 5% (Monni and Syri, 2003; Monni, 2004; IPCC, 2006). Moreover, uncertainties for other unknown vehicles were assumed to be averages of values for other modes.

Table 3.10: Average uncertainties (%) associated with fuel economies and calorific values based on various data sources

	Petrol	**Diesel**
Motorcars	37.52	69.21
LDV	6.70	20.28
Minibuses	17.76	46.20
Buses	7.11	9.99
Trucks	9.37	9.37
Motorcycles	5.00	5.00
Other unknown vehicles	16.69	26.67
Net calorific value (NCV)	0.50	4.12

Uncertainties in the calorific values of the fuel originate primarily from fuel properties. Uncertainties (Table 3.10) in the energy contents per unit volume of petrol and diesel were estimated using net calorific values obtained from DOE (2002, 2005, 2009), eThekwini (2006), Lamprecht (2007), City of Johannesburg (2008), StatsSA (2008, 2009), Leckel (2009, 2010), Smith (2012) and Swart (2012).

****

The chapter presented data and methods used in this study. Tier 1 approach was used to determine the GHG emissions in the transport sector where emissions factors from the IPCC were used. CH_4 and N_2O GHG emissions were also recalculated using Tier 2. Modal intensities were determined for road transport due to data restrictions. It was also shown how uncertainties in the emissions were calculated.

CHAPTER 4: GREENHOUSE GAS EMISSIONS

This chapter presents GHG emissions emitted by transport sector in South Africa. Emissions are calculated for each transport subsector in the country, as well as for international bunkers. Rates of emissions are outlined and comparisons of emissions are made with literature.

4.0. Greenhouse gas emissions in South Africa in 2009

The transport sector, excluding international bunkers, is estimated to have emitted a total of 54,296.30 Gg of CO_2-eq emissions in 2009. CO_2 contributed 97.90% of the total emissions, CH_4, 0.67% and N_2O, 1.42%. CO_2 component constituted approximately 97.75 % of the CO_2-eq in the previous emissions (DEA, 2009; Agyemang-Bonsu *et al.*, 2010).

Rates obtained in this study are slightly higher than values in the literature due to the different conversion factors used. Approaches used to calculate GHG emissions in this study and the previous DEA/DEAT reports slightly differ. The DEA/DEAT used CO_2 emission factors that assumed that carbon content of the fuel was completely oxidised while this study used the fact that only fraction of it (0.99) was oxidised. The total emissions by DEA/DEAT were thus slightly higher than established by this study.

Road transport is the largest emitter of the GHG emissions with 80.18% of the total transport CO_2-eq emissions (Figure 4.1). This ratio is comparable to the global ratios which show that road transport contributes between 74% and 78% in most countries (IEA, 2005 in

Meyer *et al.*, 2007; Ribeiro *et al.*, 2007; IEA, 2011a; McCollum and Yang, 2009). Road, aviation, railways and shipping transportations in India contributed 94.5%, 2.9%, 2% and 0.6% of CO_2 emissions respectively (Ramachandra and Shwetmala, 2009).

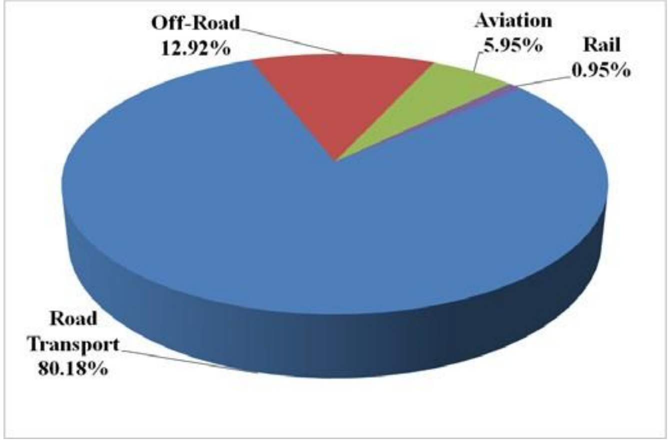

Figure 4.1: CO_2-eq emissions by transport subsector in South Africa in 2009

Motorcars, motorcycles and light duty vehicles account for approximately 49% of the transportation CO_2-eq emissions. This is similar to Canada where passenger cars, light trucks and motorcycles account for 50% of the transportation emissions (Graham, 2006).

On average, road transportation accounts for 93.09% of CO_2-eq emissions from petrol and diesel excluding contributions from rail transport and off-road vehicles (Table 4.1). Gauteng and the Eastern Cape are the only provinces where road transport produces less than 90% of the emissions from the two transportation subsectors.

Table 4.1: Provincial share (%) of CO_2-eq emissions from road and domestic aviation transportation in 2009

	GA	KZ	WC	EC	FS	MP	NW	LI	NC	RSA
Road	86.31	96.51	94.58	88.96	99.32	99.76	99.92	99.52	98.50	93.09
Aviation	13.69	3.49	5.42	11.04	0.68	0.24	0.08	0.48	1.50	6.91

Petrol and diesel are highest sources of total transport CO_2-eq emissions (Figure 4.2). The increasing share of diesel vehicles over their petrol counterparts with time also shifts the country's emissions profile. In 2000, petrol accounted for about 63% of the CO_2-eq emissions while diesel contributed 31% (DEA, 2009).

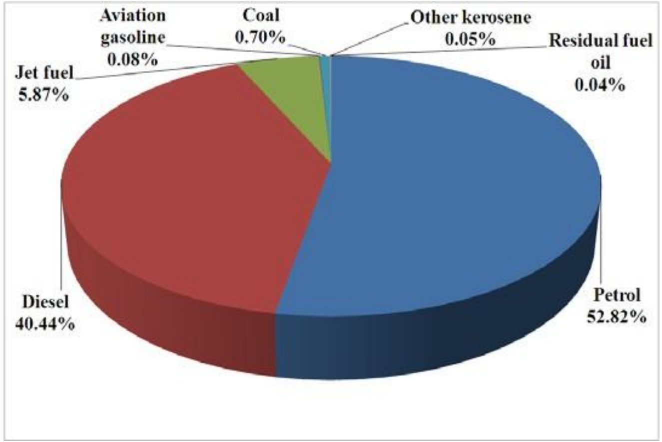

Figure 4.2: Total transport CO_2-eq emissions by fuel types in 2009

4.1. Road transport CO_2 emissions in South Africa in 2009

The road transport subsector was estimated to emit 42,589.85 Gg of CO_2 emissions in 2009, including small contributions from residual fuel oil and other kerosene. Petrol and diesel vehicles contribute 57.51% and 42.49% respectively towards this total (Table 4.2).

Table 4.2: Road transport CO_2 emissions (Gg) for each province, vehicle and fuel type in 2009

	GA	KZ	WC	EC	FS	MP	NW	LI	NC
Total	**13,293**	**6,991**	**6,326**	**2,975**	**3,090**	**4,244**	**2,510**	**2,049**	**1,064**
	Passenger Transport								
Petrol	**6,678**	**2,981**	**2,903**	**1,400**	**1,174**	**1,452**	**1,022**	**891**	**333**
Motorcycle	77	34	32	15	14	19	12	11	4
Motorcars	5,816	2,594	2,552	1,226	1,016	1,255	886	776	289
Minibuses	736	336	301	152	127	160	112	98	36
Buses	49	16	17	6	17	18	12	6	4
Diesel	**918**	**475**	**434**	**195**	**222**	**347**	**176**	**148**	**85**
Motorcars	420	152	153	70	64	109	59	56	19
Minibuses	93	35	54	19	18	21	12	11	7
Buses	406	288	226	107	141	217	105	81	58
	Freight Transport								
Petrol	**1847**	**871**	**791**	**378**	**402**	**567**	**346**	**292**	**128**
LDV	1759	838	752	365	375	519	319	269	117
Trucks	88	33	39	14	27	48	27	23	11
Diesel	**3819**	**2641**	**2180**	**993**	**1280**	**1859**	**957**	**710**	**513**
LDV	766	498	436	198	216	294	160	121	84
Trucks	3053	2143	1744	795	1064	1565	797	589	429
	Other and Unknown Vehicles								
Petrol	**3**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**
Diesel	**29**	**21**	**18**	**8**	**11**	**18**	**9**	**6**	**4**

Motorcars are the major sources of road transport emissions (Figure 4.3). They emit 41.17% of the national road transport CO_2 emissions and they are followed by heavy duty trucks and light duty vehicles with 29.36% and 19.01% respectively. Smallest contributions are from motorcycles and other unknown vehicles. Petrol motorcars contribute 38.58% and diesel heavy duty trucks account for 28.63% of road transport emissions.

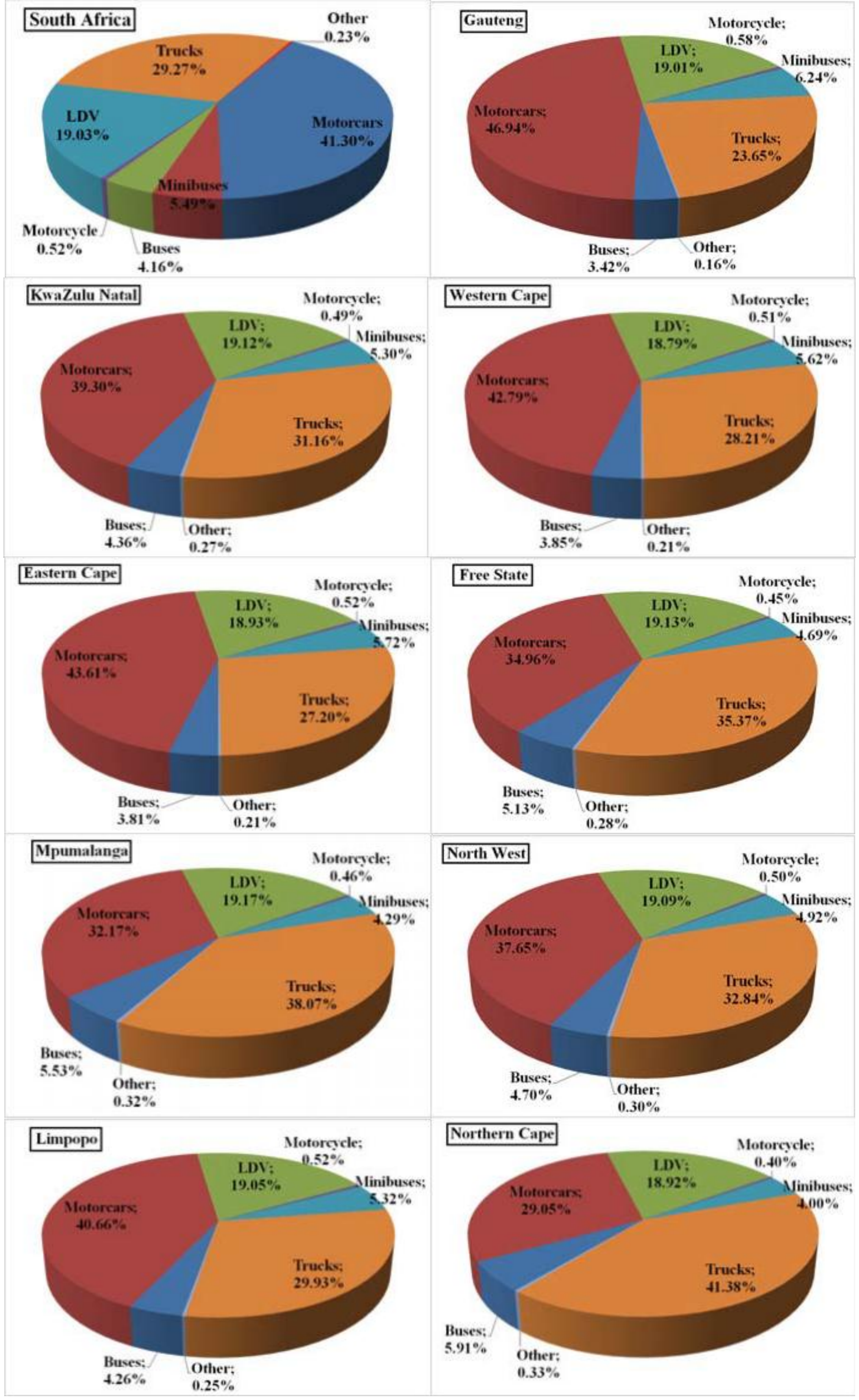

Figure 4.3: Share of provincial CO_2 emissions by type of transportation in 2009 in South Africa

Passenger road transport emits approximately 51.33% of total emissions of road transport. Motorcars account for an average of 80.20% of these emissions. Minibuses, buses and motorcycles contribute 10.66%, 8.13% and 1.00% of the total passenger transportation emissions respectively.

Road freight transport account for about 48.36% of road transport CO_2 emissions. Nationally, heavy duty trucks contribute approximately 60.70% of road freight emissions, while light duty vehicles account for 39.29% of road freight emissions. It is calculated by Chapman (2007) that in the OECD (Organisation for Economic Co-operation and Development) countries, road freight typically accounts for just under half of the road transport total.

Road transportation in Gauteng is the highest producer of GHG. It contributes about 31.25% to the national equivalent emissions and the Northern Cape is the lowest with 2.50% (Figure 4.4). Passenger vehicles in Gauteng account for 17.86% of the total transport emissions while freight vehicles in the province produce 13.32% of the subsector’s total.

