Road Transportation Impact on Ghana's Future Energy and Environment (Title)

By the Faculty of Economics and Business Administration (Faculty 6) of the Technische Universität Bergakademie Freiberg

approved

THESIS

to attain the academic degree of

doctor rerum politicarum
(Dr.rer.pol.)

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Date of award, 07-11-2008

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Foreword

The UN Kyoto Protocol, an international agreement aimed at addressing the issue of climate change is now in force. Countries classified under Non-Annex I (Developing countries) to the United Nations Framework Convention on Climate Change (as amended at the third conference of the parties in December 1997), such as Ghana can voluntary reduce their Greenhouse Gas emissions through the market based instruments of the protocol, which allows member countries listed in Annex I to undertake emissions reduction projects to earn emissions "credits". The call for such initiative under the protocol will require a credible, efficient and effective emissions inventory data, which can be use as a baseline to ascertain the amount of emissions a project avoids, reduces or sequesters.

Recognizing an emission inventory as a prerequisite for the market based instruments of the Kyoto Protocol and also as a tool for policy makers, the author undertook a research at the T U Bergakademie Freiberg in Germany to investigate road transport emissions and its effect on the environment in Ghana.

Data on-road vehicles in Ghana, such as the vehicle fleet for different classes (Passenger cars, Light Duty vehicles, Buses, and Heavy Duty Vehicles, Motor cycles), the average annual kilometer travelled, average velocity on the three different roads (Urban, Rural, and Highway), annual fuel consumption and fuel characteristics were sampled and the total emissions then computed with the use of the computer software COPERT III.

Scenarios were created and the total emissions reduction for each scenario computed. The economic potential of emissions reductions in these scenarios were then evaluated under the Kyoto Clean Development Mechanism initiative. Finally, based on these scenarios recommendations were made, describing the way forward for Ghana's road transport.

Abstract

This research work explored the environmental and socio-economic benefits derived, if some proportion of daily passenger trips made using private cars in Ghana could be shifted to the use of public transport. The research applied the computer software COPERT III in estimating road transport Greenhouse gas (GHG) emissions and fuel consumption in Ghana for the base year 2005 and forecast years 2010 and 2020. The research reveals that if no major change occur in policies or economic determinants in meeting road transport and energy in Ghana, then the 2005 total emissions value is expected to rise by 36% in 2010 and over double in 2020 i.e. from 4.6 to 6.25 in 2010 and to 9.77 Mt CO_2e in 2020. However, if just 10% of daily passenger trips using private cars can be shifted towards the use of public transport, then the end results in reduction in emissions could earn Ghana about $USD 6.6million/year under the Kyoto Protocol CDM initiative. The research also demonstrated that with a further 10% daily passenger trip shift, the outcome could be more promising, increasing to $USD 13million/year.

Key words: Greenhouse Gas Emissions, Mt CO_2e, Daily Passenger Trip, Ghana, Kyoto Protocol CDM Initiative, COPERT III®

Kurzzusammenfassung

Die Doktorarbeit untersuchte den sozio-ökonomischen Nutzen und die Auswirkungen auf die Umwelt durch die Verlagerung eines bestimmten Anteils des Pendlerverkehrs privater Autonutzer in Ghana auf öffentliche Verkehrsmittel.

Für die Untersuchungen kam die Computersoftware „COPERT III" zum Einsatz. Sie diente der Bestimmung der Treibhausabgase im Zuge des zukünftigen Verkehrsaufkommen sowie des Treibstoffverbrauchs in Ghana. Als Bezugsjahr für die Vorhersage der Jahre 2010 und 2020 diente das Jahr 2005.

Die Ergebnisse der Untersuchung zeigen, dass bei einem unveränderten Fortführen der bestehenden Politiken oder wirtschaftlichen Determinanten im Straßenverkehr sowie beim Energieverbrauch in Ghana sich die Abgase bis zum Jahr 2010 um 36% erhöhen. Bis zum Jahr 2020 ist eine Verdopplung möglich. Waren es 2005 4,6 Mio. t CO2 so sind 2010 6,25 Mio. t CO2 und 2020 9,77 Mio. t CO2 möglich.

Eine Lösung kann die Verlagerung des privaten Verkehrs auf öffentliche Transportmittel sein. Wenn dies bei nur 10% der täglichen Pendlerfahrten erfolgt, und Ghana die CO_2 Einsparungen in Form von CDM- Projekten nach dem Kyoto Protokoll finanziell verwertet, Könnte jährliche Einnahmen von über 6,6 Mio US-Dollar entstehen.

Die Untersuchung zeigt, dass mit einer Verlagerung von weiteren 10% täglicher Pendlerfahrten in öffentliche Verkehrsmittel mehr als 13 Mio. US-Dollar Einnahmen pro Jahr möglich sind.

Schlagwörter: Treibhausgase, Mio t. CO2e, Pendlerverkehr, Ghana, Kyoto Protkoll CDM Initiative, COPPERT III ®

Executive Summary

Overview

The UN Kyoto Protocol, an international agreement aimed at addressing the issue of climate change is now in force. Countries classified under Non-Annex I (Developing countries) to the United Nations Framework Convention on Climate Change (as amended at the third conference of the parties in December 1997), such as Ghana can voluntary reduce their Greenhouse Gas emissions through the market based instruments of the protocol, which allows member countries listed in Annex I to undertake emissions reduction projects to earn emissions "credits". The call for such initiative under the protocol will require a credible, efficient and effective emissions inventory data, which can be used as a baseline to ascertain the amount of emissions a project avoids, reduces or sequesters.

Hence, this research was to determine the effects of likely future traffic growth and its implications on selected scenarios for energy and environmental impact in Ghana. The study illustrates the opportunities and benefits of laying a foundation now for a more fundamental strategy shift towards low Greenhouse Gas (GHG) emissions in the future, i.e. addressing Ghana's future road transportation as it relates to energy, GHG emissions and the economy.

The thesis approach starts by synthesizing a cross-section of some of the available information relevant to mitigating transportation Greenhouse Gas emissions, so as to provide a starting point from which Ghana's road transport can advance forward in the future. It then provides a snapshot of the current and likely future state of road transport GHG emissions from Ghana, and finally, highlights those information gaps and issues which require the attention of the government and investors.

Thus the main objectives of the research were:

- Conduct a Greenhouse Gas emissions inventory from road transport in Ghana using the computer software COPERT III.
- Determine the likely future traffic growth's Greenhouse Gas emissions and fuel consumption in Ghana
- Create scenarios for the likely future traffic growth and determine its effects on emissions and fuel consumptions in Ghana.
- Determine the economic potential of emissions reductions in the scenarios if linked to the Kyoto Protocol Clean Development Mechanism initiative and finally
- Provide solution to achieving these scenarios.

Emissions from Road Transport (Mitigation Measures)

Basically, there are two major changes required to reduce emissions from road transport, i.e. changes to behaviour and technology. Behavioural changes, aim at reducing vehicle-kilometre travelled by users of vehicles can help reduce road transport emissions, hence the research reviewed a cross section of measures needed to change behaviours of users of road transport to achieve a sustainable transportation in Ghana. Among some of the measures reviewed included, measures needed for the greater use of transport modes with higher capacities (public transport), the development of non-motorised transport system such as the use of bicycles in Ghana, also reviewed was measures needed for the integration of land-use in transportation planning in Ghana.

The use of emissions reduction technology in vehicles can also help mitigate road transport emissions in a country. Though, vehicle technological changes are accomplished at the manufacturing level, the technologies used still requires regulatory policies to keep them functioning throughout the vehicle's life time. Inspection and Maintenance (IM) program, a supporting tool needed for road transport policy strategy is one sure way to check and ensure the reliability and durability of these technology equipped in vehicles to reduce emissions. Inspection and Maintenance program normally involves regular vehicle emissions testing, thus the research reviewed testing procedures and methods used for testing vehicle emissions in the US, Europe and Japan, these testing procedures and methods have been adopted by many countries in the world, and can be relevant to Ghana in choosing vehicle emissions testing procedure for Inspection and Maintenance program.

Vehicle Emissions and Fuel Consumption Computations

Greenhouse Gas (GHG) emissions (Carbon dioxide, Carbon monoxide, Nitrogen oxides, Nitrous oxide and Methane) and fuel consumption from road transport in Ghana were computed using the computer software COPERT III. The total emissions were combined by converting each pollutant to Carbon dioxide equivalent by multiplying each pollutant by its Global Warming Potential value.

The forecast emissions and fuel consumption were computed using the base year 2005 data and projected vehicle fleet for the year 2010 and 2020. Two Scenarios were generated for each of the forecast year i.e. 2010 and 2020 to determine the extent of emissions and fuel reduction, if daily trips using single occupancy vehicles such as private cars are switched to the use of high occupancy vehicles such as buses. Thus, a 10% and 20% of passenger daily trip shift was considered for the first and second scenarios respectively.

Economic Potential Evaluation

Under the Kyoto Protocol Clean Development Mechanism initiative, developing countries such as Ghana can earn some foreign currency by acquiring carbon credits in the form of coupons called Certificates of Emissions Reduction (CER) through projects that reduces emissions. In this context, the economic potential of emissions reductions in the two scenarios created in this research was evaluated and the likely socio-economic impact analysed.

Findings of the Research

- The research revealed that, for the base year 2005, the total Greenhouse Gas (i.e. comprising of Nitrogen oxides NO_x, Nitrous oxide N_2O, Carbon dioxide CO_2, Carbon monoxide CO and Methane CH_4) emitted from road transport in Ghana was 4.6 million tonnes Carbon dioxide equivalent ($MtCO_2e$). These emissions occurred as a result of the consumption of 490,000 tonnes of gasoline and 720,000 tonnes of diesel in 2005.

- The research also revealed that if no major change in policies or economic determinants from the existing trends in meeting road transport and energy need in Ghana (Business as Usual), then the 2005 emissions value is expected to rise by 36% in 2010 and over double in 2020 i.e. from 4.6 Mt CO_2e to 6.25 Mt CO_2e and then to 9.77 Mt CO_2e in 2010 and 2020 respectively. This will obviously lead to increases in fuel consumption, with gasoline consumption increasing to 710,000 t in 2010 and then to1,300,000 t in 2020 and diesel consumption increasing to 933,000 t in 2010 and then to 1,300,000 t in 2020.

- Another important observation from this research was the significant decreases in total emissions and fuel consumption from road transport in Ghana, if policies aim at shifting passenger trips from the use of single occupancy vehicles such as private cars to the use of high occupancy vehicles such as buses could be pursued in the future. More importantly to this result is the amount of foreign exchange that Ghana can generate if the emissions reduction is carried out under the Kyoto Protocol CDM initiative.

- Thus, if 10% of daily passenger trips could be shifted from the use of private cars to the use of buses, the expected emissions from road transport in Ghana could be reduced to 18.9% in 2010 and also to 24% reduction in 2020. Ghana could reduce its spending in crude oil importation by this 10% shift in daily trip, as it will lead to decreases in expected fuel consumption i.e. gasoline consumption decreasing to 33% and 35% in 2010 and 2020 respectively, and diesel consumption also decreasing by 10% in 2010 and 15% in 2020. In addition, Ghana can earn about $USD 6.6 million per year (6.2% of total net

Foreign Direct Investment received in 2005) if these emission reductions could be linked to the Kyoto Protocol CDM initiative.

- The research also, demonstrated that with a further 10% daily passenger trip shift, the outcome could be more promising as the 20% daily shift in passenger trip to buses could result to about 36% reduction in emissions in 2010 and about 47% reduction in 2020. This outcome could earn the country about $USD13 million per year (12.2% of total net Foreign Direct Investment received in 2005) if these emission reductions could be linked to the Kyoto Protocol CDM initiative. In addition, the country will benefit from fuel consumption reduction, with gasoline consumption decreasing by 69% in 2010 and 73% in 2020 and diesel consumption also decreasing to 14% in 2010 and 24% in 2020.

- Finally, it can be envisage that for these emissions and fuel consumption reduction targets to be met in Ghana, will require an improved and efficient Metro Mass Transit bus operation in the future, to entice its patronage.

List of Abbreviation

APEIS	Asia-Pacific Environmental Innovation Strategy
ASM	Acceleration Simulation Mode (ASM)
BAR	Bureau of Automotive Repair
BAU	Business As Usual
CAAA	Clean Air Act Amendments
CDM	Clean Development Mechanism
CER	Certificate of Emission Reduction
CGPS	Combined Global Positioning Satellite
CH4	Methane
CNG	Compressed Natural Gas
CO	Carbon monoxide
CO2	Carbon dioxide
CONCAWE	Conservation of Clean Air and Water in Europe
COPERT	Computer Program to calculate Emissions from Road Transport
CORINAIR	Core Inventory of Air Emissions
CVS	Constant Volume Sampler
DTC	Diagnostic Trouble Code
DVLA	Drivers Vehicle and Licensing Authority
ECE	European Commission for Europe
ECMT	European Conference of Ministers of Transport
ELR	European Load Response
ESC	European Stational Cycle
ETC	European Transient Cycle
EU	European Union
EUDC	Extra Urban Driving Cycle
FDI	Foreign Direct Investment
FTP	Federal Test Procedure
GDP	Gross Domestic Product
GEF	Ghana Energy Foundation

GHG	Greenhouse Gas
GWP	Global Warming Potential
HC	Hydrocarbon
HDV	Heavy Duty Vehicle
IEA	International Energy Agency
IM	Inspection and Maintenance
IPCC	Inter-Governmental Panel on Climate Change
ITDP	Institute for Transport and Development Policy
JI	Joint Implementation
LAFY	Los Angeles Freeway
LANF	Los Angeles Non Freeway
LDV	Light Duty Vehicle
LPG	Liquefied Petroleum Gas
MIL	Malfunction Indication Light
MMT	Metro Mass Transit
N_2O	Nitrous oxide
NEDC	New European Drive Cycle
NMT	Non-Motorised Transport
NOx	Nitrogen oxides
NYNF	New York Non Freeway
OBD	On Board Diagnostic
OD Matrix	Origin-Destination Matrix
PCV	Positive Crankcase Ventilation
PM	Particulate matter
RON	Research Octane Number
RPM	Revolution per Minute
RVP	Reid Vapour Pressure
SFTP	Supplemental Federal Test Procedure
SHED	Sealed Housing Evaporative Determination
TUB	Technische Universität Bergakademie
UDDS	Urban Dynamic Driving Schedule

UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US EPA	United States Environmental Protection Agency
UTP&TM	Urban Transport Planning and Traffic Management
VOC	Volatile Organic Compound
WCED	World Commission on Environment and Development
WRI	World Resource Institute

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Chapter 1

1.0 Introduction

Climate change is one of the most important and probably the most challenging of environmental issues facing the world this century. But, climate change is more than just an environmental problem. It is also a significant political, economic and social challenge. Concerns are growing about how increases in atmospheric Greenhouse Gases (GHG) caused by human activities are contributing to the natural greenhouse effect and raising the earth's average temperature. Since the world began seriously debating on issues of climate change there has not been a consensus on methods or approach to tackle this menace of climate change. In many countries, this has prevented the implementation of a sensible coordinated response to address the potentially serious global problem of climate change, one such coordinated effort is the United Nations Kyoto Protocol.