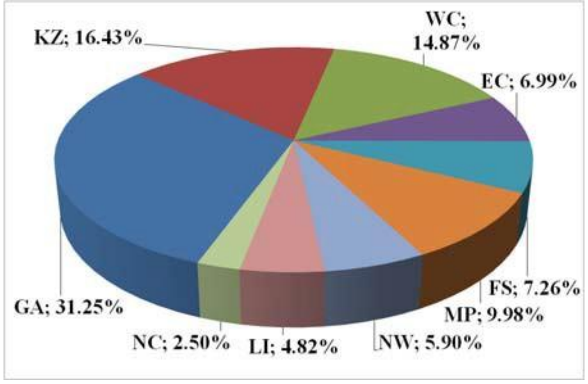

Figure 4.4: Provincial share of road transport CO_2-eq emissions in 2009

4.2. Road transport CH_4 and N_2O emissions based on energy consumption

In 2009 the road transport subsector was estimated to have emitted a total of 12.72 Gg of CH_4 and 2.10 Gg of N_2O. The majority of CH_4 emissions are as a result of petrol consumption. More than 92% and 54% of CH_4 and N_2O are produced by petrol consumption respectively. Heavy duty trucks account for 31.56% and 6.19% of road transport's N_2O and of CH_4 emissions respectively. While not dominant, heavy-duty diesel vehicles contribute measurably to both CH_4 and N_2O emissions associated with transportation (Graham *et al.*, 2008).

Motorcars are the major producers of the CH_4 and N_2O emissions from road transport being responsible for 62.52% and 39.16% of CH_4 and N_2O emissions, respectively. Light duty vehicles and heavy duty trucks are the second highest producers of CH_4 (21.25%) and N_2O (31.56%) from road transport emissions respectively.

Gauteng produces 34.22% of CH_4 and 30.97% of N_2O emissions from road transport (Figure 4.5). Three provinces Gauteng, KwaZulu Natal and the Western Cape produce nearly two thirds of the total road transport's CH_4 and N_2O emissions.

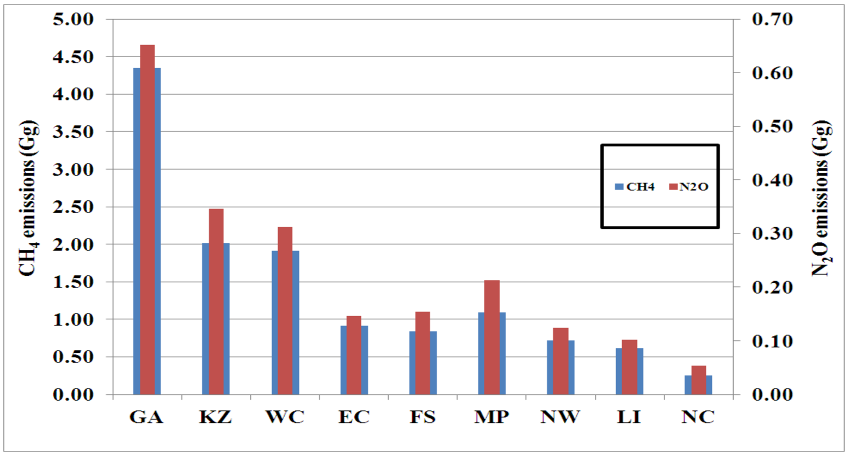

Figure 4.5: CH_4 and N_2O emissions from road transport in 2009

4.3. Road transport CH_4 and N_2O emissions based on vehicle technologies

CH_4 and N_2O emissions in 2009 based on distance based emission factors are 11.56 Gg for CH_4 and 1.98 Gg for N_2O. These are smaller than emissions calculated using fuel based emission factors by approximately 10% for CH_4 and 6% for N_2O.

Default CH_4 and N_2O emission factors that do not specify vehicle technology are highly uncertain (IPCC, 2006). However, CH_4 and N_2O emissions calculated using fuel-based emission factors can be lower or higher than distance-based emissions and it is difficult to say which approach to inventory development would produce the most credible results (Graham, 2006).

Approximately 61% of vehicles are estimated to be equipped with catalytic converters technology aimed to reduce emissions. Consequently, only 20% of all the CH_4 and N_2O emissions are produced by vehicles equipped with the technology.

Emissions from petrol fuelled vehicles equipped with catalytic converters contributed 64.20% of road transport's CH_4 emissions in 2009. Similar diesel fuelled vehicles produced 61.03% of N_2O emissions from road transport in 2009.

4.4. GHG emissions from the off-Road transport

In 2009, off-road transport is estimated to have emitted approximately 12.91% of total transport's CO_2 emissions. That made off-road vehicles the second largest emitting mode of transport in South Africa in 2009. These emissions together with those from road transport make 93.03% of the total transport emissions which is comparable to 93.59% derived from data in IEA (2011a).

Emissions databases from off-road equipment suffer immensely from insufficient real-world activity data (Gautam *et al.,* 2002). This therefore implies that emissions from this subsector have larger uncertainties than those from other transport subsectors.

4.5. Domestic aviation transport GHG emissions in 2009

Domestic flights emit approximately 6.02% of total transport CO_2 emissions excluding international transport. CO_2 contributes more than 99% of the total CO_2-eq emissions from domestic aviation. Bulk of the emissions is from jet kerosene combustion.

OR Tambo International Airport, the largest airport in southern Africa, accounts for more than 95.68% of the aviation CO_2 emissions in Gauteng and 64.02% of national emissions. Gauteng produces largest amounts of provincial CO_2 emissions (Figure 4.6). The three coastal provinces; the Eastern Cape, the Western Cape and KwaZulu Natal account for a combined 31.20% of the emissions. Each of the other provinces contributes less than a percent to the total.

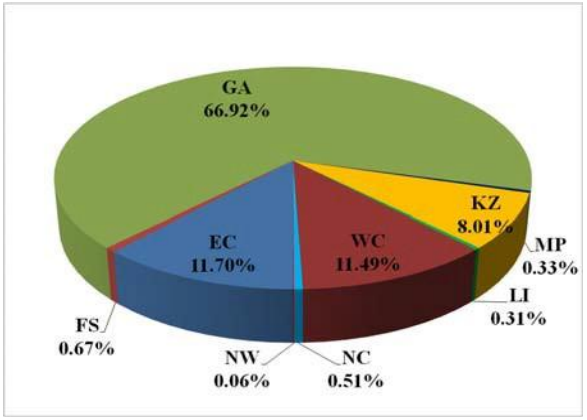

Figure 4.6: Share of domestic aviation CO_2 emissions in South Africa in 2009

KwaZulu Natal is the largest producer of CO_2 from aviation gasoline combustion in the country. The province accounts for 52.93% of the national CO_2 emissions emanating from the burning of this fuel by aircrafts. This abnormality can be as a result of the pilotage activities undertaken at Durban sea port. The other provinces that emit large amounts of CO_2 from aviation gasoline are Gauteng with 14.69% and the Western Cape with 10.92%.

4.6. Railways and waterborne transport GHG emissions in 2009

Rail is the lowest emitter of CO_2 as it is the transport mode heavily operated by electricity. It emits approximately 0.94% of the transport emissions. CO_2 contributes nearly 97% of the total CO_2-eq emissions produced by this subsector. About 70.62% of these emissions are from coal products and 29.23% are from diesel consumption.

There are emissions from waterborne activities in South Africa. However, these emissions are hard to quantify due to insufficient data on fuel usage for these domestic activities. The emissions from the energy reported to be used by the internal navigation in the energy balance are comparable to the emissions international bunkers and were therefore assumed to be from international waterborne activities. As such, the emissions from that energy are reported under the international marine bunkers. In this inventory domestic waterborne transport is assumed to be negligible.

4.7. International bunkers GHG emissions

Emissions that are included in the international bunkers are from international waterborne and aviation transport. International bunkers produced a total of 10,051.47 Gg of CO_2 and 10,956.36 Gg of CO_2-eq emissions in 2009. International aviation emissions are comparable to the value that would be obtained from jet kerosene energy reported in the energy balance.

International waterborne emissions are the largest source of bunker CO_2 emissions with 76.56% and aviation emissions account for 23.44%. These fractions are generally the same to the estimates of DEA (2009) for the year 2000. Globally, international waterborne transport accounts for approximately 58.7% of the total bunker's CO_2-eq emissions (McCollum *et al.,* 2009; IEA, 2011a). International waterborne emissions are comparable to the results in IEA (2011b).

International aviation contributed 44.29% of the total (domestic and international) aviation's emissions in South Africa in 2009. This is small compared to the global average of 60.65% in 2005 (McCollum *et al.,* 2009). In India, international aviation accounted for approximately 20% of the total emissions produced by that industry in the country (Garg and Avishia, 2011). Similarly, international waterborne transport accounts for 84.73% of total waterborne transport emissions at a global scale (McCollum *et al.,* 2009).

4.8. Trend of transport emissions from 2000 to 2009

Transport CO_2-eq emissions between 2000 and 2009 increased by 39%. The increase is higher than changes observed between 1990 and 2000. During that period, the emissions increased by 25% (DEA, 2009; DEA, 2011).

Only emissions from road transport in Gauteng are compared with other studies due to data limitations. Emissions from other modes of transport during preceding years cannot be disaggregated into provinces.

4.8.1. Trends in road transport GHG emissions

Trends in road transport emissions are investigated using two approaches. The emissions are based on fuel consumption and the technology employed in the vehicles.

4.8.1.1. Trends in road transport emissions based on fuel consumption

Road transport CO_2-eq increased by approximately 26% between 2000 and 2009. Individual emissions increased at different rates during the period (Figure 4.7). Over the ten years N_2O emissions increased by 27.34%, CO_2 by 26.19% and CH_4 by 14.98%. Emissions gradually increased except in 2008 when emissions decreased. In 2009, for the first time since 1992, there was no growth in global CO_2 emissions from fossil fuel use (Netherlands Environmental Assessment Agency, 2010). Annual changes of CO_2 and N_2O have been generally similar and are different to CH_4 changes.

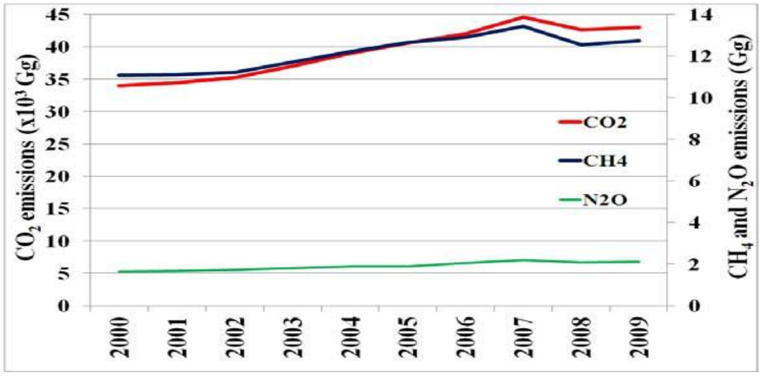

Figure 4.7: Trend of total road transport GHG emissions between 2000 and 2009 in South Africa

Between 2000 and 2009, the overall CO_2 emissions from road transport increased at approximately 2.66% per year. The rate was much higher between 2000 and 2007 during which it was 3.95% per year. These rates are comparable with the global changes of approximately 2.5% per annum since the early nineties (Netherlands Environmental Assessment Agency, 2011).

Road transport emissions in 2008 decreased by 4% compared to the preceding year. In 2008, the combination of a peak in fuel prices and the starting economic recession caused a decline in global road transport emissions (Netherlands Environmental Assessment Agency, 2011). Reductions in emissions in 2008 were all greater than 2% in all modes of road transport, except for buses and heavy duty trucks. The emissions in 2009 increased by approximately 0.67% over 2008 values. All modes of road transport increased their emissions in 2009 except for trucks.

Total road transport CO_2-eq emissions for Gauteng in 2007 is comparable with other findings (Table 4.3). Notable differences are in buses (50%) and minibuses (36%). Differences in the modal results are generally due to vehicle classification. Road transport emissions fell by about 3% between 2007 and 2009 as a result of reduced mobility of vehicles.

Table 4.3: Comparison of road transport CO_2-eq (Gg) emissions for Gauteng in 2007 based on own calculations and other studies

Road Transportation emissions calculated in this study							
Motorcar	**Motor cycle**	**Mini bus**	**Bus**	**LDV**	**Truck**	**Other**	**Total**
6,666.70	77.39	904.01	449.82	2,698.99	3,238.14	32.77	**14,067.82**
Road Transportation emissions based on EnerKey (2012)							
Passenger car	**Motor cycle**	**Mini bus**	**Bus**	**LDV**	**HDV**	**SUV**	**Total**
5,933.97	**15.37**	**1,420.51**	**299.40**	**2,444.84**	**3,737.47**	**761.22**	**14,612.77**

Generally, freight vehicles have higher rates of emissions increases than the passenger vehicles (Table 4.4). Between 2000 and 2009 emissions from trucks and light duty vehicles increased by 53.85% and 25.09% respectively. During the same period, CO_2 emissions from buses increased by 59.18%, minibuses had 12.44% increases, and for motorcars the increase was 11.69%. Other GHG had similar rates of increase.

Table 4.4: Annual changes of road transport GHG emissions between 2000 and 2009 in South Africa

	Annual average increases (% per year)		
	CO_2	**CH_4**	**N_2O**
Motorcars	1.28	1.13	1.30
Minibus	1.36	1.13	1.40
Buses	5.37	5.04	5.38
Motorcycle	2.31	2.31	2.31
LDV	2.57	2.35	2.59
Trucks	4.99	4.63	4.99
Other	5.21	5.91	5.26

Carbon dioxide emissions from diesel-fuelled vehicles have increased at a faster rate (48.26% in ten years) than those from petrol-fuelled vehicles (14.67%). For diesel-fuelled vehicles, buses have the highest increase of emissions with 60.86% and light duty vehicles experienced lowest increase with 31.35%. For petrol-fuelled vehicles, minibus taxis had the lowest increase rate of 9.66% while other unknown vehicles had highest increase rate of 102.37%.

Emission rates are affected by either vehicle population growth or distances travelled. Although the rate of increase of population of passenger vehicles has increased drastically with time, the rates of emissions and mobility of vehicles have been on a decreasing trend since 2003.

Average national changes in CO_2 emissions between 2000 and 2009 from buses, other unknown vehicles, and heavy duty vehicles are highest over the period (Figure 4.8). Increases for buses and trucks are mostly due to increase in average annual mobility of these modes while the changes for other unknown vehicles are as a result of their numbers. This shows that the emissions are very sensitive to mobility of vehicles (Thambiran and Diab, 2011). Moreover, the rates of change for buses and minibus taxis could be influenced by the Government's taxi recapitalization programme.

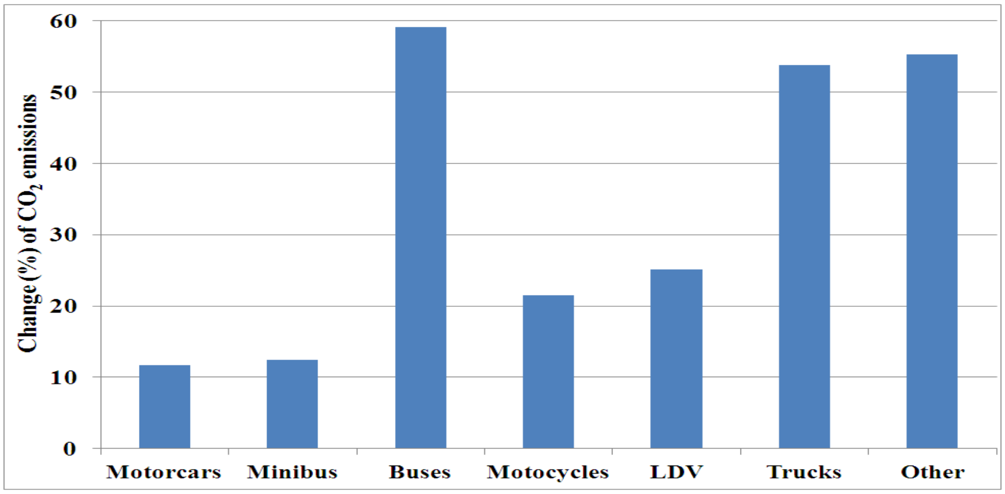

Figure 4.8: Percentage change of CO_2 emissions from road transport by vehicle type between 2000 and 2009 in South Africa

Changes of modal emissions between 2000 and 2009 vary for each province. Increases in road transport emissions are highest in Mpumalanga (56.85%), Free State (39.04%), Gauteng (27.27%) and the Eastern Cape (26.55%). Moreover, Mpumalanga is the only province that has experienced rates that exceed 20% in all vehicle modes. Similarly Limpopo where the rate is 3.45% is the only province where emissions increased by less than 10%.

Changes in emissions from Limpopo are different from the rest of the provinces. Minibuses in this province are the only mode to have a decrease in emissions between 2000 and 2009, and this is despite the province observing highest increases of minibus population in the country during the period. The decrease in emissions is therefore attributed to the decrease in distances travelled by the mode which is approximately 20% between the two years. This needs further investigation as most of the other provinces experienced increases in both the population and the mobility of the minibuses.

4.8.1.2. Trends in road transport N_2O and CH_4 emissions based on vehicle technology between 2002 and 2009

Between 2002 and 2009, total N_2O emissions increased by 28.24%, while CH_4 emissions increased by 25.91%. Total N_2O and CH_4 emissions calculated from vehicles equipped with catalytic converters experienced a nearly 3-fold increase between the two years. The increase is due to the increasing number of vehicles equipped with the catalytic converters over time while ratio of the vehicles not equipped with the converters is decreasing. Similar comparison of emissions from vehicles not equipped with catalytic converters between the two years increased by only 11.82%.

In 2002 petrol vehicles equipped with catalytic converters contributed only 6.54% to the N_2O emissions from petrol consumption. The fraction increased to 17.76% in 2009. Similarly, emissions from diesel vehicles increased from 5.72% to 18.30% between the two years. CH_4 emissions from vehicles equipped with the converters increased from 5.30% to 14.73% for petrol vehicles and from 5.72% to 18.30% for diesel vehicles.

Emissions per vehicle decreased by 6.87% for N_2O and 8.56% for CH_4 between the years 2002 and 2009. These changes are despite average increases of the rates for vehicles not equipped with catalytic converters by approximately 1.5 times for petrol vehicles and 5 times for diesel vehicle. Changes in emissions per vehicles vary remarkably among provinces from about 1-2% in the Free State to 18-19% in Limpopo (Figure 4.9). The reduction in emissions per vehicles could be attributed to the technology employed in the vehicles that were bought during the seven years (2003-2009). Catalytic converters generally reduce GHG emissions (Moriarty and Honnery, 2008).

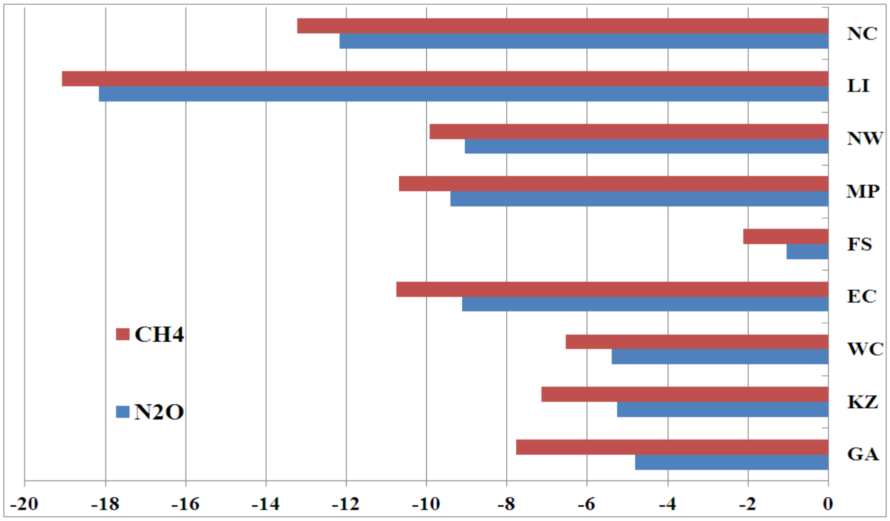

Figure 4.9: Change (%) of N_2O and CH_4 emissions per vehicle between 2002 and 2009

4.8.2. Trends in emissions from other transport subsectors

Emissions from domestic aviation experienced a considerable increase during 2000 – 2009. Nearly 6% of annual increase in emissions is observed. That is higher than 4% increase emissions in Europe for the time period 1996 and 2005 (Bows *et al.*, 2009).

Domestic aviation emissions increased by approximately 1.40% between the years 2008 and 2009 and by 3.10% between 2007 and 2009. That was low compared to changes in other developing countries. In India, emissions from domestic aviation increased by approximately 34% between 2007-2008 and 2008-2009 (Garg and Avishia, 2011). Unlike road transport, domestic aviation CO_2-eq emissions obtained here are partially comparable with other studies.

The 2009 aviation's emissions show a 1.87% decrease from the 2007 value calculated based on the energy balances. The decrease was probably due to economic recession then. Calculations based on the 2007 energy balances and EnerKey (2012) results show that Gauteng contributed 38.23% of the national domestic aviation CO_2-eq emissions in 2007. This fraction is small compared to share of the province in 2009.

Changes in GHG emissions from off-road transport are huge and vary with time. Between 2000 and 2009, CO_2-eq emissions from off-road transport had almost a 3-fold increase. However, off-road emissions decreased by approximately 25% between 2008 and 2009.

On the other hand, CO_2-eq emissions produced by rail transport decreased by 23.66% in the ten years ending in 2009. This change could be attributed to the continuing decline in the use of the rail system in the country. The uncertainty in emissions from this mode is based on the fact that calculations of emissions for 2000 are based on diesel fuel only while more fuel types were included for 2009.

4.9. Uncertainties in GHG emissions

Total uncertainty in the transport sector CO_2 emissions in South Africa is approximately 16.70%. Road transport subsector has the largest uncertainty margin of 18.18% which also varies between vehicle types and fuel types (Figure 4.10). Generally, highest uncertainties are produced by emissions from motorcars, minibus taxis and off-road vehicles. Emissions from other modes of transport have uncertainties just higher than 5%.

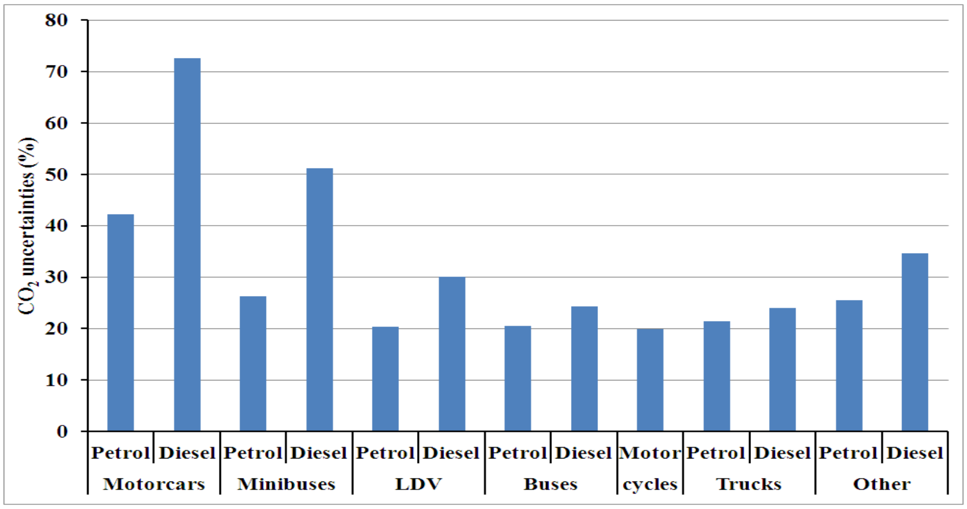

Figure 4.10: Uncertainty estimates in road transport GHG emissions in 2009

Emissions from diesel-fuelled vehicles have highest levels of uncertainties. This is influenced mainly by different uncertainties of fuel economies and energy values which were higher for diesel vehicles than their petrol counterparts. CO_2 emissions from mobile combustion are most sensitive to diesel consumption and to total consumption (Olsthoorn and Pielaat, 2003).

Generally, uncertainties associated with transport CO_2 emissions using Tier 1 and fuel sales are about 5% (Olsthoorn and Pielaat, 2003). Nonetheless, uncertainties from the overall fuel balance are usually lower than from assessing the sources separately (Winiwarter and Rypdal, 2001).

The emissions calculated here are not far from what would have been obtained had the energy balances been used. This suggests that the uncertainties are not necessarily all about the overall magnitude of the emissions, but rather the intermodal emissions. Emissions between road and off-road transportations represent areas of considerable uncertainty. This is because these two modes are often refueled from the same points. Also, off-road vehicles are not classified explicitly in the vehicle's registration system and their statistics and other characteristics could easily be mixed with the road vehicles.

****

The chapter presented GHG emissions for the transport sector in South Africa in 2009. Provincial emissions were done for each mode of road transport only. Recalculations of emissions beginning in 2000 were done for road transport only. Uncertainties associated with the emissions were also presented.

CHAPTER 5: INDICATORS ASSOCAITED WITH GHG

This chapter presents road and aviation transport GHG indicators. These indicators show efficiencies and intensities of each mode of road transport and comparisons between the modes are done. Provincial road transport emissions per capita are investigated. Total GHG emissions per capita are also done for the entire transport sector and the results are compared with rates for other countries.

5.0. Road transport vehicle efficiencies

Energy and CO_2 emissions efficiencies vary between types of vehicles. Energy efficiencies vary from 1.61 MJ/km for petrol motorcycles to 16.94 MJ/Km for diesel buses, and the corresponding CO_2 rates are 110.28 g/km and 1,242.51 g/km respectively (Table 5.1). These rates are proportional to the fuel economies of the vehicles.

Table 5.1: Road transport energy (MJ/km) and CO_2 (g/km) efficiency by vehicle and fuel type in South Africa in 2009

	Fuel type	**MJ/km**	**g/km**
Motorcars	*Petrol*	3.39	232.41
	Diesel	3.21	235.70
Minibuses	*Petrol*	4.50	309.02
	Diesel	4.57	335.25
LDV	*Petrol*	3.54	242.85
	Diesel	3.12	229.09
Buses	*Petrol*	16.67	1143.85
	Diesel	16.94	1242.51
Motorcycles	*Petrol*	1.61	110.28
Trucks	*Petrol*	7.62	558.74
	Diesel	13.53	991.77
Other unknown	*Petrol*	3.15	215.87
	Diesel	5.75	421.85

Diesel engines generally have higher engine efficiency than engines using petrol with the same engine size, particularly at low engine load (Brink and Wee, 2001). Diesel vehicles operate at higher air-fuel ratio, about 30:1 as opposed to 15:1 characteristic of petrol-fueled vehicles (Scorgie *et al.,* 2004). As a result, diesel vehicles consume less energy per distance travelled than similar petrol vehicles.