The United Nations Kyoto Protocol came into force on Feb. 16, 2005, nearly 13 years after negotiations began at the Rio Earth summit and seven years after the Kyoto protocol was negotiated. The Kyoto Protocol, an international agreement aimed at addressing the issue of climate change, commits developed countries to collectively reduce their Greenhouse Gases emissions to 5.2% below 1990 levels by the period 2008-2012 (Mckibbin, W., 2005). The Protocol also advances the implementation by all parties of their commitments under the 1992 Framework Convention on Climate Change, for example, the Protocol identifies various sectors (including energy, transport, and industry as well as agriculture, forestry and waste management) in which actions should be considered in developing national programs to combat climate change and provide for more specific reporting on actions taken.

Although the Kyoto Protocol's emphasis was on countries listed in Annex I* to the UNFCCC to compulsory reduce their emissions, it however, created a window of opportunity for non-Annex I countries to voluntary cut down on their GHG emissions. To facilitate this voluntary emissions reduction, the Kyoto Protocol contains two mechanisms, i.e. Joint Implementation JI and the Clean Development Mechanism CDM, through which countries listed in Annex I could earn emissions "credits" by investing in projects that aim at reducing GHG emissions. These mechanisms will no doubt encourage developing countries to seek foreign investments in more energy efficient projects.

One vital tool to the CDM and JI is information or data on an emission inventory in the various sectors (energy, transport, industry, agriculture, forestry and waste management), knowledge of an emission inventory can serve as a benchmark or a yardstick to ascertain the amount of Greenhouse Gas (GHG) emissions that a project avoids, reduces or sequesters. An emission inventory can also have other important uses, Scientists, for example, can use it to develop atmospheric models. An emission inventory can also be used by policy makers to develop strategies and policies for emissions reduction and to track the progress of these GHG emissions. Quite apart from these uses, regulatory agencies can rely on GHG emissions inventories to establish compliance with legally acceptable emissions rates in a country. Finally, businesses, the public, and other interest groups can use emissions inventories to better understand the sources and trends in emissions.

* Countries list in Annex I to the UNFCCC (As amended at the 3rd Conference of the Parties in December 1997): Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, the European Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America.

Unlike other environmental issues confronting the world today, GHG emissions come from a variety of sources. Historically, industry was looked upon as the number one contributor to atmospheric emissions. While industry is still a significant source of GHG, the transportation sector and, in particular, motor vehicles are now becoming the primary source of these emissions (IEA, 2005). Motor vehicle air pollution, once largely a problem of developed countries will soon spread to the developing countries in the next decade because of the rapid pace of urbanization there, the rising incomes, combined with more desire for travel and personal mobility, which will increase motor vehicle ownership and bus transport.

Economic studies in the Czech Republic, the Russia federation, the Slovak republic, Zimbabwe, Colombia, and Argentina between1997-1999 revealed that there are many potential policies to reduce Greenhouse Gas emissions from transport for which the benefits outweigh the costs (Black-Arbelaez, T. et al, 2000). The most efficient approach is through market-based policies as promulgated in the Kyoto Protocol's Clean Development Mechanism (CDM), Joint Implementation (JI) and Emission Trading. A Possible response to these market-based policies include sound based information and cost effective programs, an emission standard based on a realistic evaluation of costs and expected compliance, identification of specific problems, appropriate counter-measures and institutional set-up to monitor and evaluate these emissions.

Therefore, conducting an emission inventory is a necessary first step in this process. By properly accounting for the GHG emissions can give the opportunity to establish a foundation for setting goals and targets.

Ghana, a developing country, is aiming at becoming a middle earning income country in the year 2020. The rapid industrialization growth in Ghana to achieve a middle income status would require efficient transport for production and distribution of goods and services. The possible future rise in incomes, coupled with increases in production of goods and services will lead to an increase in the number of vehicles on the roads of Ghana in the future, this could result in more energy use, traffic congestion and Greenhouse Gas emissions. The rise in emissions will threaten the air quality in the industrial and highly populated cities of Tema, Accra and probably Kumasi and Sekondi-Takoradi due to prevailing low street-level wind speeds in the cities which are in most cases not adequate to disperse toxic pollutants (Government of Ghana Report, 2003).

In Ghana, the transportation sector accounts for more than 13% of the nation's energy requirement and about 42% emissions of carbon dioxide (CO_2) with annual motor fuel consumption of 38 litres/person (WRI, 2003). The worsening traffic congestion and air pollution which plague the major cities of Ghana and foreign crude oil dependence make the economy very vulnerable. Importation of crude oil and petroleum products and debt-servicing has been a drain on the nation's hard currency earnings.

The continued travel growth, increased awareness of environmental issues, and recognition that some types of impacts are hard to identify during project development warrant consideration of environmental issues as part of the long range planning process. A new, more rational approach to transportation is therefore needed, one among many options for travel.

1.1 Background and Objectives

As a party to the United Nations Framework Convention on Climate Change (UNFCCC), Ghana was a signatory to the Rio de Janeiro Earth summit in 1992, and has since ratified the Kyoto Protocol to UNFCCC (Government of Ghana Report, 2001). Although Ghana is not obliged under the Protocol to reduce its emissions, it is nevertheless affected by climate change and needs to join efforts with the global community in addressing the ever increasing threat of climate change.

Ghana's transportation sector emissions are increasing but climate change competes with urgent economic, social, and public health concerns for government attention. Basically, some fundamental forces influence the extent of the transportation system's impact on the environment. Trends in regulation, land use policy, transportation costs and the related changes in travel demand, fuel and vehicle technological change, each play a role in determining the extent of transportation impacts in a country.

Ghana's vision of attaining a middle income status will therefore pose a challenge to policy makers to review and develop policies, laws and regulations that will conform to changing trends and induce participation in environmental-friendly transportation. An environmental oriented policy formulation on road transportation will require vital information such as vehicular emission inventory data as well as its future projections, to make prudent decisions.

Hence, this research was to determine the effects of likely future traffic growth and its implications on selected scenarios for energy and environmental impact in Ghana. The study illustrates the opportunities and benefits of laying a foundation now for a more fundamental strategy shift towards a low Greenhouse Gas (GHG) emissions in the future, i.e. addressing Ghana's future road transportation as it relates to energy and GHG emissions.

The thesis approach starts by synthesizing a cross-section of some of the available information relevant to mitigating transportation Greenhouse Gas emissions, so as to provide a starting point from which Ghana's road transport can advance forward in the future. It then provides a snapshot of the current and likely future state of road transport GHG emissions from Ghana, and finally, highlights those information gaps and issues which require the attention of the government and investors.

The main objectives of the research were:

- Conduct a Greenhouse Gas emissions inventory from road transport in Ghana using the computer software COPERT III
- Determine the effect of likely future traffic growth on energy and environment in Ghana
- Create scenarios for the likely future traffic growth and determine its effects on energy and environment in Ghana.
- Determine the economic potential of emissions reductions in the scenarios if linked to the Kyoto Protocol Clean Development Mechanism initiative and finally
- Provide a solution to achieving the best scenarios (least GHG emissions)

1.2 Methodology

To achieve the objectives of the research work, the thesis was divided into three main phases

Phase One:

The concept of sustainability, by and large, is gaining acceptance by all policy makers and is viewed by many stakeholders in policies formulation as the solution to economic growth in a country, being developed or developing. Therefore, phase one of the research focuses on the concept and application of road transport sustainability. The phase begins by defining and explaining some basic concepts of road transport emissions, and continues with the theory underlying sustainability development as applied to road transport development. A major problem facing road transportation in Ghana is the ability to contain the volume of traffic on the roads, due partly to the rapid increases in vehicle fleet compare to road infrastructure development, and partly due to the deficiencies in road transport development planning in the country. Policies which aim at reducing travel demand, increasing the share of public transport and land planning can help tackle this problem for a sustainable road transport in Ghana. Thus, phase one will also elaborate on some policy options needed to tackle this problem of road traffic congestion and its negative effects such as, fuel consumptions, air pollutions and noise in Ghana.

Inspection and Maintenance (IM) program, a supporting tool needed for road transport policy strategy, is one sure way to check and evaluate road transport emissions. Formulating procedures and methods to carry out vehicle emission testing requires a huge amount of data and logistics, hence the cheapest and easiest option used in most countries is through adoption. Finally, phase one of the research concludes by reviewing the three most adopted vehicle emission testing procedures used in the world, i.e. The European Union, the United States and the Japanese testing procedures

Phase Two:

The second phase focuses mainly on input data analysis, starting with the description of software used for the research i.e. the COPERT III software which is used for the computation of vehicle emissions and the QUESTOR model which is used in determining the vehicle fleet for the forecast year 2010 and 2020 and also for analysing passenger trip pattern for cars and buses in Ghana needed for this research.

Data used for the research was sampled through: vehicle and household surveys, interviews with passengers, car dealers, land and economic experts, also some vehicle related data such as total annual vehicle fuel consumption, vehicle population, and fuel properties were obtained from some governmental institutions.

Some data sampled for the vehicle emissions computations are however, not in the form or structure required by the COPERT III software. Therefore, in this phase input data needed for the emissions computations are converted and structured to conform to the COPERT software, also emission factors for the different pollutants needed for the emissions computations are calculated using formulas provided in the COPERT III technical report. Finally, trip computation analysis needed for vehicle emissions computation for each of the two separate scenarios created for the forecast year 2010 and 2020 are analysed.

Phase three:

Phase three focuses mainly on the presentation, and the analysis of results of the vehicle emissions computations in phase two. Vehicle emissions pollutants have different degree of effect on health and the environment, thus to assess the effect of the results on global warming, the total emissions for each pollutant is normalized to its Carbon dioxide equivalent. The normalization is done by multiplying the results of total emissions of each pollutant emitted by its Global Warming Potential (GWP) value. Thus, total vehicle emissions results of pollutants such as, Nitrogen oxides NO_X, Carbon dioxide CO_2, Carbon monoxide CO, Nitrous oxide N_2O, and Methane CH_4 in Ghana are presented for the base year 2005, forecast years 2010, 2020 and the two scenarios created for each of the forecast years. To give a clearer view of the results, graphs are plotted showing the percentage share of each pollutant's contribution towards global warming. Also, fuel consumption for the base year 2005, the forecast years and scenarios are presented in this phase.

A comparative analysis of results, showing how the forecast years' results deviate from the base year results, and secondly, how the forecast year results also deviate with the corresponding scenarios results. The economic potential and the socio-economic impact of implementing policies to achieve outcomes in the scenarios created are discussed. Finally, based on some of the theories and applications reviewed in phase one, recommendations are given detailing possible ways to achieve these scenarios.

Chapter 2

2.0 Types of Vehicle Emissions

Emissions from road transport can be classified into three main components; exhaust emissions, evaporative emissions and abrasion and dust resuspension, these are further broken down into other categories. Therefore, the purpose of this chapter is to highlight the concepts of these different categories of emissions.

2.1 Exhaust Emissions

Exhaust or tailpipe emissions are products resulting from the combustion of fuel in vehicle's engine which are emitted from the vehicle exhaust system. The major pollutants emitted include:

- *Hydrocarbon (HC)*: Also referred to as Volatile Organic Compounds (VOCs) are normally emitted from motor vehicles as exhaust emissions or evaporative emissions. Exhaust Hydrocarbon emissions occur when the condition in the engine is not conducive for a complete combustion of air-fuel mixture, thus resulting in unburned fuel and products of partial combustion, such as Ethylene and Formaldehyde (U.S EPA, 2007). These emissions can react in the presence of Nitrogen oxides and sunlight to form ground-level ozone, a major component of smog. Some Hydrocarbon emissions also have the potential to cause cancer. Hydrocarbon pollutants have varying impacts on the environment and human health, therefore in analyzing vehicle emissions HCs are normally sub-divided into two categories: Methane and Non-Methane Hydrocarbons (NMHC) also referred to as Non-Methane Volatile Organic Compounds (NMVOC). One way to prevent or minimize hydrocarbon exhaust emissions from motor vehicles is to raise the temperature of the combustion chamber to high temperatures preferably above 600^{o}C with sufficient Oxygen to aid the combustion process (Faiz, A. et al, 1996).