Generally, these emission rates are comparable with other results including Stone and Bennett, (1998); Scorgie *et al.,* (2004); Wang *et al.,* (2008); D'Angiola *et al.,* (2010); Wang *et al.,* (2010); Warren and Avila, (2010) and Zervas, (2010). Moreover, the results obtained here are comparable to that of other BRICS (Brazil, Russia, India, China, and South Africa) countries (Table 5.2). However, this indicator does not adequately compare modal efficiencies within and outside the country.

Table 5.2: Modal energy per distance (MJ/km) in BRICS countries in 2009 (Data obtained from IEA)

	Motorcycles	**Trucks**	**LDV**	**Mass Transport**	**Medium trucks**	**Motorcars**
Brazil	1.6	17.08	6.19	9.91	10.84	3.71
China	0.4	11.72	6.24	8.63	11.30	3.80
India	1.4	17.08	4.57	11.81	9.97	2.55
Russia	1.3	13.86	3.55	4.58	7.06	2.61

5.1. Energy and CO_2 modal intensities in South Africa in 2009

Energy consumption of all modes of transport and associated emissions are best compared using their modal intensities. Aviation transport is the most energy intensive mode of transport in South Africa. On the other hand, rail is the most energy efficient mode of transport in terms of the energy expended per passenger-kilometre (Winkler *et al.*, 2006). However, rail uses electricity as a primary source of energy. The efficiency in road transportation greatly varies between the modes concerned.

5.1.1. Road transport modal energy intensity

Energy intensities of different road transportation vehicles in South Africa vary between the modes and provinces (Table 5.3). At the national level, the intensities range from 1.88 MJ/Pass-km (Pass-km; passenger-kilometres) for motorcars to 0.11 MJ/Pass-km for minibuses.

Table 5.3: Road transport modal energy intensity in South Africa in 2009

	GA	**KZ**	**WC**	**EC**	**FS**	**MP**	**NW**	**LI**	**NC**
	Passenger vehicles (MJ/Pass-km)								
	Petrol								
Motorcycles	1.72	1.67	1.64	1.66	1.66	1.83	1.74	1.78	1.69
Motorcars	1.97	1.53	1.94	1.76	2.02	2.51	1.44	1.87	1.93
Minibuses	0.14	0.06	0.20	0.08	0.17	0.17	0.08	0.05	0.13
Buses	0.66	0.08	0.54	0.20	1.26	0.36	0.16	0.09	0.88
	Diesel								
Motorcars	1.75	0.79	2.11	0.86	2.15	1.69	0.74	0.89	1.58
Minibuses	0.14	0.07	0.21	0.09	0.17	0.17	0.08	0.05	0.13
Buses	0.67	0.08	0.55	0.20	1.28	0.37	0.16	0.09	0.89
	Freight vehicles (MJ/Ton-km)								
	Petrol								
LDV	1.19	1.20	1.17	1.19	1.20	1.21	1.19	1.23	1.20
Trucks	0.30	0.31	0.30	0.31	0.31	0.31	0.31	0.32	0.31
	Diesel								
LDV	1.05	1.06	1.03	1.05	1.06	1.07	1.05	1.08	1.06
Trucks	0.54	0.55	0.54	0.54	0.55	0.54	0.55	0.57	0.55

The results show that motorcars and motorcycles are the least efficient modes in road transportation. These show that the energy used per passenger-kilometre is huge and this is associated with the current low occupancy rates of these modes. Motorcars are the most energy intensive modes for short distance travel (Akerman and Hojer, 2006). Minibus taxis are the most energy efficient mode of road passenger transportation. This is because largest number of passengers in the country uses this mode compared to other modes. Buses also have low modal intensities.

Public transportation modal intensities in the Free State are generally higher than in other provinces. Modal intensities of public transportation in KwaZulu Natal and Limpopo are lower than their counterparts in other provinces. Private road transportation intensities in Mpumalanga are higher than in other provinces.

The intensities observed in South Africa are generally similar to other developing countries. The major difference is that minibus taxis in other developing countries have intensities much higher than in South Africa. On the other hand, motorcycles in other developing countries have lower intensities than their counterparts in South Africa.

For freight vehicles, the intensities are 0.52 MJ/Ton-km (Ton-km; tonne kilometres) for heavy duty vehicles and 1.14 MJ/Ton-km for the LDVs. The intensities are consistent with the results of Haw and Hughes (2007). In this category light duty vehicles have highest energy intensities. Nationally, the energy intensities in this mode are nearly twice the values for heavy duty vehicles. The differences between provincial freight transport intensities are also vast. Freight vehicles in Gauteng still have largest modal intensities.

5.1.2. Aviation energy modal intensities

Aviation transport modal intensities are higher than modal intensities calculated for road transport. Modal energy intensity for aviation was calculated to be approximately 4.63 MJ/Pass-km in South Africa. Aviation is generally more energy intensive than any other mode of transport (Becken, 2008; Laird, 2011).

5.2. CO_2 modal intensities

This section presents CO_2 modal intensities for road and aviation transport. This study establishes that modal intensity for aviation is higher than that of road transport and probably every mode of transport in the country.

5.2.1. Road transport CO_2 modal intensities

Carbon dioxide intensities vary widely between vehicle modes. Modal intensities in grams per passenger-kilometre (g/Pass-km) for passenger vehicles at a national level are dominated by motorcars, while minibuses have lowest intensities (Table 5.4). Both energy and CO_2 modal intensities suggest that public transport is overworked in the country and private transportation is underutilized. Occupancy rates of motorcars and motorcycles are low. Trucks have nearly half of modal intensities of light duty vehicles.

Table 5.4: Road transport CO_2 modal intensities in South Africa in 2009

	GA	**KZ**	**WC**	**EC**	**FS**	**MP**	**NW**	**LI**	**NC**
	Petrol								
Motorcycle	118.3	114.9	112.2	113.6	113.7	125.8	119.1	122.4	115.9
Motorcars	134.8	104.8	133.2	120.8	138.9	172.2	99.1	128.5	132.5
Minibuses	9.3	4.4	13.9	5.8	11.7	11.5	5.3	3.3	9.0
Buses	45.3	5.1	37.2	13.8	86.6	24.8	11.0	6.3	60.2
	Diesel								
Motorcars	136.7	106.3	135.0	122.5	140.9	174.6	100.5	130.3	134.4
Minibuses	10.1	4.8	15.1	6.3	12.7	12.5	5.8	3.6	9.7
Buses	49.2	5.6	40.4	15.0	94.1	26.9	11.9	6.8	65.4
	Freight vehicles (g/Ton-km)								
	Petrol								
LDV	81.4	82.6	80.0	81.7	82.4	82.8	81.6	84.1	82.0
Trucks	22.2	22.6	22.2	22.4	22.6	22.5	22.6	23.5	22.9
	Diesel								
LDV	76.8	77.9	75.5	77.1	77.7	78.1	77.0	79.3	77.4
Trucks	39.4	40.1	39.4	39.8	40.1	39.9	40.2	41.7	40.7

The road transport energy and CO_2 modal intensities calculated for 2009 are comparable with values in the literature. Energy intensities are similar to the estimates of Haw and Hughes (2007) while the CO_2 figures are comparable to the Ribeiro *et al.,* (2007) values.

Modal intensities for passenger vehicles in 2009 have increased from 2003. The highest and lowest changes are associated with the buses and minibuses (Figure 5.1). That is caused by the different changes in populations for the two categories between the two years. Generally, numbers of buses increased and minibuses either had minimum increases or remained constant depending on the province. Moreover, the changes indicate that vehicle ownership is increasing and the occupancy rates of the vehicles are decreasing. High increases in Limpopo may also be influenced by the observation that number of people in Limpopo decreased between 2003 and 2009 as per national statistics.

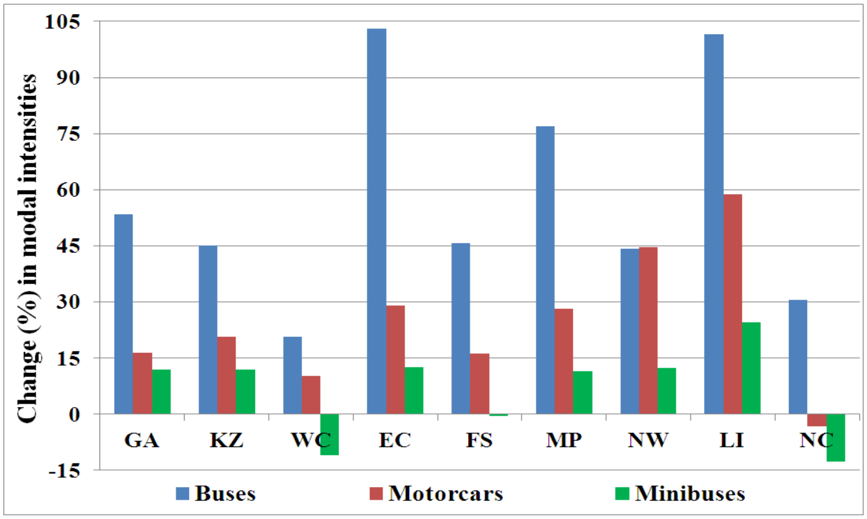

Figure 5.1: Change in road transport modal intensities between 2003 and 2009

5.2.2. Aviation CO_2 modal intensities

Aviation modal intensity in South Africa in 2009 was 330.47 gCO_2-eq/Pass-km. This is comparable with the intensities in other countries. On average, India's domestic carriers had 270 gCO_2-eq/Pass-km in 2008–2009 where individual airlines emissions ranged from 151 to 444 gCO_2-eq/Pass-km (Garg and Avishia, 2011). These values were lower than those for the preceding year.

5.3. Road transport CO_2 emissions per capita

Road transport CO_2 emissions per person vary considerably among provinces. Emissions per person are highest in Gauteng and Mpumalanga and lowest in Limpopo and the Eastern Cape (Figure 5.2). This suggests that people in Gauteng and Mpumalanga are the most mobile people in the country.

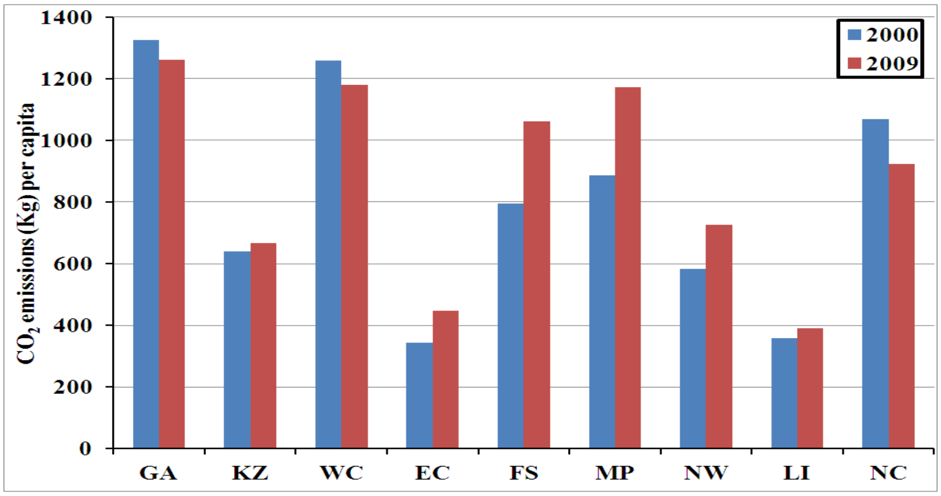

Figure 5.2: Provincial road transport CO_2 per person in South Africa

Between 2000 and 2009, CO_2 emissions per capita have increased in all provinces but Gauteng, the Western Cape and the Northern Cape. The highest increases are in the Free State, the Eastern Cape and Mpumalanga. The emissions per capita are affected by different demographical and emission change rates between the years.

5.4. Transport CO_2 emissions per GDP

At the national level, transport CO_2 emissions per population and GDP are 1091.16 Kg/capita and 101.93 g/PPP (2000 Purchasing Power Parity (PPP) value) respectively. The ratio of emissions per population is higher than that of Africa and it is equivalent to the global average. The rate is higher in South Africa than in most of the other developing countries (Figure 5.3). Compared to the developed countries, the emissions per population in South Africa are generally lower. South Africa's emissions per GDP are slightly lower than global average and they are similar to the average of Africa.

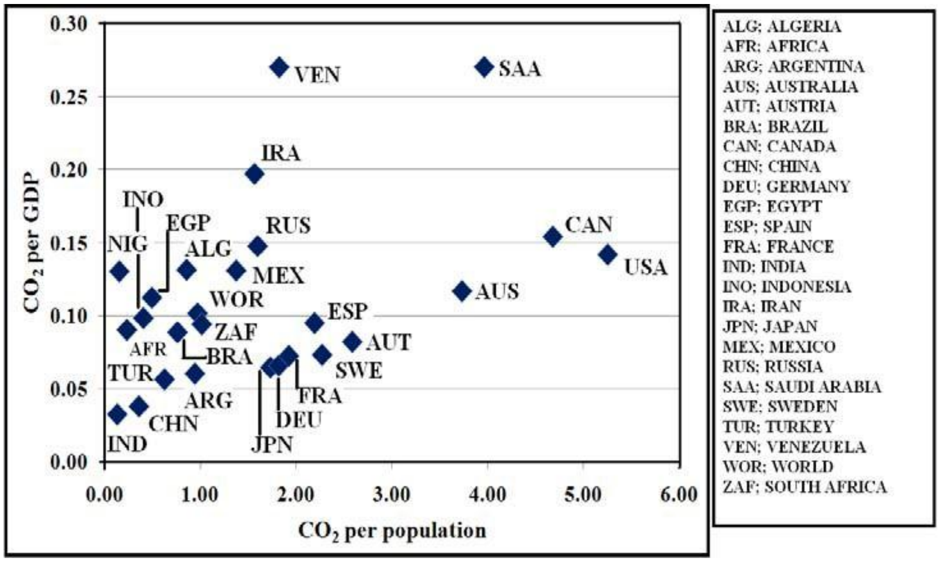

Figure 5.3: Transport sector CO_2 (Kg) per capita and GDP for selected countries in 2009

Transportation of a person using road vehicles in South Africa yields approximately a kilogram of CO_2. South Africa’s CO_2 emissions per capita are marginally higher than the global average. They are also higher than those from other BRICS countries except Russia. Compared to Africa, South Africa’s emissions per capita are notably high.

****

> This chapter presented both energy and CO_2 indicators for road and aviation transportations. It discussed energy and CO_2 intensities for these modes. Efficiency was done for road transport. Emissions per GDP and emissions per capita were also presented.

CHAPTER 6: SUMMARY AND CONCLUSIONS

Findings of this study are summarized in this chapter. GHG emissions from different modes of transport in each province are presented. Emissions from rail and waterborne activities are aggregated national totals based on national energy balance data.

6.0. CO_2 and CO_2-eq gas emissions in 2009

Transportation activities produced a total of 54,296 Gg of CO_2 equivalent emissions in 2009. Approximately 80% of the emissions are from road transport, 13% from off-road transport and 6% from domestic aviation. Motorcars and heavy duty vehicles make a combined contribution of nearly 70% of the total emissions from road transport. Other important points are presented below;

- Transportation of passengers by road produce 51.33% of the road transport's total.
- Gauteng accounts for 31.25% of the emissions from road transport.
- Gauteng is the largest producer of domestic aviation emissions with 66.92% of the total CO_2 emissions. OR Tambo International accounts for about 95.68% of the provincial domestic emissions, and the airport contributes about 64.02% of the national emissions.
- Railways contribute less than a percent of the sector's emissions.
- Emissions from waterborne transport cannot be quantified due to unavailable data.

6.1. Emissions of CH_4 and N_2O

Unlike CO_2, the transport sector emits small amounts of CH_4 and N_2O. Characteristics of emissions of these gases are similar to those of CO_2 discussed above.

- A total of 14.62 Gg of CH_4 is emitted by the transport sector.
- Similarly, a total 2.59 Gg of N_2O is emitted by the sector.
- Approximately 94.78% of these emissions are from road transport.

6.2. Trend in road transport emissions

Road transport emissions are continually increasing with time. The rates of emissions are slightly higher than global estimates. The rates also vary between provinces and to some extend between modes.

- CO_2-eq emissions have increased by approximately 37% between 2000 and 2009.
- Economic recession in 2008 and 2009 affected purchases of new vehicles and the overall mobility of vehicles. That resulted in the reduction of emissions over the 2007 figures.
- On average, the emissions grew by 2.66% per year.
- CO_2 emissions from buses increased by 59.18% between the ten years, and the emissions from trucks rose by 53.85%.

6.3. Emissions' indicators from road transport

- There is a general decrease of emissions per vehicle kilometre in the small vehicles. Heavy vehicles show an increase of emissions per distance travelled. Minibuses have lowest modal intensities in terms of passenger kilometres. For freight transport, heavy duty vehicles are the most efficient mode.
- Road transport CO_2 emissions per capita per province vary from province to province. They range from below 400 Kg per person in Limpopo to over 1200 Kg per person in Gauteng.
- South Africa's CO_2 emissions per GDP are slightly lower than global average and slightly higher than Africa's average. However, the total emissions per capita are marginally higher global average.

6.4. Uncertainties

Empirical analysis is always accompanied by some uncertainties. Total uncertainties in CO_2 emissions are estimated to be approximately 16.70%. Road transport has highest uncertainty level of 18.18%. Major uncertainties are in the shares of the emissions between the modes of transport and their fuel consumption profiles rather than the overall total of the emissions.

6.5. Remarks

This work provides the first synoptic transport GHG emissions for each province, vehicle type and fuel type in South Africa. It presents basic data necessary for mitigation plans in the country. Although it gives comprehensive overview of the transportation emissions, future research ideas that can enhance knowledge of emissions' profile of the sector can be obtained. However, data availability and quality remains a key challenge that needs urgent attention.

CHAPTER 7: REFERENCES

ACSA, 2011: Statistics on passenger traffic and aircraft movements files, http://www.acsa.co.za/home.asp?pid=100, accessed on 20th June 2011.

Adam, F. and Vanderschuren, M. 2009: Determining long-term parking needs at OR Tambo International Airport in Johannesburg, *Journal of Air Transport Management*, Vol. 15, pp. 363–367.

Agnolucci, P. Ekins, P. Iacopini, G. Anderson, K. Bows, A. Mander, S. and Shackley, S. 2009: Different scenarios for achieving radical reduction in carbon emissions: A decomposition analysis, *Ecological Economics,* Vol. 68, pp. 1652–1666.

Agyemang-Bonsu, K. Dontwi, I. Tutu-Benefoh, D. Bentil, D. Boateng, O. Asuobonteng, K. and Agyemang, W. 2010: Traffic-data driven modelling of vehicular emissions using COPERT III in Ghana: A case study of Kumasi, *American Journal of Scientific and Industrial Research*, Vol. 1, No. 1, pp. 32-40.

Akerman, J. and Hojer, M. 2006: How much transport can the climate stand?— Sweden on a sustainable path in 2050, *Energy Policy*, Vol. 34, pp. 1944–1957.

Akinboade, O. Ziramba, E. and Kumo, W. 2008: The demand for gasoline in South Africa: An empirical analysis using co-integration techniques, *Energy Economics,* Vol. 30, pp. 3222–3229.

Anderson, K. and Bows, A. 2008: Reframing the climate change challenge in light of post-2000 emission trends, *Philosophical Transactions of The Royal Society A,* Vol. 366, pp. 3863-3882.

Asif, M. and Muneer, T. 2007: Energy supply, its demand and security issues for developed and emerging economies, *Renewable and Sustainable Energy Reviews*, Vol. 11, pp. 1388–1413.

Awerbuch, S. and Sauter, R. 2006: Exploiting the oil–GDP effect to support renewables deployment, *Energy Policy*, Vol. 34, pp. 2805–2819.

Bader, N. and Bleischwitz, R. 2009: *Study Report Comparative Analysis of Local GHG Inventory Tools*, Institut Veolia Environnement, College of Europe, Brugge.

Baidya, S. and Borken-Kleefeld, J. 2009: Atmospheric emissions from road transportation in India, *Energy Policy*, Vol. 37, pp. 3812–3822.

Barker, T. Bashmakov, I. Bernstein, L. Bogner, J. Bosch, P. Dave, R. Davidson, O. Fisher, B. Gupta, S. Halsnaes, K. Heij, G. Ribeiro, S. Kobayashi, S. Levine, M. Martino, D. Masera, O. Metz, B. Meyer, L. Nabuurs, G. Najam, A. Nakicenovic, N. Rogner, N. Roy, J. Sathaye, J. Schock, R. Shukla, P. Sims, R. Smith, P. Tirpak, D. Urge-Vorsatz, D. Zhou, D. 2007: Technical Summary. In: *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment*

Report of the Intergovernmental Panel on Climate Change [B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Becken, S. 2008: Developing indicators for managing tourism in the face of peak oil, *Tourism Management*, Vol. 29, pp. 695–705.

Becken, S. and Patterson, M. 2006: Measuring national carbon dioxide emissions from tourism as a key step towards achieving sustainable tourism, *Journal of Sustainable Tourism*, Vol. 14, No. 4, pp. 323-338.

Beer, T. Grant, T. Williams, D. and Watson, H. 2002: Fuel-cycle greenhouse gas emissions from alternative fuels in Australian heavy vehicles, *Atmospheric Environment*, Vol. 36, pp. 753–763.

Beer, T. and Grant, T. 2007: Life-cycle analysis of emissions from fuel ethanol and blends in Australian heavy and light vehicles, *Journal of Cleaner Production*, Vol. 15, pp. 833-837.

Behrentz, E. Ling, R. Rieger, P. and Winer, A. 2004: Measurements of nitrous oxide emissions from light-duty motor vehicles: a pilot study, *Atmospheric Environment*, Vol. 38, pp. 4291–4303.

Betts, R. Falloon, P. Goldewijk, K. and Ramankutty, N. 2007: Biogeophysical effects of land use on climate: Model simulations of radiative forcing and large-scale temperature change, *Agricultural and Forest Meteorology*, Vol. 142, pp.

216–233.

Bhattacharya, S. and Salam, P. 2002: Low greenhouse gas biomass options for cooking in the developing countries, *Biomass and Bioenergy*, Vol. 22, pp. 305 – 317.

Blakey, S. Rye, L. and Wilson, C. 2011: Aviation gas turbine alternative fuels: A review, *Proceedings of the Combustion Institute*, Vol. 33, pp. 2863–2885.

Blignaut, J. Chitiga-Mabugu, M. and Mabugu, R. 2005: Constructing a greenhouse gas emissions inventory using energy balances: the case of South Africa for 1998, *Journal of Energy in Southern Africa,* Vol. 16, No. 3, pp. 21-32.

Bogetic, Z. and Fedderke, J. 2005: Infrastructure and Growth in South Africa: Benchmarking, Productivity and Investment Needs, Paper prepared for presentation at the bi-annual conference of the Economic Society of South Africa, September 7-9, 2005, Durban.

Bond, T. Bhardwaj, E. Dong, R. Jogani, R. Jung, S. Roden, C. Streets, D. and Trautmann, N. 2007: Historical emissions of black and organic carbon aerosol from energy-related combustion 1850–2000, *Global Biogeochemical Cycles*, Vol. 21.

Bosker, M. and Krugell, W. 2008: Regional income evolution in South Africa after apartheid, *Journal of Regional Science*, Vol. 48, No. 3, pp. 493-523.

Bows, A. Anderson, K. and Mander, S. 2009: Aviation in turbulent times, *Technology Analysis and Strategic Management*, Vol. 21, No. 1, pp. 17-37.

Brand, C. and Boardman, B. 2008: Taming of the few – The unequal distribution of greenhouse gas emissions from personal travel in the UK, *Energy Policy*, Vol. 36, pp. 224-238.

Brink, M. and Wee, B. 2001: Why has car-fleet specific fuel consumption not shown any decrease since 1990? Quantitative analysis of Dutch passenger car-fleet specific fuel consumption, *Transportation Research Part D*, Vol. 6, pp. 75-93.

Campbell, B. and Vigar-Ellis, D. 2012: The importance of choice attributes and the positions of the airlines within the South African domestic passenger airline industry as perceived by passengers at Durban International Airport, *Southern African Business Review*, Vol. 16, No. 2.

Chapman, L. 2007: Transport and climate change: a review, *Journal of Transport Geography*, Vol. 15, pp. 354–367.

Chapman, H. and Chapman, P. 2005: Seascapes and Landscapes — the Siting of the Ferriby Boat Finds in the Context of Prehistoric Pilotage, *The International Journal of Nautical Archaeology*, Vol. 34, No. 1, pp. 43–50.

Chasomeris, M. 2006: South Africa's maritime policy and transformation of the shipping industry, *Journal of Interdisciplinary Economics*.

City of Johannesburg. 2008: *City of Johannesburg State of Energy Report 2008*, City of Johannesburg, Johannesburg.

Collins, W. Ramaswamy, V. Schwarzkopf, M. Sun, Y. Portmann, R. Fu, Q. Casanova, S. Dufresne, J. Fillmore, D. Forster, P. Galin, V. Gohar, L. Ingram, W. Kratz, D. Lefebvre, M. Li, J. Marquet, P. Oinas, V. Tsushima, Y. Uchiyama, T. and Zhong, W. 2006: Radiative forcing by well-mixed greenhouse gases: Estimates from climate models in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), *Journal Geophysics Research*, 111, D14317, doi:10.1029/2005JD006713.

Cruz, R. Kuzwayo, S. Huizenga, C. Barrett, J. Valentyn, C. Eloff, B. Naude, L. and Snyman, C. 2011: A guide to low-carbon transport 2011; Transportation, climate change and the United Nations Framework Convention on Climate Change, 17th Conference of the Parties (COP17), Durban.

Cruz-Nu´n˜ez, X. Conde, L. and Ruiz-Sua´rez, L. 2008: Use of IPCC GHG key sources analysis to Mexico’s environmental policy, *Mitigation Adaptation Strategies Global Change*, Vol. 13, pp. 179–191.

CSIR, 2008: The fourth annual state of logistics survey for South Africa – 2007 logistics for growth and development, Pretoria.