- *Nitrogen oxides (NO_x)*: The two main Nitrogen oxides emitted from combustion engines are Nitric oxide (NO) and Nitrogen dioxides (NO_2). These gases normally occur when Nitrogen and free Oxygen react at high temperatures and pressure conditions inside the engine. Nitrogen oxides contribute to both smog and acid rain. In internal combustion automotive engines, these gases form early in the combustion process just when the temperature are at the highest, hence these emissions can be controlled by reducing the flame temperature by retarding the combustion process, this can be achieved by diluting the reacting mixture, or by minimizing the time that the burnt gases stay at high temperatures or doing both (Faiz, A., et al, 1996). Thus, a possible modification to reduce Nitrogen oxides emissions from combustion engines is to redirect a certain proportion of the exhaust gases back into the air-gasoline mixture going into the engine. This cuts peak temperatures during combustion, lessening the amount of Nitrogen oxides produced.
- *Carbon monoxide (CO)*: These results from incomplete burning of vehicle Hydrocarbon-based fuels, Carbon monoxide reduces the blood's ability to carry oxygen and therefore are poisonous when it is inhaled especially people suffering from heart diseases. There are two possible conditions in which Carbon monoxide are generated from car engines. The first possibility occurs during an early morning start of an engine (i.e. after the engine has been turn off for a long period of time) where the fuel pumped into the combustion chamber is normally higher, creating a rich air-fuel mixture (less air), this limitation of air required for complete fuel combustion results in the production of Carbon monoxides. Hence adjusting the air-fuel ratio to attain a lean mixture (excess air) could limit Carbon monoxide emissions in gasoline engines. The other possible condition under which Carbon monoxide are generated is when vehicles are not properly tuned for high altitudes where "thin" air effectively reduces the amount of Oxygen available for combustion.
- *Carbon dioxide*: Though this is a product of complete combustion of Hydrocarbon, it is abundant in the atmosphere and thus has no immediate harmful effects to humans and is essential to plant life. However, Carbon dioxide is

considered as a pollutant because it is a significant Greenhouse Gas and increasing its levels in the atmosphere contributes to global warming.

- *Particulate matter(PM)*: Particulate matter emissions from internal combustion engines results from unburned lubricating oil in the exhaust, another possible source is from the ash forming fuel and oil additives such as tetra ethyl lead added to boast its octane rating. Although PM emissions rates for spark-ignition engines are low compared with diesel engines, its emissions from spark-ignition combustion can be significant under poor engine maintenance which leads to higher oil consumption. Thus a possible solution to these PM emissions is to improve the engine's oil consumption rate through design techniques such as improvement in cylinder bore roundness, surface finish, optimization of piston ring tension and shape, valve stem seals, and turbocharger oil seals. Another option is to use reformulated lubricating oil, these oils have been proven to reduce PM emissions by 10 to 20% (Dowling, M., 1992)

The quantity of each pollutant (discussed above) emitted depends on the vehicle emissions performance, which also depends on the engine thermal operating conditions i.e. either at the warming up or stabilized operation condition. In most cases the concentration of pollutants during the warming up period are many times higher than during stabilized or hot operations. Thus in analyzing or estimating exhaust emissions there is the need for different methodological approach for the different operational conditions, on this basis vehicle exhaust emissions are further grouped into two categories; cold start exhaust emissions (warming-up) and hot exhaust emissions (stabilized).

2.1.1 Cold Start Emissions

Cold start emissions are exhaust emissions which occurs under a cold start engine condition i.e. with the temperature of coolant in the engine below 70^{o}C (Ahlvik, P. et al., 1997), where the vehicle engine has been turned off for some time, rendering vehicle emissions control system, such as catalytic converter ineffective (i.e. if the vehicle is equipped with one). Under this condition, Hydrocarbon and Carbon monoxide emissions are higher than after the engine has reached a stable thermal condition. This is because catalytic emission control systems do not provide full control until the catalytic converters reaches its operating temperature (i.e. light-off). Another reason for the high emissions is due to the excess fuel within the air-fuel mixture entering the engine under cold operating conditions, which results in incomplete combustion.

Cold start emissions is more prevalent with gasoline (petrol) engines where the process of perfect combustion in the engine requires a right fuel to air mixture, however, during engine warm up the fuel do not fully vaporize before mixing with the air in the cold engine, therefore to achieve a combustible mixture, extra fuel is needed to ensure adequate amount of vaporized fuel. This leads to an excess fuel to air ratio mixture, which eventually results to partially burned fuel and unburned fuel emissions in relatively high concentrations from a cold engine. This is the reason behind the high emissions rate during cold start of a gasoline vehicle engine.

2.1.2 Hot Exhaust Emissions

Hot exhaust emissions are emissions from the vehicle exhaust when the engine has warmed up to its normal operating temperature. This type of emissions depend on the type of vehicle, the type of fuel its engine runs, the driving profile for the vehicle on a journey and the emission regulations which applied when the vehicle was first registered, as this defines the type of vehicle technology that exist or existed.

The process of combustion under hot exhaust emissions is quite similar to that of cold start conditions. However, during hot exhaust emissions, the engine is warm enough, allowing a large portion of the fuel entering the combustion chamber to be vaporized before mixing with the air, hence fuel to air mixture is just adequate and there is no need for extra fuel as in the case of cold start conditions. For that reason, Hydrocarbon and

Carbon monoxide hot exhaust emissions are significantly lower than under cold start operations. Also, vehicles fitted with emission control systems such as catalytic converters become operational after the engine is warmed up. These catalysts tend to break these emitted gases from the engine to less harmful gases before it is released to the atmosphere. Therefore, not only are hot exhaust emissions less in quantity but also a large portion of it are emitted as less harmful gases.

2.2 Evaporative Emissions

Vehicle evaporative emissions consist entirely of Hydrocarbon (HC) emissions, emitted from other sources besides the vehicle's exhaust pipe. These emissions often occur during vehicle refueling, vehicle operations, and even when the vehicle is parked. There are six evaporative emissions associated with gasoline engine vehicles, these are diurnal, hot soak, running losses, resting losses, refueling, and crankcase. However, because of the difficulties involve in sampling and measuring the last three types of evaporative emissions mentioned above, they are mostly neglected in vehicle emissions computations (Eriksson, O., 2003).

2.2.1 Diurnal Evaporative Emissions

This type of evaporative emissions is associated with the daily (diurnal) variation in ambient temperature, which results in vapor expansion inside the gasoline tank as the ambient temperature rises during the daylight hours. To prevent the escape of fuel vapor, vents through which these vapor escape to the atmosphere are normally routed to a charcoal canister where the vapor can be adsorbed and later purged into the running engine. However, without an evaporation control system, some of the increasing volume of fuel vapor is vented to the atmosphere.

At night, when the temperature drops, vapor contracts and fresh air is drawn into the gasoline tank through the vent. This lowers the concentration of hydrocarbons in the vapor space above the liquid gasoline, which subsequently, leads to additional evaporation.

2.2.2 Hot Soak Emissions

Hot soak evaporative emissions occurs when a hot vehicle engine is turned off, and the fuel is exposed to the hot engine (e.g. in carburetor float bowls or in fuel injectors). Heat from the engine and exhaust system increases the temperature of the fuel in the system that is no longer flowing. The fuel gets vaporized and escapes to the atmosphere.

2.2.3 Running Losses

This type of evaporative emissions are associated with fuel evaporation in the fuel tank, running losses are similar to that of diurnal evaporative emissions, but unlike the diurnal evaporative emissions where the engine is turned off, running losses occur during the car engine operation. It is most significant during periods of high ambient temperatures. The combined effect of high ambient temperature and exhaust system heat and heated fuel that returns back to the tank from the engine can generate a significant amount of vapor in the gasoline tank. Running losses are a significant problem with vehicles that have exhaust systems in close proximity to the gasoline tank. Running evaporative losses had been neglected in emissions calculation methodology in the past, with the assumption that its amount is insignificant, but research findings from CONCAWE (1990), Eggleston, H.S., et al CORINAIR (1993), RWTÜV (1993) and the USEPA (1991) have proven otherwise and running losses had since been incorporated into some emissions models, such as USEPA MOBILE model and European sponsored model COPERT (Joumard, R., 1999).

2.2.4 Resting Losses

These include those emissions resulting from vapors permeating parts of the evaporative emissions control system (e.g. rubber vapor routing hoses), migrating out of the carbon canister, or evaporating liquid fuel leaks. Resting losses are in most cases neglected during emissions evaluation or analyzed as a percentage of hot soak or diurnal emissions. The amount of resting losses depends upon temperature and the type of carbon canister used as evaporative emissions control system (i.e. open-bottom versus closed bottom).

2.2.5 Refueling Losses

There are two components of refueling emissions, vapor space displacement and spillage. As a fuel tank is being refueled, the incoming liquid fuel displaces gasoline vapor that has established pseudo equilibrium with the fuel in the tank, effectively "pushing" the vapor out of the tank. Spillage simply refers to that small amount of fuel that is assumed to drip on the ground and subsequently evaporating into the atmosphere.

To reduce refueling losses, vehicles are now designed to have a diameter of the filler necks of the fuel tanks just enough to fit the filler nozzle of the filling station, also the filler necks are fitted with hinged and spring loaded door to prevent leakage when the filler cap is removed. Modifications to filling station pumps, such as having intakes around the head of the filler nozzle to suck the vapors back into the pump as they are displaced by the fuel, and having a rubber "boot" that presses securely around the end of the filler neck to prevent vapors escaping, have led to improvement in refueling losses.

2.2.6 Crankcase Emissions

Although not a true evaporative source, crankcase emissions are generally considered in the evaporative emission category. Crankcase emissions occur during air-fuel intake engine operation, where vaporized gasoline entering the combustion chamber escape into the atmosphere as a result of defective Positive Crankcase Ventilation (PCV) systems (which is normally routed to the vehicle's intake manifold).

Chapter 3

3.0 Road Transport Sustainability

The basic theory underlying road transport sustainability is imbedded in the broader concept of sustainability development. The word sustainable development became a popular phrase among policy makers after the publication of the World Commission on Environment and Development report (also known as the Brundtland's commission report) "*our future*" in 1987. Thus, the word sustainability was explained by the Brundtland commission as the ability to meet the needs of present generation without compromising the ability of future generations to meet their own needs (WEDC, 1987). The ultimate goal of sustainability therefore, is to have an interconnected link between the three main facets of development i.e. balancing a growing economy and at the same time protecting the environment and meeting social responsibilities. For the transport sector, the goals of sustainable road transport development are: meeting the necessary demand for transport, reducing the reliance of petroleum, avoiding negative environmental consequences and reducing the cost of road infrastructure (Liu, D.Q. et al, 1999).

The use of costing plays a central role in determining policies for road transport sustainable development in a country. Basically, the costs of road transportation can be categorized into two main groups; internal and external costs. The internal costs arise as a result of road construction, maintenance and provision of road infrastructure. Internal costs form the basis for decisions on the transport market such as determining both the individual mobility demand and transport supply. The external costs are not part of the supply or demand decisions on the transport market; they arise as a result of the negative effect of road transport (such as accidents, emissions and noise) on people and/or future generations.

Both internal and external costs are indispensable elements of sustainable road transport, however, in many developing countries, even the internal costs of transport are not fully borne by road users, and the transport costs are normally subsidized out of the nation's general budget (Schwaab, A.J. and Thielmann, S., 2001). The difficulty in measuring external costs coupled with political expediency in many developing countries makes it more difficult to shift these external cost to motorists.

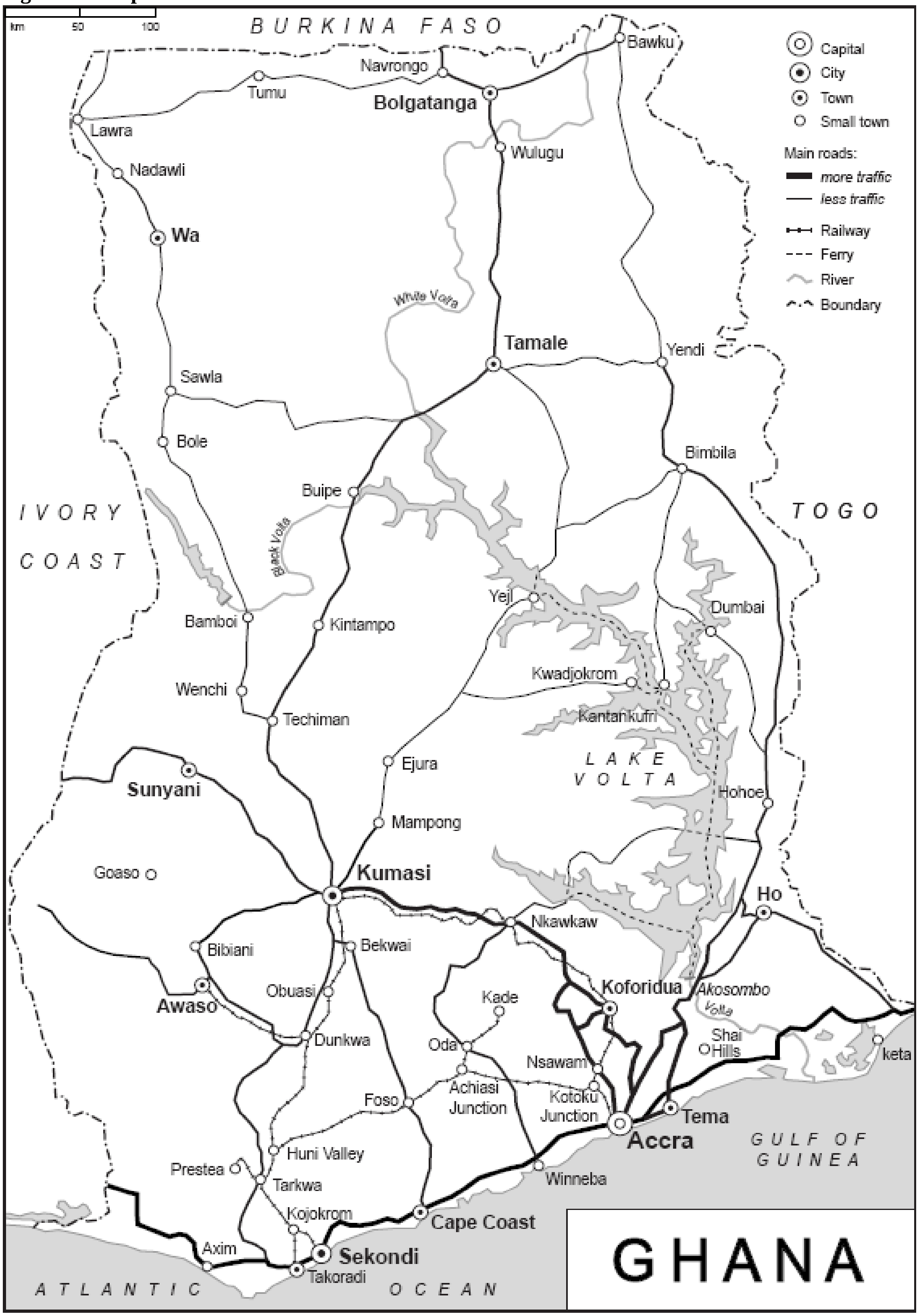
In this chapter, in the context of road transport sustainability, will analyze the major problems and challenges facing Ghana's road transport development, more importantly, the chapter will highlight the deficiencies in road transport planning in Ghana, the possible policy changes and adjustment needed. Finally, the chapter will provide some lessons on road transportation from other countries that Ghana can learn from.