D'Angiola, A. Dawidowski, L. Gomez, D. and Osses, M. 2010: On-road traffic emissions in a megacity, *Atmospheric Environment*, Vol. 44, pp. 483-493.

D'Avignon, A. Carloni, F. Rovere, E. and Dubeux, C. 2010: Emission inventory: An urban public policy instrument and benchmark, *Energy Policy*, Vol. 38, pp. 4838–4847.

de Haan, P. Peters, A. and Scholz, R. 2007: Reducing energy consumption in road transport through hybrid vehicles: investigation of rebound effects, and possible effects of tax rebates, *Journal of Cleaner Production*, Vol. 15, pp. 1076-1084.

DEA, 2009a: *State of Air Report 2005-A report on the state of air in South Africa*, Department of Environmental Affairs, Pretoria.

DEA, 2009b: *Greenhouse Gas Inventory Report for South Africa 1990 – 2000*, Department of Environmental Affairs, Pretoria.

DEA 2011: *South Africa's Second National Communication under the United Nations Framework Convention on Climate Change*, Department of Environmental Affairs, Republic of South Africa, Pretoria.

DEAT, 2003: *South Africa's Initial Communication to the United Nations Framework Convention on Climate Change*, Department of Environmental Affairs and Tourism, Pretoria.

Ding, Y. Ren, G. Zhao, Z. Xu, Y. Luo, Y. Li, Q. and Zhang, J. 2007: Detection, Causes and Projection of Climate Change over China: An Overview of Recent Progress, *Advances in Atmospheric Sciences,* Vol. 24, NO. 6, pp. 954–971.

DME, 2002: *Digest of South African energy statistics 2002*, Department of Minerals and Energy, Pretoria.

DME, 2005: *Digest of South African Energy Statistics - 2005*, Department of Energy, Pretoria.

DOE, 2009a: *South Africa Fuel Sales Volume*, Department of Energy, Pretoria. http://www.energy.gov.za/files/media/SA%20FUEL%20SALES%20VOL UME/SA%20AVIATION%202009.pdf , obtained on the 5th April 2011

DOE, 2009b: *Commodity Flow and Energy Balance 2009*, Department of Energy, Pretoria, obtained from http://www.energy.gov.za/files/media/media_energy_balances.html; on the 26th September 2011.

DOE, 2010a: *Digest of South African energy statistics 2009*, Department of Energy, Pretoria.

DOE, 2010b: National Energy Balance data for 2009. Department of Energy, Pretoria, Obtained from http://www.energy.gov.za/files/media/media_energy_balances.html; last accessed on 20th September 2011.

DOT, 2005: *The First South African National Household Travel Survey 2003 Technical report*, Department of Transport, Pretoria.

DOT, 2008a: *Economic Analysis – transport picture*, Department of

Transport, Pretoria.

DOT, 2008b: National Transport Master Plan 2005-2050 – KwaZulu Natal Province Phase 2: Status Quo - First Draft, Department of Transport, Pretoria.

DOT, 2009a: *Transport statistics 2008*, Department of Transport, Pretoria.

DOT, 2009b: *National Transport Master Plan 2050*, Department of Transport, Pretoria.

DOT, 2010: Database of vehicles' registration in South Africa, Department of Transport, Pretoria.

EnerKey, 2012: *Development of an Energy and Emissions Balance for Gauteng 2007*, Enerkey Fact Sheet No. 1, University of Stuttgart, Stuttgart.

eThekwini, 2006: *eThekwini Economic Review 2006/2007*, eThekwini Municipality, Durban.

eThekwini, 2011: *eThekwini Greenhouse Gas Emissions Inventory 2010 Technical Report*, eThekwini Municipality, Durban.

European Union. 2010: *Europe's energy position – markets and supply*, Luxembourg.

Fisher, B. N. Nakicenovic, K. Alfsen, J. Corfee Morlot, F. de la Chesnaye, J. Hourcade, K. Jiang, M. Kainuma, E. La Rovere,

A. Matysek, A. Rana, K. Riahi, R. Richels, S. Rose, D. van Vuuren, R. and Warren. 2007: Issues related to mitigation in the long term context, In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Inter-governmental Panel on Climate Change [B. Metz, O. Davidson, P. Bosch, R. Dave, L. Meyer (eds)], Cambridge University Press, Cambridge.

Flamm, B. 2009: The impacts of environmental knowledge and attitudes on vehicle ownership and use, *Transportation Research Part D*, Vol. 14, pp. 272–279.

Forster, P. Ramaswamy, V. Artaxo, P. Berntsen, T. Betts, R. Fahey, D. Haywood, J. Lean, J. Lowe, D. Myhre, G. Nganga, J. Prinn, R. Raga, G. Schulz M. and Van Dorland, R. 2007: Changes in Atmospheric Constituents and in Radiative Forcing. *In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S. Qin, D. Manning, M. Chen, Z. Marquis, M. Averyt, K. Tignor, M. and Miller, H. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Garg, A. and Avashia, V. 2011: Carbon competition up above: estimating greenhouse gas emissions of Indian domestic airlines, *Greenhouse Gas Measurement and Management*, Vol. 1, No. 2, pp. 93-104.

Gautam, M. Carder, D. Clark, N. and Lyons, D. 2002: *Testing for*

Exhaust Emissions of Diesel Powered Off-Road Engines, Final project Report, Project Reference Number: ARB Contract Number 98-317.

Geels, F. 2005: Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective, *Technological Forecasting and Social Change*, Vol. 72, pp. 681–696.

Geurs, K. and van Wee, B. 2004: Accessibility of land-use and transport strategies: review and research directions, *Journal of Transport Geography*, Vol. 12, pp. 127-140.

Goyns. P. 2008: *Modelling real-world driving, fuel consumption and emissions of passenger vehicles: a case study in Johannesburg*, PhD Thesis Report, University of Johannesburg, Johannesburg.

Graham, L. 2006: Greenhouse Gas Emissions from Light Duty Vehicles Under a Variety of Driving Conditions, *EIC Climate Change Technology, 2006 IEEE*, Vol., No., pp. 1-8, 10-12, doi: 10.1109/EICCCC.2006.277273.

Graham, L. Rideout, G. Rosenblatt, D. and Hendren, J. 2008: Greenhouse gas emissions from heavy-duty vehicles, *Atmospheric Environment*, Vol. 42, pp. 4665–4681.

Graham, L. Belisle, S. and Rieger, P. 2009: Nitrous oxide emissions from light duty vehicles, *Atmospheric Environment*, Vol. 43, pp 2031–2044.

Grazi, F. and van den Bergh, J. 2008: Spatial organization, transport, and climate change: Comparing instruments of spatial planning and policy, *Ecological Economics,* Vol. 67, pp. 630-639.

Gregory, J. Huybrechts, P. and Rapers, S. 2004: Threatened loss of the Greenland ice-sheet, *Nature*, Vol. 428.

Hankey, S. and Marshall, J. 2010: Impacts of urban form on future US passenger- vehicle greenhouse gas emissions, *Energy Policy*, Vol. 38, pp. 4880–4887.

Hansen, J. Nazarenko, L. Ruedy, R. Sato, M. Willis, J. Genio, A. Koch, D. Lacis, A. Lo, K. Menon, S. Novakov, T. Perlwitz, J. Russell, G. Schmidt, G. and Tausnev, N. 2005: Earth's Energy Imbalance: Confirmation and Implications, *Science*, Vol. 308.

Haw, M. and Hughes, A. 2007: *Clean Energy and Development for South Africa*, Background data, Report 1 of 3, Energy Research Centre, University of Cape Town, Cape Town.

Hensher, D. 2008: Climate change, enhanced greenhouse gas emissions and passenger transport-What can we do to make a difference? *Transportation Research Part D,* 13, pp. 95-111.

Hoogwijk, M. Can, S. Novikova, A. Urge-Vorsatz, D. Blomen, E. and Blok, K. 2010: Assessment of bottom-up sectoral and regional mitigation potentials, *Energy Policy*, Vol. 38, pp. 3044–3057.

Hueglin, C. Buchmann, B. and Weber, R. 2006: Long-term observation of real-world road traffic emission factors on a motorway in

Switzerland, *Atmospheric Environment*, Vol. 40, pp. 3696–3709.

ICAO, 2009: *Annual Report*, International Civil Aviation Organisation, Montreal.

ICAO, 2010: *Annual Report*, International Civil Aviation Organisation, Montreal.

ICAO, 2011: *Annual Report*, International Civil Aviation Organisation, Montreal.

IEA, 2006: *World Energy Outlook*, International Energy Agency, Paris.

IEA, 2009: *Transport Energy Efficiency–Implementation of IEA Recommendations since 2009 and next Steps*, International Energy Agency, Paris.

IEA, 2010: *IEA Statistics–*CO_2 *emissions from fuel combustion Highlights–2010 Edition*, International Energy Agency, Paris.

IEA, 2011a: *Advantage energy – Emerging economies, developing countries and the private-public sector interface: Information Paper, International Energy Agency*, International Energy Agency, Paris.

IEA, 2011b: CO_2 *emissions from fuel combustion – highlights*, International Energy Agency, Paris.

IIED, 2009: Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories, *Environment and Urbanization*, Vol. 21 No. 1.

IMF, 2012: World Economic Outlook, International Monetary Fund, Washington, obtained from http://www.imf.org/external/pubs/ft/weo/2012/01/weodata/download.aspx on the 15th May 2012.

Institute for Environmental Studies, 2003: *Tier-2 uncertainty analysis of the Dutch greenhouse gas emissions 1999*, R-03/06, Amsterdam.

IPCC 1997: Houghton, J. Meira Filho, L. Lim, B. Tréanton, K. Mamaty, I. Bonduki, Y. Griggs, D. and Callander, B. (Eds). *Revised 1996 IPCC Guidelines for National Greenhouse Inventories*. IPCC/OECD/IEA, Paris, France.

IPCC 2000: Penman, J. Kruger, D. Galbally, I. Hiraishi, T. Nyenzi, B. Emmanuel, S. Buendia, L. Hoppaus, R. Martinsen, T. Meijer, J. Miwa, K. and Tanabe, K. (Eds). *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. IPCC/OECD/IEA/IGES, Hayama, Japan.

IPCC 2003: Penman, J. Gytarsky, M. Hiraishi, T. Krug, T. Kruger, D. Pipatti, R. Buendia, L. Miwa, K. Ngara, T. Tanabe, K. and Wagner, F., *Good Practice Guidance for Land Use, land-Use Change and Forestry* IPCC/IGES, Hayama, Japan.

IPCC 2006: 2006 IPCC Guidelines for National Greenhouse Gas

Inventories, Prepared by the National Greenhouse Gas Inventories Programme,

Eggleston, H. Buendia, L. Miwa, K. Ngara, T. and Tanabe, K. (eds). Published: IGES, Japan.

Johns, T. Gregory, J. Ingram, W. Johnson, C. Jones, A. Lowe, J. Mitchell, J. Roberts, D. Sexton, D. Stevenson, D. Tett, S. and Woodage, M. 2003: Anthropogenic climate change for 1860 to 2100 simulated with the HadCM3 model under updated emissions scenarios, *Climate Dynamics*, Vol. 20, pp. 583–612.

Jonas, M. Marland, G. Winiwarter, W. White, T. Nahorski, Z. Bun, R. and Nilsson, S. 2010: Benefits of dealing with uncertainty in greenhouse gas inventories: introduction, *Climatic Change*, Vol. 103, pp. 3-18.

Joubert, J. and Axhausen, K. 2011: Inferring commercial vehicle activities in Gauteng, South Africa, *Journal of Transport Geography*, Vol. 19, pp. 115-124.

Kennedy, C. Gasson, B. Hansen, Y. Hillman, T. Havranek, M. Pataki, D. Phdungsilp, A. Ramaswami, A. and Mendez, G. 2009: Greenhouse Gas Emissions from Global Cities, *Environment Science and Technology*, Vol. 43, pp. 7297–7302.

Kenworthy, J. 2003: Transport energy use and greenhouse gases in urban passenger transport systems: a study of 84 global cities. In: Presented to the Third Conference of the Regional Government Network for Sustainable Development, September

17–19, 2003, Notre Dame University, Fremantle, Western Australia.

King, D. 2004: Climate change science: Adapt, Mitigate, or Ignore, *Science*, Vol. 303.

Kioutsioukis, I. Tarantola, S. Saltelli, A. and Gatelli, D. 2004: Uncertainty and global sensitivity analysis of road transport emission estimates, *Atmospheric Environment*, Vol. 38, pp. 6609–6620.

Kis-Kovács, G. Lovas, K. Nagy, E. Tarczay, K. 2010: Greenhouse gas emissions and removals in Hungary based on IPCC methodology — Methodological introduction and overall trends in anthropogenic emissions in Hungary. In: *Atmospheric Greenhouse Gases: The Hungarian Perspective* (Ed.: Haszpra, L.), pp. 333–344.

Krewitt, W. Teske, S. Simon, S. Pregger, T. Graus, W. Blomen, E. Schmid, S. and Schafer, O. 2009: Energy Revolution – a sustainable world energy perspective, *Energy Policy,* 37, pp. 5764-5775.

Laird, P. 2011: Potential reduction in energy use from a High Speed Rail network in Australia, Australasian Transport Research Forum 2011 Proceedings 28-30 September 2011, Adelaide, Australia.