3.1 Current State of Road Transportation in Ghana

Ghana is located on West Africa‘s Gulf of Guinea, only a few degrees north of the equator. It is bordered to the north by Burkina Faso, to the east by Togo and to the west by Cote d'Ivoire. Figure 3.1 below shows the map of Ghana detailing the main transportation networks in the cities and towns.

Road transportation serves as a dominant mode of transport in Ghana, it accounts for about 98% of freight and 95% of passenger movement in the country (Ghana Ministry of Transport Report, 2007). According to available statistics from the national registry, total road transport registered in Ghana from 1995 to March, 2006 were 783,531, comprising of 336,740 Private Cars (42%), 100,183 Taxis (13%), 51,724 Light Duty Vehicles (7%), 109,258 Buses (14%), 69,274 Heavy Duty Vehicles (9%) and 116,352 Motor Cycles (15%) (DVLA, 2006). Assuming these vehicles are all still operational, then considering the total population in Ghana i.e. 2006 estimated figure of 21,029,853 (Ghana Statistical Service, 2007), the number of vehicles per 1000 people is 37, whilst the figure for Private cars per 1000 people is 16 and 5 for Buses and Taxis each. The forecast growth for the different mode also shows between 6% and 10% growth for private cars, about 3% growth for taxis and a 2% growth for buses.

Figure 3.1 Map of Ghana



Source: Pedersen, O, 2001

Generally, the road network in Ghana is about 50,000 km in length with 65% of the road classified as feeder or rural roads, 27% as trunk or highway roads and the remaining 8% classified as urban roads (Ghana Ministry of Transport Report, 2007). A large proportion of the roads in Ghana are gravel roads which make them venerable to the periodic rainfalls, and therefore requires constant maintenance program to sustain. Generally, the road network condition in Ghana can be classified according to international standards as poor, 40% of the total road network are in really bad conditions, with 26% in fair conditions (Ghana Ministry of Transport Report, 2007). Also, roads in the cities were not built to handle the volume and types of vehicles current plying the roads, many road arteries have only two lanes, thus providing inadequate road space for the number of vehicles plying the roads.

The rapid increases in car ownership as shown in the growth rate compared to buses, coupled with poor land use planning, inadequate road space, lack of regulated parking system, uneducated use of the road by pedestrians, and motorist indiscipline have compounded the problem of vehicle congestions in major urban and highway roads in Ghana.

The public road transportation in Ghana is largely owned and operated by the private sector, with government controlling only a small portion of buses. The overall quality of public transportation in Ghana is poor, most vehicles are close to or beyond their service life and maintenance standards are extremely low, high maintenance costs arising from poor road surfaces and revenue losses as a result of road congestion, constrain the operators to invest in new vehicles. Also, there are no provisions for non-motorized vehicles such as bicycles, nor are there buses and emergency stopping lanes and turning areas.

3.2 Policy Option for Road Transportation Sustainability

A major issue, crippling the road transport system in Ghana is the rapid population growth, especially in the urban cities, comprising of over 40% of the total population and growing between 3.2% and 4.8% per year (UTP&TM Report, 2005). The unrelenting population growth, and expected increases in economic activities will induce a continuous increase in the travel activities of people and goods in Ghana, and consequently its negative effects such as air pollution, global warming, accidents, congestion, noise, energy consumption, and use of land. Thus, possible policy options needed for a sustainable road transport in Ghana will need to address three main issues, i.e. the problem of increases in travel demand, increases in the use of private cars and the high environmental impact due to vehicle use in Ghana.

3.2.1 Reducing Travel Demand

The issue of increases of public travel demand can be tackled in two main ways i.e. by either decreasing travel activities within urban cities or by changing travel behaviors to reduce the frequency of trips. The former, will require policies to decentralized or relocate some urban functions especially governmental functions to small towns and villages, to ease travel activities within the urban cities. This strategy can be best enforced through close cooperation among national and local government, infrastructure developers (transportation, housing etc.), and the local people (APEIS, 2006).

The other approach, which soaks the travel demand pressures from increases in urban population, by reducing the frequency of trips through land use policies that focuses on higher population density and better accessibility to daily activities. Examples of some cities that have experience such a system include Curitiba (Brazil), Singapore, Hong Kong (People Republic of China), Freiburg (Germany), and Portland (US) (Litman, T., 2003). The success of such a system may require a good coordination with all public transport infrastructure development and coordination at different governmental levels.

Apart from the use of land policies, to reduce travel activities, the use of Information Technology (IT) based communication and services can provide alternative services so that people do not have to physically travel to destinations, this is possible through shopping, banking and payment of services. The potential of such a strategy has been investigated in the capital city Accra and proven as a positive instrument to reduce travel demands in Ghana (Tryzno, P., 2004). However, such an initiative may require government promotion, public awareness and planning programs (APEIS, 2006).

3.2.2 Modal Shift to Less Polluting Modes

The strategy to provide more environmentally sound, higher usage of public transport as well as non-motorized transport involves: improving the efficiency of public transport, providing alternative to vehicle use such as walking and cycling, and finally, reducing car ownership and/or its use. Public transport efficiency depends on the carrying capacity, operational speed, infrastructure and financial requirement, flexibility to transport demand and environmental effect. Metro Mass Transit (MMT), a system that offers priority for rapid movement of buses by securing segregated bus ways (IEA, 2002) can provide these attributes of public transport efficiency needed in Ghana. Though, MMT started in 2003, it is at the infant stages in Ghana, and can be improved to tackle the problem of road traffic congestion, This however, will require a well planned MMT, which can provide high capacity, comfortable, rapid and low-cost transport. A similar bus system introduced in some cities such as Curitiba (Brazil), Bogota (Columbia) and Quito (Ecuador) have proven to be a very cost effective alternative (APEIS, 2006). Some cities in some developing countries such as Taipei (China), Jakarta (Indonesia), Delhi (India), Dacca (Bangladesh) and Bangkok (Thailand), have started or are in the process of introducing such rapid bus systems (APEI, 2006; IEA, 2002; Wright, L and Fjellstrom, K., 2003a, 2003b; ITDP, 2003a).

Another solution similar to the MMT, to reducing traffic congestion in Ghana is the use of 'community vehicles', where private vehicle operators provide buses to satisfy community services such as schools, factories or to a group of commuters. Though, such schemes exist in Ghana, it is only common within the mining communities, it could be instituted and strengthen on a large scale in the big cities in Ghana where traffic congestions are more pronounced. For such a scheme to be successful, government rules and regulations are very important, particularly, where such services are meant for the public in general. 'Vehicle Community' schemes have been proven to be very effective in meeting the needs of public transport in Bangkok (Thailand), Rome (Italy) and Tokyo (Japan) (APEI, 2006).

In addition to these solutions to tackling road traffic congestions in Ghana, policies aiming at promoting alternatives to vehicle use such as walking and cycling could be introduced. Although, walking and cycling are not recognized as a significant solution to the problem of road congestion, walking and cycling can serve as a viable option to meet the basic mobility needs of all groups in a sustainable way. Walking and cycling are environmentally friendly, i.e. no air or noise pollution, in addition, it is more efficient in terms of scarce road space, to combat road traffic congestion (APEI, 2006; Hook, W., 2002). A number of European countries have worked actively to promote walking and cycling, pressured by both social and environmental problems induced by motorization.

Lastly, the problem of road traffic congestion can also be effectively tackled by instituting policies to reduce the number of car ownership and restrict its use. Vital strategy such as creating car-free zones (limiting the use of private cars in some areas) offers a sustainable commuting strategy without limiting mobility and introducing a more civilized infrastructure, attractive to both tourist and residents. Another strategy, which can also be implemented to shape the transportation policies in Ghana, is by instituting a car-free day, a day set aside where no cars are allowed on the streets and the public is educated and encouraged to use public transport. The car-free day, could also be used to promote walking and cycling as an environmentally sustainable transport system. For such a program to be implemented successfully in Ghana, it will require the closure of the streets to traffic on that day and the inclusion of various activities that will be attractive to persuade the public to come and walk on the streets.

3.2.3 Reducing Emissions from Vehicles

Generally, policies strategies needed for tackling road transport emissions include, introduction of vehicle emissions standards and Inspection/Maintenance (I/M) program, introduction of vehicle fuel standards, introduction of green fuel tax, promoting the use of high efficiency vehicles, promoting the use of alternative fuels and finally promoting good vehicle driving. Considering the development level of a developing country like Ghana, the introduction and promotion of some of these strategies to tackle road transport emissions will require some time to be fully implemented, however, the introduction of vehicle emission standards and I/M program and promotion of alternative fuel such as Liquefied Petroleum Gas (LPG) and good driving behaviors can immediately be effected.

The introduction of vehicle emission standards and I/M program in Ghana, will require a huge amount of capital and logistics, thus, the best solution is to adopt already established vehicle emission standards in use i.e. the US, the European Union, and the Japanese emissions standards. However, procedures applied in testing emissions need to be adjusted to suit vehicle operation conditions in Ghana. The different procedures used in testing vehicle emissions and the various operation condition applied in the US, the European Union and Japanese emission standards will be analyzed in details in the next chapter.

3.3 Concluding Remarks

The reality about the road transport situation in Ghana is that, growth in fleet will continue with the highest rates in the urban cities, modal split will become more unbalanced, and fuel use would steadily increase as will noise and the use of land for transport. These transport trends call for a reorientation of transport policies and practices to ensure sustainability and to maintain the benefits of the transport sector in Ghana.

The degree of benefits of policies discussed in this chapter will depend so much on the efficiency of road transport policies implementation in Ghana. The current policy approach which offers the promise of mitigation of growing costs while providing little restraint on growth in transport activity will need to be changed in Ghana, because, more often than not the resulting mitigation is insufficient to offset the increased growth in the volume of transport activities. Some of the elements of the policies discussed in this chapter are already known to policy makers or already in place in Ghana, however, their implementation need to be strengthened.

Chapter 4

4.0 Quantifying Vehicle Emissions

The process of vehicle emissions regulation control is normally in two stages, setting emissions standards at the manufacturing stage of the vehicle and secondly during its use stage. With the current state of technology and environmental awareness, vehicle manufacturers are now forced by vehicle standards and emissions regulations, either in the country of manufacture or place of use of these vehicles, to equip vehicles with emissions control systems or devices, consequently new vehicles released into the market tend to have low emissions rate. Incorporating emissions control technologies and new vehicle emissions standards into vehicle production is a necessary but not a sufficient condition for achieving low emissions. Measures are also required to ensure the durability and reliability of emissions controls throughout the vehicle's lifetime.

To ensure the effectiveness of vehicle emissions control devices throughout a vehicle's life time, most countries have updated their emissions regulation standards and complemented it with inspection and maintenance (IM) programs. Inspection and Maintenance normally involves regular vehicle emissions testing, which depends on several factors such as, jurisdiction under which these vehicles ply, the type of fuel used by these vehicles, the instrument used for the test and the type of vehicle emissions (exhaust or evaporative).

There are several techniques developed to measure vehicle emissions, however the most popular measuring method employed in vehicle emissions regulations and standardizations are: the dynamometer method, the remote sensing method, and on-board measuring systems. The U.S., the European Union (EU) and Japan have each developed elaborate vehicle emissions test procedures which uses the dynamometer method for verifying new and in-used vehicles emissions level. Though test procedures employed uses the dynamometer, procedures tend to vary from one jurisdiction to another due to differences in emissions standards and regulations and different driving conditions under which these vehicles ply. Even within a country, procedures using the dynamometer method may vary according to vehicle technology, size, fuel used, and type of emissions to be measured. The introductions of stringent vehicle emissions standards and regulations have in most cases led to changes in emissions testing procedures.

Formulating a vehicle emissions measuring procedure for regulation and certification requires a huge amount of vehicular data and capital input, thus most countries have opted for a cheaper option by adopting one of the international system of vehicle emissions testing procedures i.e. the U.S., the European Union and that of the Japanese (Faiz, A., 1996).

In this chapter, a brief review of these three vehicle emissions measuring methods and how they are used in some measuring techniques will be highlighted. The procedures developed for vehicle emissions testing and certification by the U.S., the European Union, and the Japanese environmental authorities will also be illustrated in this chapter. Finally a brief description is given on how data sampled from these emission measuring methods are used to estimate vehicle emissions for a certain class of vehicle.

4.1 Dynamometer Method

One very common instrument used in determining vehicle emissions is a treadmill-like device known as the "Dynamometer". For light vehicles (weight less than 3,500kg) including motorcycles, emissions measurements are done by mounting the entire vehicle on a chassis dynamometer, where as for heavy vehicles (weight above 3,500kg) the engines are normally removed and bench tested using an engine dynamometer. The use of the dynamometer is to help stimulate a vehicle or engine operation under a laboratory condition while collecting the exhaust emissions in a Constant Volume Sample (CVS) system. Exhaust emissions concentration in the CVS are later measured by a Gas analyzer, usually expressed as the weight of pollutant per kilometer traveled (g/km) for light vehicles or as weight of pollutant per engine power (g/KWh) for heavy vehicles.

Dynamometer emissions measuring methods are often used in regulatory procedures to check compliance of new vehicles with emissions standards or to inspect in-use vehicles, it can also be used to develop emissions estimation models. Several procedures have been developed using the dynamometer method for measuring vehicle emissions for regulatory purposes, the most commonly used are the U.S. federal, the United Nations Economic Commission for Europe (ECE), and the Japanese procedures. Although these three emissions measuring procedures employ the use of dynamometer, procedures tend to differ based on the type of driving cycle (for light vehicles) or operating cycle (for heavy vehicles) used. A driving cycle normally composes of a unique profile of stops, starts, constant speed cruises, accelerations and deceleration and is typically characterized by an overall time-weighted average speed.

Different driving cycles are usually used to represent driving under different conditions. This tends to limit the dynamometer method, because emissions are not measured on actual driving roads, thus an important factor such as drivers' behaviors which affects the duration of events leading to high emissions enrichment operations are neglected in the measurement (Frey, H.C and Kim, K., 2005).

There are a variety of test cycles used for measuring vehicle emissions with the dynamometer, and they are generally categorized as either steady state or transient tests. Steady state tests involve running the vehicle or engine under constant conditions, such as constant vehicle speed or engine Revolution per Minute (RPM) and load. Many of the steady state tests involve more than one "mode", where each mode has constant conditions as part of the test schedule. Transient dynamometer test cycles involve dynamic variation in vehicle or engine operating conditions on a continuous basis during the course of a test. Even though transient tests can include portions during which vehicle or engine operations may reach a steady state, they also include portions during which vehicle or engine speed, vehicle or engine load or both the load and the speed are varied in order to mimic a real world driving or engine operations (Frey, H.C. and Kim, K., 2005).

The next section of this chapter will therefore provide an overview of some of these test cycles widely used in vehicle emission testing and regulations.

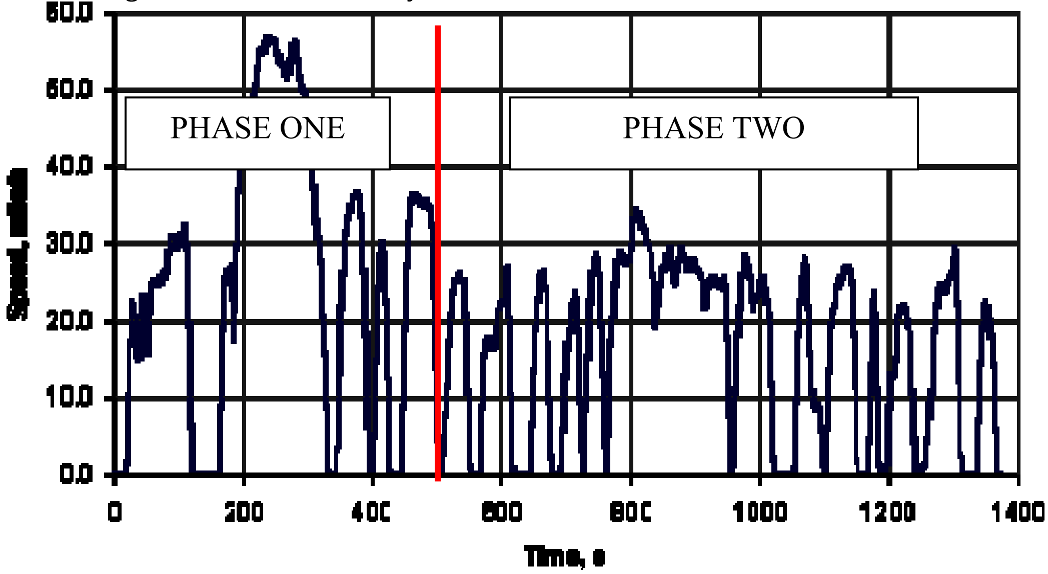
4.1.1 The U.S. Emissions Testing Cycles (Light Vehicles)

The first large-scale sampling of vehicle emissions in the US was for the purpose of certifying manufacturer compliance with new car emissions standards prescribed in the Clean Air Act Amendments (CAAA) of 1970 (Wenzel, T. et al, 2000). In pursuance of the CAAA the U.S. Environmental Protection Agency (EPA) established an elaborate testing protocol, called the Federal Test Procedure (FTP), so that all vehicles could be tested under identical preparation and driving conditions. The FTP tests were designed to test evaporative and exhaust emissions under several simulated situations and were intended to represent typical driving patterns in primarily urban areas. The driving cycle therefore used for the FTP was derived to simulate a vehicle operating over a road route in Los Angeles-California, believed to be representative of typical home to work commuting (Faiz, A., et al, 1996).

The first FTP cycle promulgated by the USEPA was the FTP-72 also called Urban Dynamometer Driving Schedule (UDDS) or LA-4 cycle, the same engine driving cycle is known in Sweden as A-10 or CVS (Constant Volume Sampler) cycle and in Australia as the ADR-27 (Australia Design Rules) cycle, the FTP-72 has been the standard driving cycle used for the certification of light vehicles including light duty trucks since the 1972 model year in the United States (Pidgeon, W.M. and Dobie, N., 1991).

The FTP-72 cycle simulates an urban trip of 7.46 mile (12.07 km) under two conditions: with a cold start designed to represent a morning start-up after a long soak (a period of non-use) and with a hot start after stopping the engine for 10 minutes while the engine is still hot. The two phase of the FTP-72 cycle can be represented on a continuous graph as shown in figure 4.1.1.

Figure 4.1.1 The FTP-72 Cycle



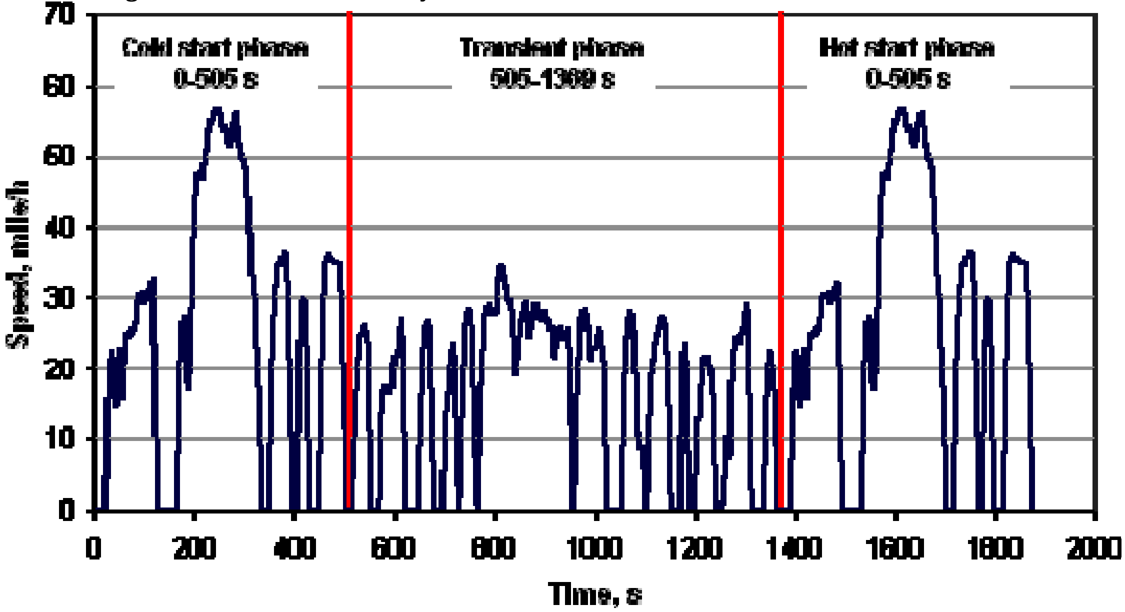
Source: DieselNet, 2006

The maximum speed for the FTP-72 cycle is obtained at 56.7 mph (91.2 km/h) as shown in the graph above, with an average speed of 19.6 mph (31.5 km/h). The first phase last for 505 seconds and covers a distance of 3.59 mile (5.78 km) while the second phase last for 864 seconds and covers a distance trip of 3.91 mile (6.29 km).

4.1.1.1 The US FTP-75 Cycle

Since the FTP-72 was designed mainly for vehicle models since 1972, the USEPA had to make some modification to the cycle in order to cover other models, this led to another cycle FTP-75. The FTP-75 also known in Australia as the ADR-27 cycle was derived from the FTP-72 cycle by adding a third phase of 505 seconds (Faiz, A., 1996), identical to the first phase of the FTP-72 cycle (figure 4.1.1) but with a hot start. The third phase therefore starts after the engine is stopped for another 10 minutes. Thus the entire FTP-75 cycle consist of the following segments; cold start phase, transient phase (hot stabilized) and finally the hot start phase as illustrated on figure 4.1.1.1.

Figure 4.1.1.1The FTP-75 Cycle



Source: DieselNet, 2006

The following are the basic parameters of the FTP-75 cycle: The maximum speed for the FTP-75 cycle is 56.7 mph (91.2 km/h) as shown in the graph in figure 4.1.1.1, with an average speed of 21.2 mph (34 km/h) and total trip distance of 11.04 mile (17.77 km) covered within 1874 seconds.

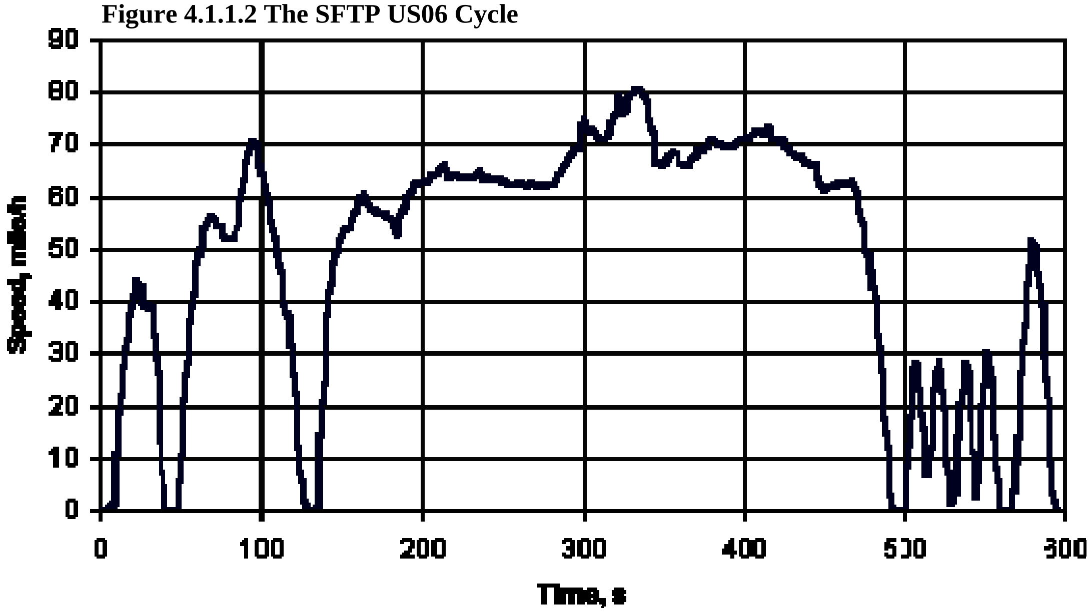
Subsequent to changes in modern driving patterns i.e. higher speeds and accelerations on the urban roads as pertained in the early 1970s when the FTP-75 was adopted, the FTP-75 cycle could no longer cover the full range of speeds and accelerations vehicles experience. Another failing of the FTP-75 is the poor simulation of air conditioner operation, where air conditioners are shut off during the test and instead a dynamometer load is increased to simulate the additional load on the engine due to the air conditioner compressor (Faiz, A. et al, 1996).

To address the shortcomings of the FTP-75, the USEPA developed two supplementary testing protocols the US06 and SC03 to augment the testing procedures for emission certification of light vehicles model year 2000 and after.

4.1.1.2 The SFTP US06 Cycle

The US06 Supplemental Federal Test Procedure (SFTP) was developed to address the shortcomings with the FTP-75 test cycle in the representation of aggressive, high speed and/or high acceleration driving behavior, rapid speed fluctuations, and driving behavior following startup. The SFTP US06 cycle can be represented graphical as shown in figure 4.1.1.2.

Figure 4.1.1.2 The SFTP US06 Cycle



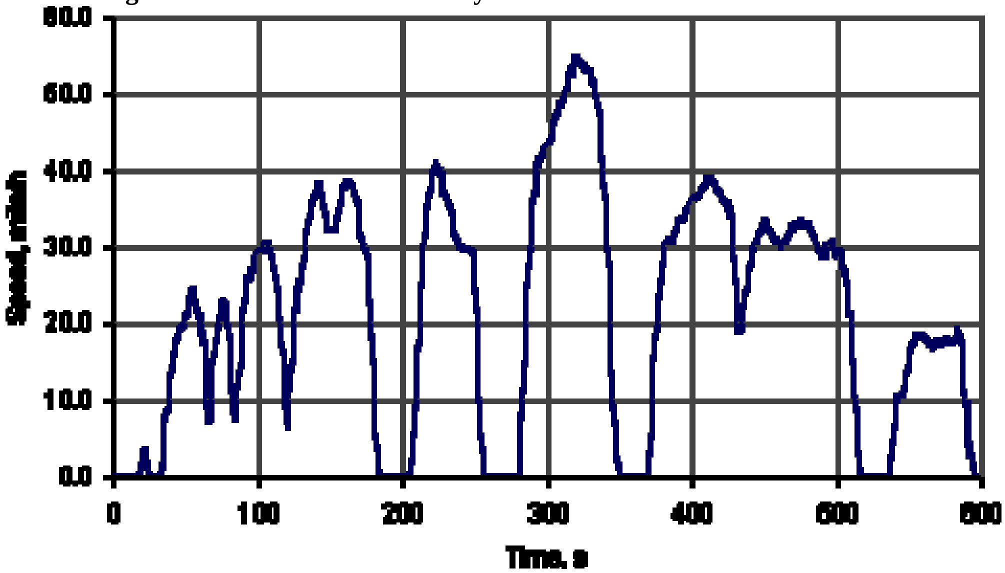
Source: DieselNet, 2006

Comparing the SFTP US06 cycle with the FTP-75 cycle, the SFTP US06 is a short cycle with a trip distance of 8.01 mile (12.8 km) covered within 596 seconds. However, speeds in the SFTP US06 are relatively higher to reflect the higher speeds and more aggressive driving patterns. The SFTP US-06 cycle was therefore designed to have a maximum speed of 80 mph (129.2 km/h) as can be shown in the cycle diagram in figure 4.1.1.2, and an average speed of 48.4 mph (77.9 km/h)

4.1.1.3 The SFTP SC03 Cycle

The SC03 Supplemental Federal Test Procedure (SFTP) was introduced by the USEPA to represent the engine load and test emissions associated with the use of air conditioning units in vehicles certified over the FTP-75 cycle. The SFTP SC03 cycle is represented graphically as shown in figure 4.1.1.3.