Lamprecht, D. 2007: Fischer-Tropsch fuel for use by the U.S. Military as a battlefield-use fuel of the future, *Energy and Fuels,* Vol.

21, pp. 1448-1453.

Leckel, D. 2009: Hydroprocessing Euro 4-Type Diesel from High Temperature Fischer–Tropsch Vacuum Gas Oils, *Energy and Fuels*, Vol. 23, pp. 38-45.

Leckel, D. 2010: *Upgrading of Fischer-Tropsch Products to Produce Diesel*, Sasol Technology Research and Development, South Africa.

Letete, T. Moyo, A. Vanderschuren, M. and Lane, T. 2010: Transport data gaps in South Africa, The Energy Research Centre, University of Cape Town, Cape Town.

Li, L. Chen, C. Xie, S. Huang, C. Cheng, Z. Wang, H. Wang, Y. Huang, H. Lu, J. and Dhakal, S. 2010: Energy demand and carbon emissions under different development scenarios for Shanghai, China, *Energy Policy*, Vol. 38, pp. 4797-4807.

Liao, C. Lu, C. and Tseng, P. 2011: Carbon dioxide emissions and inland container transport in Taiwan, *Journal of Transport Geography*, Vol. 19, pp. 722–728.

Liddle, B. 2011: Consumption-driven environmental impact and age structure change in OECD countries: A co-integration-STIRPAT analysis, *Demographic Research*: Volume 24, Article 30.

Liimatainen, H. and Pollanen, M. 2010: Trends of energy efficiency in Finnish road freight transport 1995–2009 and forecast to 2016, *Energy Policy*, Vol. 38, pp. 7676–7686.

Limmeechokchai, B. and Suksuntornsiri, P. 2007: Embedded energy and total greenhouse gas emissions in final consumptions within Thailand, *Renewable and Sustainable Energy Reviews*, Vol. 11, pp. 259–281.

Lise, W. 2006: Decomposition of CO_2 emissions over 1980–2003 in Turkey, *Energy Policy,* Vol. 34, pp. 1841–1852.

Lutsey, N. and Sperling, D. 2009: Greenhouse gas mitigation supply curve for the United States for transport versus other sectors, *Transportation Research Part D*, Vol. 14, pp. 222–229.

Macintosh, A. and Wallace, L. 2009: International aviation emissions to 2025: Can emissions be stabilized without restricting demand? *Energy Policy*, Vol. 37, pp. 264–273.

McCollum, D. and Yang, C. 2009: Achieving deep reductions in US transport greenhouse gas emissions: Scenario analysis and policy implications, *Energy Policy*, Vol. 37, pp. 5580-5596.

McKinsey Global Institute, 2009: Averting the next energy crisis: The demand challenge, McKinsey & Company.

Meinshausen, M. Smith, S. Calvin, K. Daniel, J. Kainuma, M. Lamarque, J. Matsumoto, K. Montzka, S. Raper, S. Riahi, K. Thomson, A. Velders, G. and van Vuuren, D. 2011: The RCP greenhouse gas concentrations and their extensions from 1765 to 2300, *Climatic Change,* Vol. 109, pp. 213- 241.

Menyah, K. and Wolde-Rufael, Y. 2010: Energy consumption, pollutant emissions and economic growth in South Africa, *Energy Economics,* Vol. 32, pp. 1374–1382.

Meyer, I. Leimbach, C. and Jaeger, C. 2007: International passenger transport and climate change: A sector analysis in car demand and associated CO_2 emissions from 2000 to 2050, *Energy Policy*, Vol. 5, pp 6332-6345.

Mickūnaitis, V. Pikūnas, A. and Mackoit, I. 2007: Reducing fuel consumption and CO_2 emission in motor cars, *Transport*, Vol. 22, No. 3, pp. 160-163.

Miyoshi, C. and Mason, K. 2009: The carbon emissions of selected airlines and aircraft types in three geographic markets, *Journal of Air Transport Management*, Vol. 15, pp. 138–147.

Mohammed, S. and Venter, C. 2009: Analyzing passenger transport energy consumption from travel survey data: A case study of Nelson Mandela Metropolitan Area, Proceedings of the 28th Southern African Transport Conference, Pretoria.

Monni, S. and Syri, S. 2003: *Uncertainties in the Finnish 2001 Greenhouse Gas Emission Inventory*. Espoo 2003. VTT Tiedotteita – Research Notes 2209,

Monni, S. Syri, S. and Savolainen, I. 2004: Uncertainties in the Finnish greenhouse gas emission inventory, *Environmental Science & Policy,* Vol. 7, pp. 87–98.

Monni, S. 2004: *Uncertainties in the Finnish 2002 Greenhouse Gas Emission Inventory*, ESPOO 2004, VTT Working Papers 5.

Mopani and Capricorn Districts, 2010: *Final report: study on the economic impact of fuel costs and interest rates on public passenger transport in Mopani and Capricorn districts*, Limpopo Department of Roads and Transport, Polokwane.

Moriarty, P. and Honnery, D. 2008: The prospects for global green car mobility, *Journal of Cleaner Production*, Vol. 16, pp. 1717-1726.

Moss, R. Edmonds, J. Hibbard, K. Manning, M. Rose, K. van Vuuren, D. Carter, T. Emori, S. Kainuma, M. Kram, T. Meehl, G. Mitchell, J.. Nakicenovic, N. Riahi, K. Smith, S. Stouffer, R. Thomson, A. Weyant, J. and Wilbanks, T. 2010: The next generation of scenarios for climate change research and assessment, N*ature*, Vol. 463, pp. 747-756.

Murphy, D. Solomon, S. Portmann, R. Rosenlof, K. Forster, P. and Wong, T. 2009: An observationally based energy balance for the Earth since 1950, *Journal of Geophysical Research*, Vol. 114, d17107.

Mwakasonda, S. and Winkler, H. 2005: Carbon capture and storage in South Africa, In: Growing in the greenhouse: protecting the climate by putting development first, Chapter VI.

National Treasury, 2009: Provincial budgets and expenditure review: 2005/06–2011/12, Chapter 8: roads and transport, http://www.treasury.gov.za/publications/igfr/2009/prov/08.%20Chapter%208%20-%20Roads%20and%20Transport.pdf (accessed, 26 April 2012).

National Treasury, 2010: Press Release regarding CO_2 vehicle emissions tax, National Treasury, Pretoria.

Naude, C. Mirrlees, R. Dehlen, G. Pretorius, J. Mangera, M. Moleho, C. Meyer, A. Sperling, D. and Redmond, L. 2000: Global Climate Change, Developing Countries and Transport Sector Options in South Africa, Institute of Transportation Studies, University of California, Davis.

Ndebele, S. 2010: Keynote address by Minister of Transport Mr Sibusiso Ndebele, MP, to the South African National Taxi Association Council (SANTACO) National Conference, Department of Transport, Pretoria, May 2010, http://www.info.gov.za/speech/DynamicAction?pageid=461&sid=10392&tid=10409 Accessed 26th April 2012.

Netherlands Environmental Assessment Agency, 2010: *No growth in total global CO_2 emissions in 2009*, PBL publication number 500212001, Bilthoven.

Netherlands Environmental Assessment Agency, 2011: *Long-term trend in global CO_2 emissions, 2011 report*, European Union, PBL publication number 500253004, The Hague.

NIES, 2006: Greenhouse gas inventory developments in Asia – Experiences from workshops on greenhouse gas inventories in Asia, [Umemiya, C. (ed)], National Institute for Environmental Studies, Ibaraki.

Nygren, E. Aleklett, K. Hook, M. 2009: Aviation fuel and future oil production scenarios, *Energy Policy*, Vol. 37, pp. 4003–4010.

Oanh, N. Reutergardh, L. and Dung, N. 1999: Emission of Polycyclic Aromatic Hydrocarbons and Particulate Matter from Domestic Combustion of Selected Fuels, *Environmental Science Technology*, Vol. 33, pp. 2703-2709.

Olivier, J. and Peters, J. 1999: International marine and aviation bunker fuel: trends, ranking of countries and comparison with national CO_2 emissions, RIVM Report 773301 002, National Institute of Public Health and the Environment, Bilthoven.

Oosthoek, J. 2008: The IPCC and the Ozone Hole: A Warning from History, *Globalizations*, Vol. 5, No. 1, pp. 63-66.

Otter, L. Masondo, N. Khutswane, O. Jako, B. Mugeri, S. Ngobeni, H. Tongwane, M. and Piketh, S. *in press:* GHG Inventory for the South African Transport sector: 2007, University of the Witwatersrand, Johannesburg.

Paravantis, J. and Georgakellos, D. 2007: Trends in energy consumption and carbon dioxide emissions of passenger cars and buses, *Technological Forecasting and Social Change*, Vol. 74, pp. 682-707.

Pejout, N. 2004: Hypercapitalism in a developing country – The "new economy" of South Africa: economic performance, time and social sustainability, Paper presented in the International Conference, ICTs and Inequalities, 18-19 November 2004, Paris.

Perkins, P. Fedderke, J. and Luiz, J. 2005: An analysis of economic infrastructure investment in South Africa, *South African Journal of Economics*, Vol. 73, No 2, pp. 211-228.

Pirie, G. 2006: Africanisation of South Africa's international air links, 1994–2003, *Journal of Transport Geography*, Vol. 14, pp. 3–14.

Pulles, T. and Yang, H. 2011: GHG emission estimates for road transport in national GHG inventories, *Climate Policy*, Vol. 11, No. 2, pp. 944-957.

Quadrelli, R. and Peterson, S. 2007: The energy–climate challenge: Recent trends in CO_2 emissions from fuel combustion, *Energy Policy*, Vol. 35, pp. 5938–5952.

Ramachandra, T. and Shwetmala. 2009: Emissions from India's transport sector: Statewise synthesis, *Atmospheric Environment*, Vol. 43, pp. 5510–5517.

Ramanathan, R. 2006: A multi-factor efficiency perspective to the relationships among world GDP, energy consumption and carbon dioxide emissions, *Technological Forecasting & Social*

Change, Vol. 73, pp. 483–494.

Ramanathan, V. Feng, Y. 2009: Air pollution, greenhouse gases and climate change: Global and regional perspectives, *Atmospheric Environment,* Vol. 43, pp. 37–50.

Rayner, S. *personal communication*: South African Motor Industry experience and new vehicle technology related fuel requirements, National Association of Automobile Manufacturers of South Africa: Abidjan, August 2010.

Reddy, B. 2000: Urban transportation in India: a tale of two cities, *Energy for Sustainable Development*, Vol. IV, No. 1.

Ribeiro, K. Kobayashi, S. Beuthe, M. Gasca, J. Greene, D. Lee, D. Muromachi, Y. Newton, P. Plotkin, S. Sperling, D. Wit, R. and Zhou, P. 2007: Transport and its infrastructure. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Metz, B. Davidson, O. Bosch, P. Dave, R. Meyer L. (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Rogner, H. Zhou, D. Bradley, R. Crabbé, P. Edenhofer, O. Hare,B. Kuijpers, L. and Yamaguchi, M. 2007: Introduction. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Metz, B. Davidson, O. Bosch, P. Dave, R. Meyer, L. (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Romano, D. Bernetti, A. and Lauretis, R. 2004: Different methodologies to quantify uncertainties of air emissions, *Environmental International,* 30, pp. 1099-1107.

Romano, A. 2011: The Investments in Renewable Energy Sources: Do Low Carbon Economies Better Invest In Green Technologies? *International Journal of Energy Economics and Policy,* Vol. 1, No. 4, pp. 107-115.

Roy, J. Sarkar, P. Biswas, S. and Choudhury, A. 2009: Predictive equations for CO_2 emission factors for coal combustion, their applicability in a thermal power plant and subsequent assessment of uncertainty in CO_2 estimation, *Fuel*, Vol. 88, pp. 792–798.

RTMC, 2010: Vehicle population.xls, http://www.rtmc.co.za/RTMC/TReports.jsp, accessed 25th March 2011.

Rypdal, K. *undated*: Aircraft Emissions in Background Papers IPCC Expert Meetings on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/gp/bgp/2_5_Aircraft.pdf accessed on 02 July 2012.

Rypdal, K. and Winiwarter, W. 2001: Uncertainties in greenhouse gas emission inventories—evaluation, comparability and implications, *Environmental Science & Policy,* Vol. 4, pp. 107–

116

Salter, R. Dhar, S. and Newman, P. (Eds). 2011: Technologies for Climate Change Mitigation, United Nations Environmental Programme, New Delhi.

Saayman, M. and Saayman, A. 2006: Estimating the Economic Contribution of Visitor Spending in the Kruger National Park to the Regional Economy, *Journal of Sustainable Tourism*, Vol. 14, Vol. 1, pp. 67-81.

Samaras, C. and Meisterling, K. 2008: Life Cycle Assessment of Greenhouse Gas Emissions from Plug-in Hybrid Vehicles: Implications for Policy, *Environmental Science Technology*, Vol. 42, pp. 3170–3176.

SAPIA, 2010: 2010 Annual Report, South African Petroleum Industry Association, Johannesburg.

SARB, 2012: Annual Economic Report 2012, South African Reserve Bank, Pretoria.

SARCC, 2006: National Railplan Consolidated Report, South African Rail Commuter Corporation, Johannesburg.

SARS, 2010: Reference Guide Environmental Levy on Carbon Dioxide Emissions of New Motor Vehicles Manufactured in the Republic, South African Revenue Services, Pretoria.