Figure 4.1.1.3 The SFTP SC03 Cycle



Source: DieselNet, 2006

The SFTP SC03 cycle covers a trip distance of 3.6mile (5.8 km) within 596 seconds, with an average speed of 21.6 mph (34.8 km/h) and a maximum speed of speed of 54.8 mph (88.2 km/h).

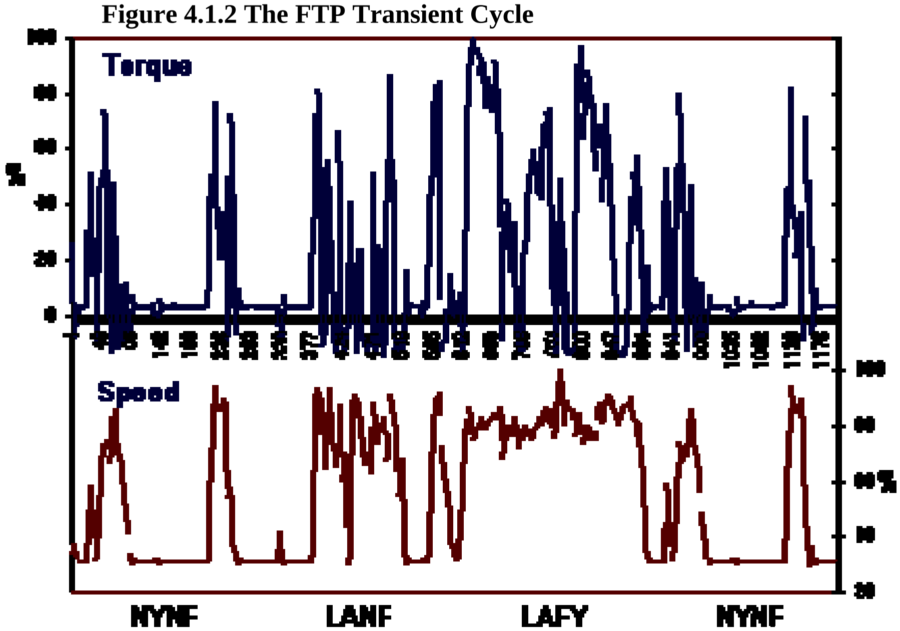
4.1.2 The U.S Emissions Testing Cycles (Heavy Duty Vehicles)

The U.S. exhaust emissions testing procedures for heavy duty vehicles (with weight above 3,500 kg) for emissions standard certification mostly involves measuring emissions from the engine alone (removed from the vehicle) while operating over a specified cycle on an engine dynamometer. The testing procedures involve transient changes in speed and load to mimic actual road operations, emissions from the test are often express as mass of pollutant per engine power (per unit work output) rather than emissions per vehicle kilometer. This is because of the wide range of sizes and applications in heavy duty vehicles, each of which would otherwise have to be tested individually on the dynamometer, thus regulations based on work output allows one set of standards to be applied to engines used in a broad range of vehicles.

The FTP (Federal Test Procedure) heavy duty transient cycle, as at 2007 is still being used for emissions certification testing of heavy duty on road engines in the USA. The USEPA developed the transient test to take into account the variety of heavy duty truck and buses in American cities, including traffic in and around the cities on roads and expressways. The FTP transient test was based on the Urban Dynamometer Drive Schedule (UDDS) chassis dynamometer driving cycle (this will be further discussed in the next section of this chapter), a test cycle used for testing heavy duty vehicles for inspection and maintenance program in the U.S.

The transient cycle as illustrated on the graph in figure 4.1.2 consists of four phases: the first is a NYNF (New York Non Freeway) phase typical of light urban traffic with frequent stops and starts, the second is LANF (Los Angeles Non Freeway) phase typical of crowded urban traffic with few stops, the third is a LANF (Los Angeles Freeway) phase simulating crowded expressway traffic in Los Angeles, and the fourth phase repeats the first NYNF phase.

Figure 4.1.2 The FTP Transient Cycle



Source: DieselNet, 2006

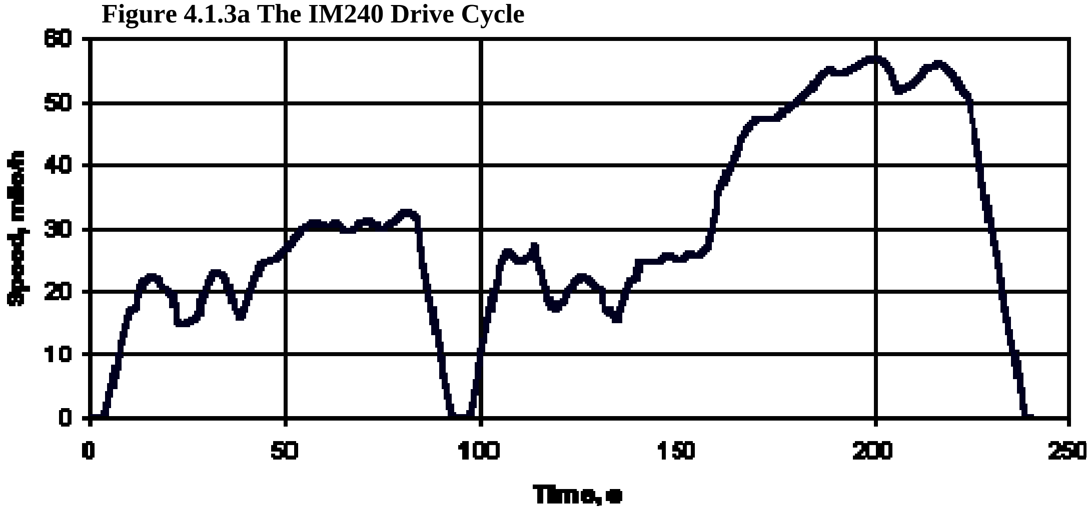
The FTP transient test procedure comprises of a cold start after the vehicle has been parked overnight, followed by idling, acceleration and deceleration phases, and a wide variety of different speeds and loads sequenced to simulate the running of the vehicle that corresponds to the engine being tested. There are few stabilized running conditions, and the average load factor is about 20% to 25% of the maximum horse power available at a given speed. The cycle is carried out twice and the second repetition is made with a warm start after a stop of 1200 seconds (20 minutes) on completion of the first cycle. The variation of normalized speed and torque with time is shown in figure 4.1.2.

4.1.3 The US Inspection and Maintenance (I/M) Testing Cycles

The testing procedures adopted by the USEPA for Inspection and Maintenance (I/M) programs in the US are quite different from the FTP which is used for vehicle emissions certification testing. The most common emissions test in the US I/M program is a measurement of Hydrocarbon and Carbon monoxide concentrations in the exhaust while the vehicle is idling (no engine or transient load). These measurements do not require a dynamometer or other expensive equipment. The idle test was originally developed for vehicles with little or no emissions control, such as vehicles still using old technologies (e.g. carburetors), light trucks, and most heavy duty gasoline vehicles (Faiz, A. et al, 1996). The idling test is characterized with one major flaw, the inability to measure NO_x emissions which requires loaded mode vehicle operation. To address this flaw of the idling test and meet the Inspection and Maintenance program mandate of the 1990 US Clean Air Amendment Act, the USEPA instituted another testing procedure the IM240 for testing in-use light vehicles.

The IM240 is a chassis dynamometer schedule test which uses 240 seconds of the FTP driving schedule to measure hot stabilized emissions during transient and loaded mode vehicle operation. In the IM240 test, exhaust emissions are run directly through gas analyzers and can be quantified on a test composite or a second by second basis. It is a short 240 second test representing a 1.96 mile (3.1 km) route with an average speed of 29.4 mph (47.3 km/h) and a maximum speed of 56.7 mph (91.2 km/h) as shown on the IM240 drive cycle in figure 4.1.3a.

Figure 4.1.3a The IM240 Drive Cycle



Source: DieselNet, 2006

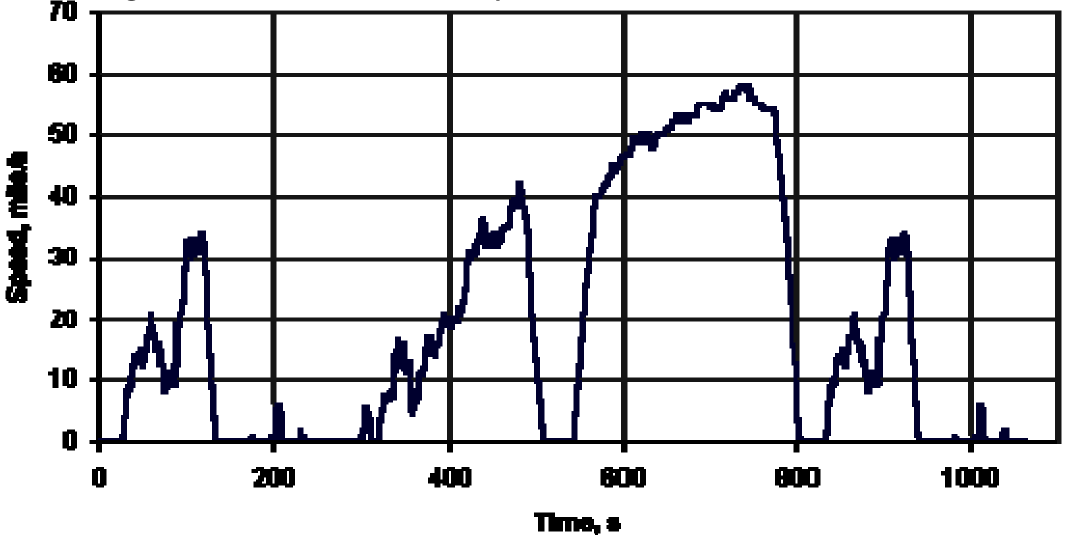
Many states in the U.S resisted the use of the IM240 testing, citing the length of the test and the inconvenience to motorists of driving further to a small number of centralized test stations. The California Bureau of Automotive Repair (BAR) therefore developed an alternative test method to the IM240 called the Acceleration Simulation Mode (ASM) test. The ASM test also uses the chassis dynamometer but operates on one or more distinct operating modes, these modes are defined as a certain vehicle load at a given speed. For instance, the California I/M program gives each vehicle a 2525, i.e. 25% of the maximum vehicle load encountered on the FTP at 25 miles per hour, and 5015, 50% of the maximum vehicle load encountered on the FTP at 15 miles per hour. The ASM test also measures exhaust concentration using a tailpipe probe, just as in the idle test, but unlike the idle test the ASM test measurement is done under load. However, the ASM does not measure emissions under varying loads and speeds, as does the IM240.

The USEPA has now relaxed its requirement of centralized IM240 testing and has allowed states to use alternative test methods such as the ASM if the states could demonstrate that their alternative method would achieve the same reduction in emissions as the IM240.

For heavy-duty vehicles, the proper approach for testing emission for I/M program is to test only the engine with an engine dynamometer, however because of the difficulties involve in dismantling these engines for test, the engine dynamometer approach has been limited to only emissions standards certification test. Accordingly, emissions from in-service heavy duty vehicles are usually measured with the whole vehicle operating on a chassis dynamometer. A number of test cycles have been developed for this purpose, one such test cycle developed by the USEPA is a chassis version of the FTP transient test cycle (earlier discussed in chapter 4.2.1), known as the Heavy Duty Urban Dynamometer Drive Schedule (HD UDDS).

The HD UDDS cycle has the following basic parameters, the cycle covers a trip distance of 5.55 mile (8.9 km) within a time of 1060 seconds with an average speed of 18.86 mph (30.4 km/h) and a maximum speed of 58 mph (93.3km/h) as depicted in the HD UDDS cycle shown in figure 4.1.3b below.

Figure 4.1.3b The US HD UDDS Cycle



Source: DieselNet, 2006

Some other in-used heavy duty vehicle testing cycles been used in some states in the US include:

- New York Composite (NY Comp) cycle, a cycle that depicts actual driving patterns in New York City.
- New York Bus (NYBus) cycle, a cycle depicting actual observed driving patterns of transit buses in New York City.
- Manhattan Bus Cycle, a cycle developed based on actual observed driving patterns of urban transit buses in the Manhattan core of New York City.
- Orange County Bus Cycle, a cycle based on the driving patterns of urban transit buses in the Los Angeles-California area.

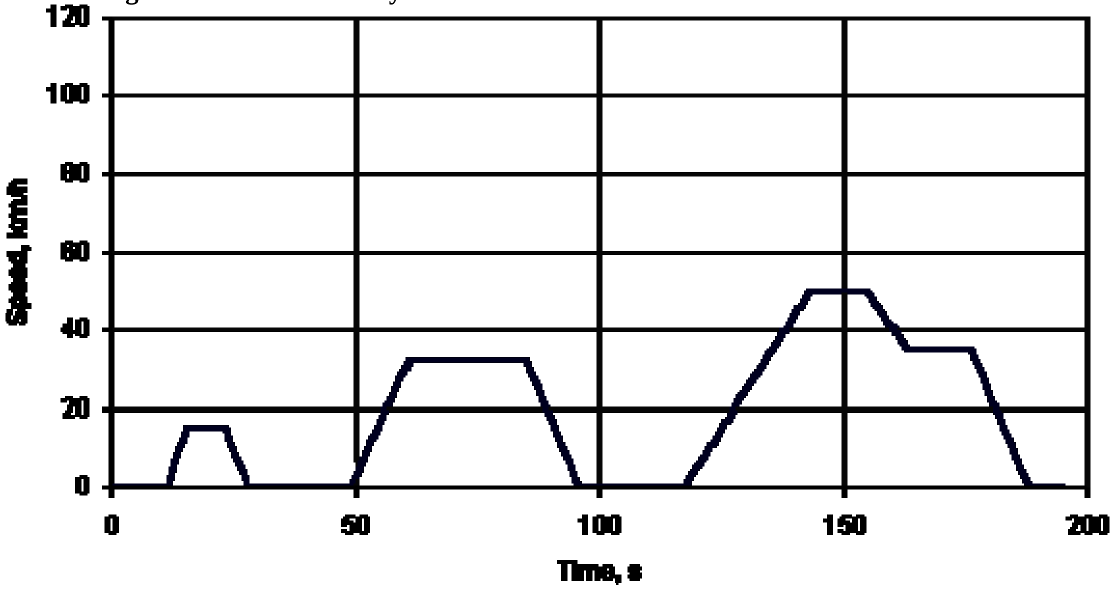
4.1.4 UNECE Emissions Testing Cycles (Light Vehicles)

The European vehicle emissions testing procedures was established by the United Nations Economic Commission for Europe (UNECE). These test procedures are widely used in the European Union, and also in most eastern European countries, China and India (Faiz, A. et al, 1996). The UNECE vehicle emissions testing procedures are quite similar to the US testing procedures, i.e. measuring vehicle emissions by driving the vehicle on a chassis dynamometer (for light vehicles) or by operating an engine on a bench using an engine dynamometer (Heavy vehicles). The main difference between the procedures is the driving cycle (for light vehicles) or operating cycle (for heavy vehicles).

The emissions test procedures for European passenger cars and light duty vehicles was initially defined by the United Nations Economic Commission for Europe regulation 15 and later replaced with regulation 83. The procedure for testing compose of four different ECE Urban Driving Cycles, stimulating city driving, and one Extra Urban Driving Cycle (EUDC), simulating highway driving conditions. These combined chassis dynamometer test are used for emissions testing for vehicle I/M programs and certification in Europe.

Before the test, the vehicle is allowed to soak for at least six hours at a test temperature of 20-30^{o}C, it is then started and allowed to idle for 40s. The test then starts by mounting the vehicle on the chassis dynamometer and subjecting it to an ECE drive cycle as shown in figure 4.1.4a. This is repeated four times without any interruption, and then followed by one EUDC cycle (shown in figure 4.1.4b) test. Emissions are sampled at the end of each cycle using the "Constant Volume Sampling" system, analyzed and expressed in g/km for each of the pollutants.

Figure 4.1.4a The ECE Cycle

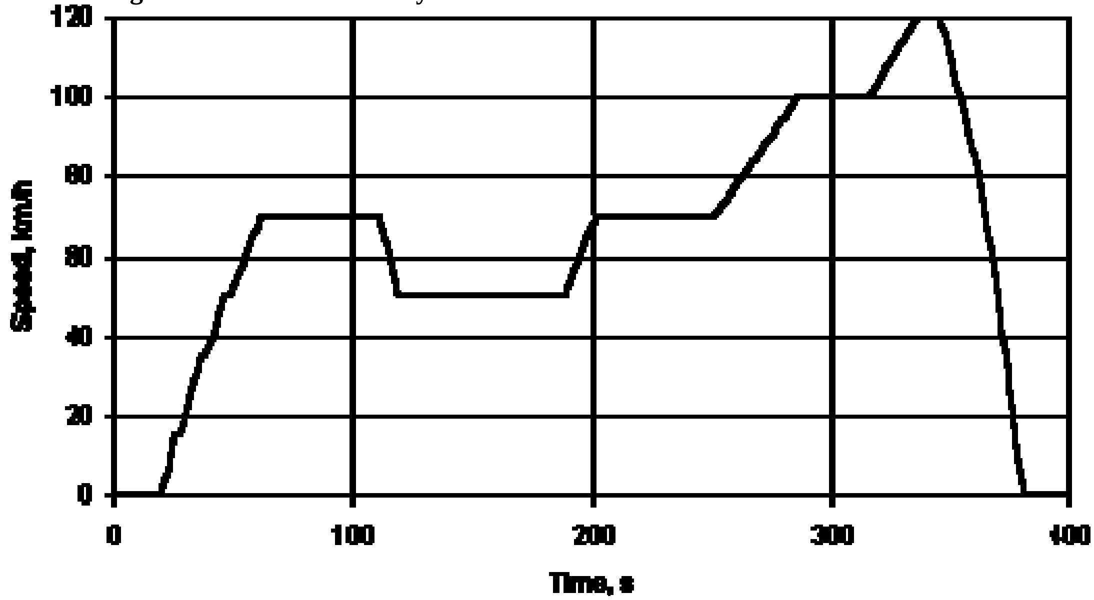


Source: DieselNet, 2006

The ECE cycle was developed to simulate a city driving conditions, e.g. in Paris or Rome. It is characterized by low vehicle speed, low engine load, and low exhaust gas temperature. This cycle therefore represents Type I test, as defined by the ECE regulation 83 emissions procedure i.e. test procedure for measuring exhaust emissions after a cold start. The ECE cycle has the following characteristics: a trip distance of 1.013 km covered within a period of 195 seconds with a maximum speed of 50 km/h.

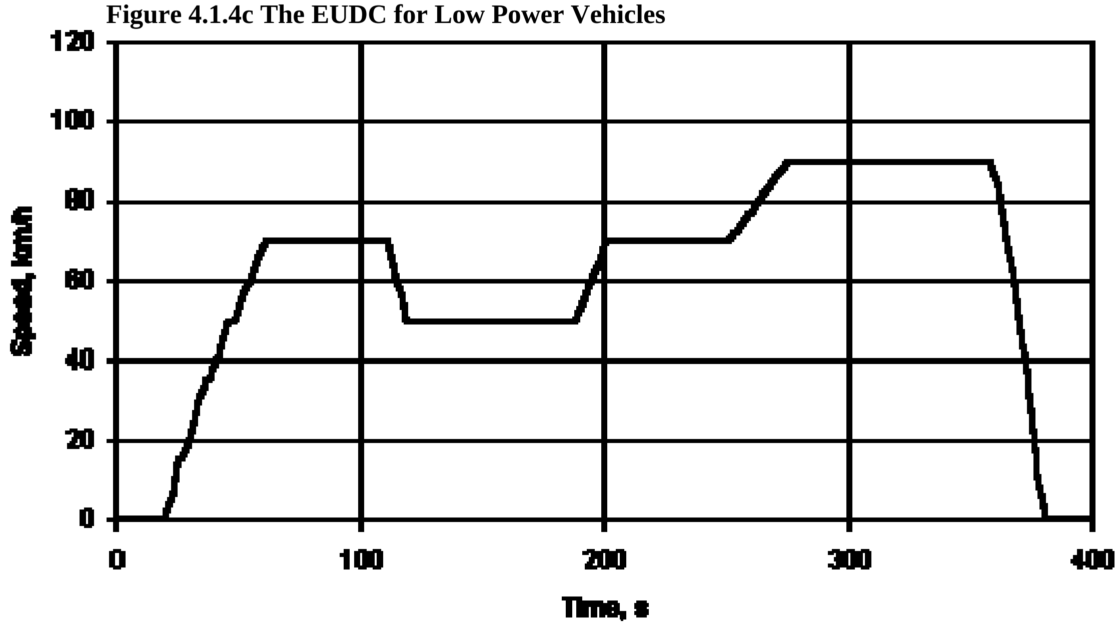
Also defined in United Nations ECE regulation 83, Type II test is to comprise a warmed-up idle exhaust Carbon monoxide test conducted immediately after the fourth cycle of the Type I test. Therefore EUDC cycle was included in the test procedure to account for more aggressive, high speed driving modes. From the EUDC cycle shown in figure 4.1.3b the maximum speed is at 120km/h, which is quite high for most low powered vehicles and hence cannot be used for such vehicles. Therefore, an alternative EUDC cycle was developed purposely for testing low powered vehicle with a maximum speed limited to 90 km/h (shown in figure 4.1.4c)

Figure 4.1.4b The EUDC Cycle



Source: DieselNet, 2006

Figure 4.1.4c The EUDC for Low Power Vehicles



Source: DieselNet, 2006

In order for cold start emissions to reflect in the testing procedures for light vehicles the UNECE introduced a cold start version of ECE+EUDC cycle test, known as the New European Drive Cycle (NEDC). Basically, the NEDC is the same as the ECE+EUDC, except that in the case of the NEDC the idling period is eliminated, i.e. emissions sampling begins at the start of the vehicle engine.

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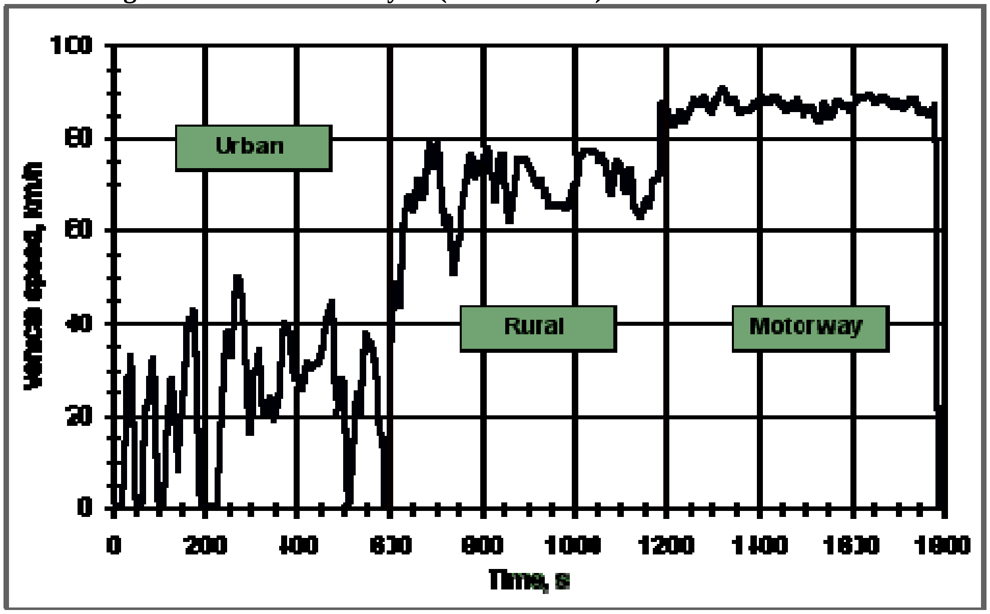
4.1.5 UN ECE Emissions Testing Cycles (Heavy Vehicles)

The emissions testing procedures used for European heavy vehicles including buses were defined by UN ECE regulation 49, which has led to a number of test cycles generated for use in emissions testing and certification over the years. Test cycles have been adjusted or modified to address existing emissions standards in force. Before the year 2000, an engine dynamometer test cycle ECE R49 was in use for heavy duty engine emissions certification through the Euro II emissions standard. Effective October 2000, when the Euro III emissions standard came into effect, the R49 cycle was then replaced with another steady state cycle, European Stationary Cycle (ESC).

With the insertion of Euro IV emissions standard which took effect from the year 2005, the emissions testing procedure has been strengthened by two additional cycles, the European Transient Cycle (ETC) to complement the ESC cycle for emissions certification of heavy duty diesel engines in Europe, and the European Load Response (ELR) used for opacity determination during emissions certification of heavy duty diesel vehicles.

The ETC cycle developed by the FIGE Institute in Aachen (Germany), has three parts representing the three different driving modes i.e. urban, rural and motorway as shown in figure 4.1.5a. The duration of the entire cycle is 1800 seconds, i.e. 600 seconds for each driving mode. The first part of the ETC cycle represents urban driving which involves frequent starts, stops and idling with a maximum speed of 50 km/h, the second part which represents rural driving mode involves a steep acceleration segment with an average speed of 72 km/h and the third part represent a motorway or highway driving with an average speed of 88 km/h.

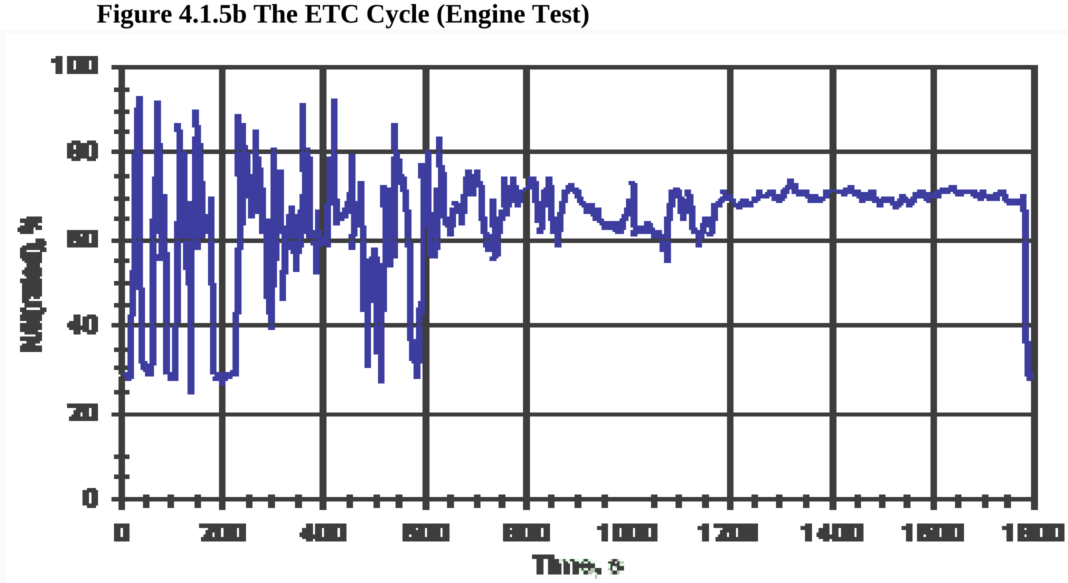
Figure 4.1.5a The ETC Cycle (Chassis Test)



Source: DieselNet, 2006

The ETC cycle was developed in two variant, one variant for chassis dynamometer testing (shown in figure 4.1.5a) and the other for engine dynamometer testing (shown in figure 4.1.5b).