Schafer, A. and Jacoby, H. 2006: Vehicle technology under CO_2

constraint: a general equilibrium analysis, *Energy Policy*, Vol. 34, pp. 975–985.

Schafer, A. and Victor, D. 1999: Global passenger travel: implications for carbon dioxide Emissions, *Energy*, Vol. 24, pp. 657–679.

Scheutz, C. Kjeldsen, P. and Gentil, E. 2009: Greenhouse gases, radiative forcing, global warming potential and waste management – an introduction, *Waste management and Research*, Vol. 27, pp. 716-723.

Schipper, L. Marie-Lilliu, C. and Gorham, R. 2000: Flexing the link between transport and greenhouse gas emissions: A path for the World Bank, International Energy Agency, Paris.

Schipper, L. Cordeiro, M. and Wei-Shiuen, N. 2007: Measuring the Carbon Dioxide Impacts of Urban Transport Projects in Developing Countries, World Resources Institute.

Schipper, L. Fabian, H. and Leather, J. 2009: Transport and Carbon Dioxide Emissions: Forecasts, Options Analysis, and Evaluation, Asian Development Bank, No. 9.

Scholes, R. and van der Merwe, M. 1996: Greenhouse gas emissions from South Africa, *South African Journal of Science*, Vol. 92, pp. 220-222.

Scholl, L. Schipper, L. and Kiang, N. 1996: CO_2 emissions from passenger transport – a comparison ofinternational trends from 1973 to 1992, *Energy Policy*, 24, pp. 17-30.

Scorgie, Y. Burger, L. Annegarn, H. and Kneen, M. 2004: Part 2 Report: Establishment of source inventories and identification and prioritization of technology options, Fund for Research into Industrial Development Growth and Equity, Trade and Industry Chamber.

Sebitosi, A. and Pillay, P. 2008: Renewable energy and the environment in South Africa: A way forward, *Energy Policy,* Vol. 36, pp. 3312–3316.

Sharma, S. Bhattacharya, S. and Garg, A. 2006: Greenhouse gas emissions from India: A perspective, *Current Science,* Vol. 90, No. 3.

Shindell, D. and Faluvegi, G. 2009: Climate response to regional radiative forcing during the twentieth century, *Nature Geoscience*, Vol. 2.

Sims, R. Schock, R. Adegbululgbe, A. Fenhann, J. Konstantinaviciute, I. Moomaw, W. Nimir, H. Schlamadinger, B. Torres-Martínez, J. Turner, C. Uchiyama, S. Vuori, J. Wamukonya, N. and Zhang, X. 2007: Energy supply. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Singh, A. Gangopadhyay, S. Nanda, P. Bhattacharya, S. Sharma, C.

and Bhan, C. 2008: Trends of greenhouse gas emissions from the road transport sector in India, *Science of the Total Environment*, Vol. 390, pp. 124–131.

Solomon, S. Plattner, G. Knutti, R. and Friedlingstein, P. 2009: Irreversible climate change due to carbon dioxide emissions, *PNAS*, Vol. 106, No. 6, pp. 1704–1709.

SARCC, 2006: *National Rail-plan consolidated report*, South African Rail Commuter Corporation, Johannesburg.

Smith, T. Johnson, M. and McConnell, S. 2012: CTL Fuel Emissions and Economy for a Diesel Passenger Vehicle, Spring Technical Meeting of the Central States Section of the Combustion Institute, April 22-24, 2012.

Sorell, S. Dimitropoulos, J. and Sommerville, M. 2009: Empirical estimates of the direct rebound effect: A review, *Energy Policy*, Vol. 37, pp. 1356-1371.

Soylu, S. 2007: Estimation of Turkish road transport emissions, *Energy Policy*, Vol. 35, pp. 4088–4094.

StatsSA, 2009: *Energy Accounts for South Africa: 2002–2006*, Statistics South Africa, Pretoria.

StatsSA, 2010a: *Gross Domestic Product – Fourth Quarter 2010*, Statistics South Africa statistical release P0441, Pretoria.

StatsSA, 2010b: *Land and transport survey (Preliminary)*, Statistics

South Africa press release P7162, Pretoria.

Stern, N. 2008: The Economics of Climate Change, *American Economic Review*: Vol. 98, No. 2, [Papers and Proceedings of the One Hundred Twentieth Annual Meeting of the American Economic Association].

Stone, A. 2000: South African Vehicle Emissions Project: Phase II, Final Report: Diesel Engines.

Stone, A. and Bennett, K. 1998: A bulk model of emissions from South African diesel commercial vehicles, Energy Research Institute, University of Cape Town, Cape Town.

Stott, P. Mitchell, J. Allen, M. Delworth, T. Gregory, J. Meehl, G. and Santer, B. 2006a: Observational Constraints on Past Attributable Warming and Predictions of Future Global Warming, *American Meteorological Society*.

Stott, P. Jones, G. Lowe, J. Thorne, P. Durman, C. Johns, T. and Thelen, J. 2006b: Transient Climate Simulations with the HadGEM1 Climate Model: Causes of Past Warming and Future Climate Change, *Journal of Climate*, Vol. 19, pp. 2763-2782.

Swart, W. 2012: The economic feasibility of commercial biodiesel production in South Africa including sensitivity analyses of important production and related parameters, Doctor of Philosophy Dissertation, University of Stellenbosch, Cape Town.

Szemesova, J. Gera, M. 2010: Uncertainty analysis for estimation of landfill emissions and data sensitivity for the input variation, *Climatic Change,* 103, pp. 37–54.

Taviv, R. Trikam, A. Lane, T. O'Kennedy, K. Mapako, M. and Brent, A. 2008: Population of the LEAP system to model energy futures in South Africa. South African National Energy Research Institute.

Thagard, P. Findlay, S. 2011: Chapter 14, Changing minds about climate change: Belief revision, coherence, and emotion. In: Olsson. E.J., Enqvist. S., eds. *Belief Revision Meets Philosophy of Science,* Logic, Epistemology, and the Unity of Science 21, DOI 10.1007/978-90-481-9609-8_14.

Thambiran, T. and Diab, R. 2011: Air pollution and climate change co-benefit opportunities in the road transportation sector in Durban, South Africa, *Atmospheric Environment,* 45, pp. 2683-2689.

Trans-Africa Consortium, 2010: Public Transport in Sub-Saharan Africa – Major trends and case studies, Brussels.

UITP, 2010: Report on statistical indicators of public transport performance in Africa.

UNIDO, 2010: Impact of the Global Economic and Financial Crisis over the Automotive Industry in Developing Countries, Research and Statistics Branch working paper 16/2009, Vienna.

United Nations, 1992: United Nations Framework Convention on Climate

Change.

Vanderschuren, M. Jobanputra, R. and Lane, T. 2008: Potential transportation measures to reduce South Africa’s dependency on crude oil, *Journal of Energy in Southern Africa,* Vol 19, No. 3.

Vanderschuren, M. 2010: Determining long-term parking needs at OR Tambo International Airport, Civil Engineering.

van den Berg, H. and Mbara, T. 2011: Are risks associated with energy pipelines in South Africa appreciated? Proceedings of the 30th Southern African Transport Conference, 11-14 July 2011, Pretoria.

van der Zwaan, B. and Gerlagh, R. 2006: Climate sensitivity uncertainty and the necessity to transform global energy supply, Energy Vol. 31, pp. 2571–2587.

van Dyk, J. Keyser, M. and Coertzen, M. 2006: Syngas production from South African coal sources using Sasol-Lurgi gasifiers, *International Journal of Coal Geology*, 65, pp. 243-253.

van Eeden, J. and Havenga, J. 2010: Identification of key target markets for Intermodal freight transport solutions in South Africa, *Journal of Transport and Supply Chain Management*, pp. 255-267.

van Vliet, J. den Elzen, M. and van Vuuren, D. 2009: Meeting radiative forcing targets under delayed participation, *Energy Economics,* Vol. 31, pp. S152– S162.

van Vuuren, D. Weyant, J. and de la Chesnaye, F. 2006: Multi-gas scenarios to stabilize radiative forcing, *Energy Economics*, Vol. 28, pp. 102–120.

van Vuuren, D. Stehfest, E. den Elzen, M. van Vliet, J. and Isaac, M. 2010: Exploring IMAGE model scenarios that keep greenhouse gas radiative forcing below 3 W/m2 in 2100, *Energy Economics*, Vol. 32, pp. 1105–1120.

Vidal, R. Martinez, P. Mulet, E. Gonzalez, R. Lopez-Mesa, B. Fowler, P. and Fang, J. 2007: Environmental assessment of biodegradable multilayer film derived from carbohydrate polymers, *Journal of Polymer Environment*, Vol. 15, pp. 159-168.

Wakeford, J. 2006: The Impact of Oil Price Shocks on the South African Macroeconomy: History and Prospects, Paper prepared for the TIPS/DPRU Forum: “Accelerated and Shared Growth in South Africa: Determinants, Constraints and Opportunities” Johannesburg, 18-20 October 2006.

Wang, C. Cai, W. Lu, X. and Chen, J. 2007: CO_2 mitigation scenarios in China’s road transport sector, *Energy Conversion and Management*, Vol. 48, pp. 2110–2118.

Wang, H. Chen, C. Huang, C. and Fu, L. 2008: On-road vehicle emission inventory and its uncertainty analysis for Shanghai, China, *Science of The Total Environment*, Vol. 398, pp. 60-67.

Wang, H. Fu, L. Zhou, Y. Du, X. and Ge, W. 2010: Trends in vehicular emissions in China's mega cities from 1995 to 2005, *Environmental Pollution*, Vol. 158, pp. 394–400.

Warren, P. and Avila, J. 2010: Modelling urban bus transport emissions in Santiago de Cuba. In: 6th Cuban Congress on Mechanical Engineering (CCIM2010), 29 Nov - 03 Dec 2010, Palacio de Convenciones, de La Habana.

Weber, K. Eliasson, J. Vogel, A. Fischer, C. Pohl, T. van Haren, G. Meier, M. Grobéty, B. and Dahmann, D. 2012: Airborne in-situ investigations of the Eyjafjallajökull volcanic ash plume on Iceland and over north-western Germany with light aircrafts and optical particle counters, *Atmospheric Environment, Atmospheric Environment*, Vol. 48, pp. 9-21.

Weisser, D. 2007: A guide to life-cycle greenhouse gas (GHG) emissions from electric supply technologies, *Energy*, Vol. 32, pp. 1543–1559.

Winkler, H. Borchers, M. Hughes, A. Visagie, E. and Heinrich, G. 2006: Policies and scenarios for Cape Town's energy future: Options for sustainable city energy development, *Journal of Energy in Southern Africa*, Vol. 17, No. 1.

Winkler, H. 2007a: Energy policies for sustainable development in South Africa, *Energy for Sustainable Development*, Vol. XI, No. 1.

Winkler, H. 2007b: Long Term Mitigation Scenarios: Technical

Report, Prepared by the Energy Research Centre for Department of Environment Affairs and Tourism, Pretoria, October 2007.

Winkler, H. and Marquard, A. 2007: Energy Development and Climate Change: Decarbonising Growth in South Africa, Human Development Report 2007/2008, Occasional Paper, United Nations Development Programme.

Winiwarter, W. and Rypdal, K. 2001: Assessing the uncertainty associated with national greenhouse gas emission inventories: a case study for Austria, *Atmospheric Environment*, Vol. 35, pp. 5425–5440.

Winiwarter, W. and Muik, B. 2010: Statistical dependence in input data of national greenhouse gas inventories: effects on the overall inventory uncertainty, *Climatic Change*, 103, pp. 19-36.

Wong, 1999: *Vehicle Emissions Project (Phase II)*. Vol. I, Main Report, Engineering Research, Report No. CER 161.

Wright, L. 2004: The limits of Technology: Achieving transport efficiency in developing nations, University College London.

Yang, C. McCollum, D. McCarthy, R. and Leighty, W. 2008: *Identifying Options for Deep Reductions in Greenhouse Gas Emissions from California Transportation*: Meeting an 80% Reduction Goal in 2050, Institute of Transportation Studies, University of California, Davis.

Yang, C. McCollum, D. McCarthy, R. and Leighty, W. 2009: Meeting an 80% reduction in greenhouse gas emissions from transportation by 2050: A case study in California, *Transportation Research Part D*, 14, pp. 147-156.

Zachariadis, T. 2007: Exploring the relationship between energy use and economic growth with bivariate models: New evidence from G-7 countries, *Energy Economics*, Vol. 29, pp. 1233–1253.

Zegras, P. 2007: As if Kyoto mattered: The clean development mechanism and transportation *Energy Policy*, Vol. 35, pp. 5136–5150.

Zervas, E. 2010: Analysis of the CO_2 emissions and of the other characteristics of the European market of new passenger cars. 2. Segment analysis, *Energy Policy*, Vol. 38, pp. 5426–5441.

Zheng, N. Zhou, N. Price, L. and Ohshita, S. 2011: *A low carbon development guide for local government actions in China*, Preprint version of paper for conference proceedings, ECEEE Summer Study, Giens, France, June 6-11, 2011.

Zhou, N. Price, L. Ohshita, S. and Zheng, N. 2011: *A guidebook for low-carbon development at the local level*, Ernest Orlando Lawrence Berkeley National Laboratory.

Ziramba, E. 2009: Disaggregate energy consumption and industrial production in South Africa, *Energy Policy*, Vol. 37, pp. 2214–2220.