Figure 4.1.5b The ETC Cycle (Engine Test)



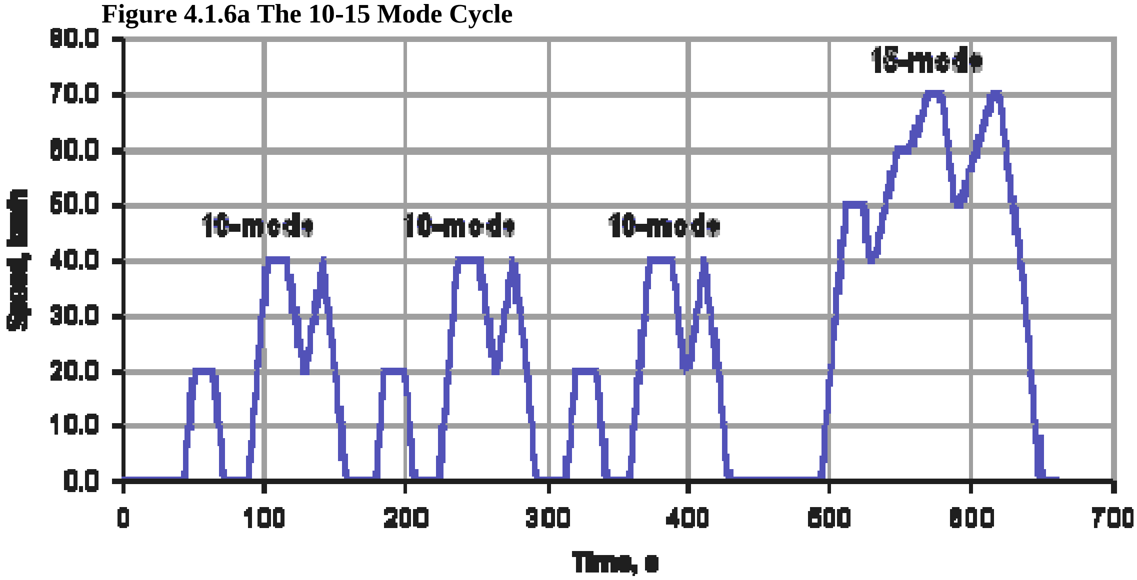
Source: DieselNet, 2006

4.1.6 Japanese Emissions Test Cycle (Light Vehicles)

The early Japanese emissions testing procedures were quite similar to the European stationary or steady state test procedures R49 or ESC, where emissions were measured at a number of specified steady state conditions known as modes, and combined by assigning weight to the various modes. Until 1991, the main Japanese emissions testing procedure for light vehicles (with weight less than 3,500 kg) was a 10-mode driving cycle, which was designed to simulate congested urban driving conditions. The 10-mode has since been replaced with the 10-15 mode cycle, a slight modification of the 10-mode cycle by an additional 15 mode segment of a maximum speed of 70 km/h as compared to 40 km/h in the 10-mode cycle.

The entire 10-15 mode cycle includes a sequence of a 15 minute warm-up at 60 km/h, an idle test, a 5 minute warm-up at 60 km/h, and one 15-mode segment, followed by three repetitions of 10-mode segments and one 15-mode segment as shown in figure 4.1.6a. Sampling of emissions is normally carried out in the last four segments i.e. 3x10-mode+1x15-mode)

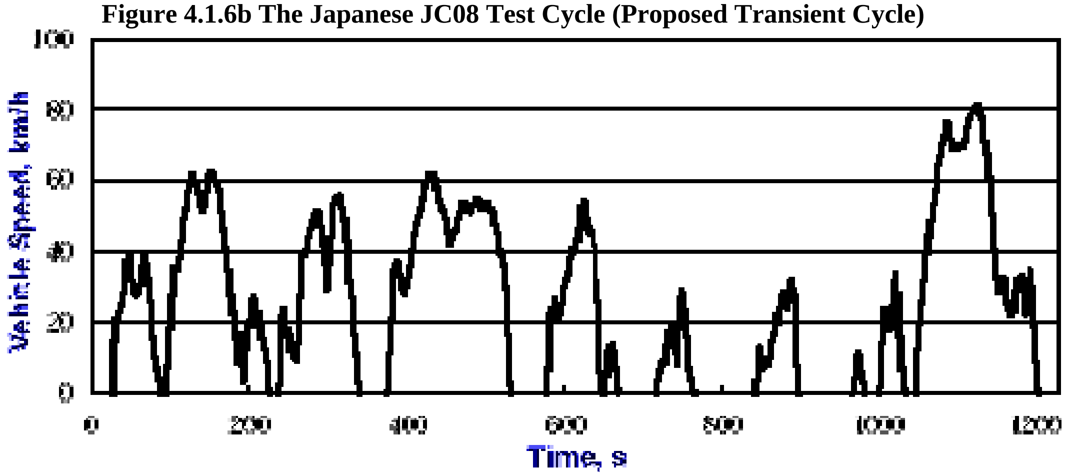
Figure 4.1.6a The 10-15 Mode Cycle



Source: DieselNet, 2006

A new test cycle JC08 shown in figure 4.1.6b has been proposed for light duty vehicles and is expected to be fully phased in by the year 2011

Figure 4.1.6b The Japanese JC08 Test Cycle (Proposed Transient Cycle)



Source: DieselNet, 2006

4.1.7 Japanese Emissions Testing Cycle (Heavy Vehicles)

Just like the light weight vehicle emissions testing discussed in chapter 3.1.6, the Japanese heavy duty vehicle emissions testing has undergone a series of changes over the years. One such early test procedure which was in used for heavy duty vehicles in Japan was the two 6-mode cycle, used for testing vehicles weighing more than 2,500 kg or vehicles having a sitting capacity more than 10 passengers. The 6-mode test procedure measures emissions at each mode and averaged over the cycle using a set of weighting factors: one set for diesel engines and another set for gasoline and Liquefied Petroleum Gas. The 6-mode was later replaced with another engine test procedure, the 13-mode.

The 13-mode includes 13 stabilized engine modes, unlike the 6-mode test procedure where weight factors were the only difference between the diesel and gasoline/LPG engine test, the 13 mode has two different versions for the diesel test and the gasoline/LPG test (see table 4.1.7a and table4.1.7b). However, both test cycle versions are characterized by low speeds, low engine loads, and low exhaust temperatures.

Table 4.1.7a The Diesel 13-Mode Cycle

Mode	Speed	Load	Weighting Factor
	% of Nominal	%	
1	idle	-	0.410/2
2	40	20	0.037
3	40	40	0.027
4	Idle	-	0.410/2
5	60	20	0.029
6	60	40	0.064
7	80	40	0.041
8	80	60	0.032
9	60	60	0.077
10	60	80	0.055
11	60	95	0.049
12	80	80	0.037
13	60	5	0.142

Source: DieselNet, 2006

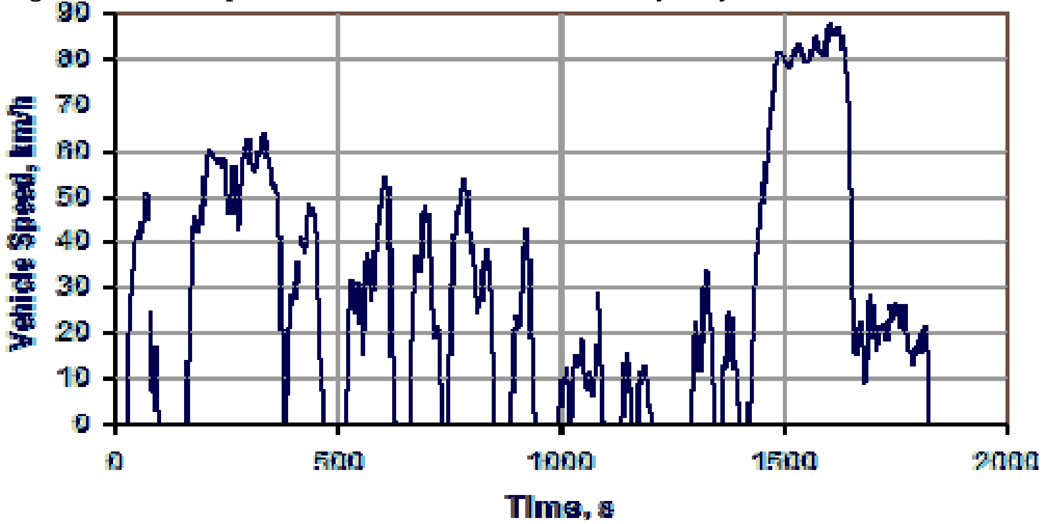
Table 4.1.7b The Gasoline/LPG 13-Mode Cycle

Mode	Speed	Load	Weighting Factor
	% of nominal	%	
1	Idle	-	0.314/2
2	40	40	0.036
3	40	60	0.039
4	Idle	-	0.314/2
5	60	20	0.088
6	60	40	0.117
7	80	40	0.058
8	80	60	0.028
9	60	60	0.066
10	60	80	0.034
11	60	95	0.028
12	40	20	0.096
13	40	20*	0.096

Source: DieselNet, 2006

With the insertion of the Japanese 2005 emission standards also led to the introduction of another emission test cycle the JE05 by the Japan environmental authorities. Unlike the previous 6- and 13-mode cycles, the JE05 test cycle is a transient driving schedule cycle and it is used for emission testing for both diesel and gasoline vehicles. The JE05 test is defined through vehicle speed verse time points as shown in figure 4.1.6.

Figure 4.1.7 The Japanese New Transient Mode for Heavy Duty Vehicles



Source: DieselNet, 2006

For the JE05 engine dynamometer testing, computer programs are used to generate the torque-speed data for both gasoline and diesel engines.

4.1.8 Testing Procedure Used For Evaporative Emissions

Unlike exhaust emissions which are easy to sample and measure, evaporative emissions are complex to handle and in most cases are neglected in computations. Testing procedures therefore are limited to some evaporative emissions and mainly on vehicles using gasoline or other volatile fuels but not diesel run vehicles. Evaporative emissions testing are normally done by driving the vehicle on a chassis dynamometer in an enclosure, the type of driving cycle used for a test depends on the size and type of vehicle, the jurisdiction under which the test is done, and the purpose for the test.

The early method used for measuring evaporative emissions was the "Carbon trap" methodology. The "Carbon trap" method utilizes activated Carbon traps connected to the fuel system at selected locations where vapor are likely to escape. The traps adsorb vapor emitted at these locations, and the change in weight of Carbon traps thus, represents the evaporated emissions. The test is normally carried out under different engine conditions to determine the various evaporative emissions. Hence emissions are measured during a one-hour diurnal test and over a running loss test designed to represent evaporative losses during urban driving and a one-hour hot soak test following engine shut-off. The sum of these measurements eventually becomes the total evaporative emissions rate.

The "Carbon trap" method, however, does not accurately measure evaporative emissions from all possible sources, so a more accurate methodology was introduced: The Sealed Housing Evaporative Determination (SHED), which captures all evaporative vapor emitted from the vehicle in a special enclosure test cell. The tests are normally in two parts: a diurnal test and hot soak test (Faiz, A., et al, 1996).

The diurnal tests is conducted prior to the exhaust emissions test and consist of first draining and filling the fuel tank (about 40% full) with initial temperature at 15.6^{o}C (60F). The vehicle is then placed in the special test enclosure and the temperature of the fuel raise to 28.9^{o}C (84F) within a period of one hour (A heat blanket is placed on the outside of the fuel tank to boast the temperature increase).

The hot soak portion of the evaporative emissions from the test measures emissions from the vehicle for one hour following the exhaust emissions test. The vehicle is then moved from the dynamometer into the special test enclosure as soon as the exhaust emissions test is completed.

The total evaporative emissions is then evaluated as the sum of diurnal and hot soak evaporative emissions in total grams per test. Individual diurnal and hot soak test results can also be used to translate from grams per test into grams per kilometer. The formula for the conversion is:

$$\text{Grams/Kilometer} = \frac{\text{Diurnal grams/test} + \text{N x (Hot Soak grams/test)}}{\text{Average km driven/day}}$$

N is the average number of trips per day. This conversion makes it possible to compute the total evaporative emission over any distance travelled.

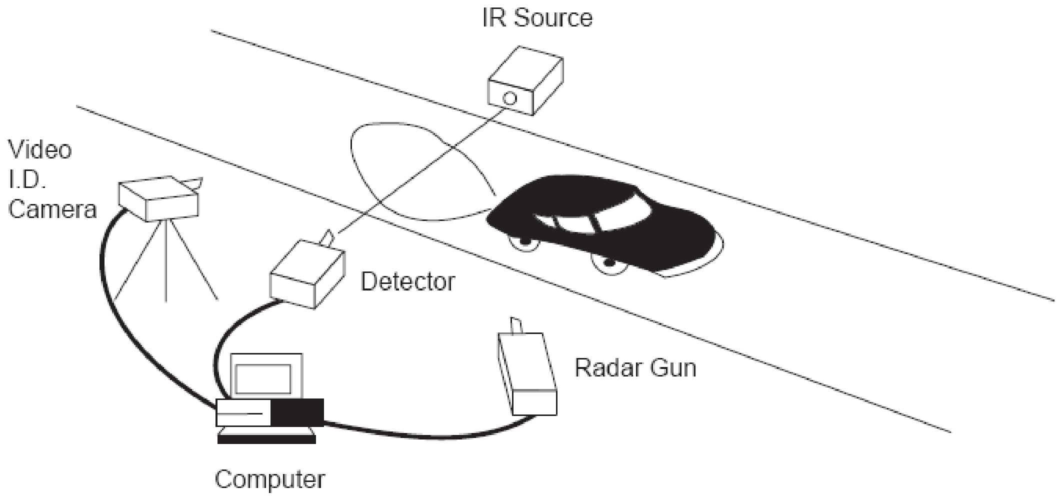
Evaporative emissions arising from refueling are tested by measuring concentrations of volatile organic compounds in the vapors vented from gasoline tanks during the refueling process and observing spillage frequency and volume.

Until 1991, The European Union testing procedures did not include evaporative emissions measurements, as evaporative Hydrocarbon emissions were not regulated. This was remedied by the consolidated emissions directive contained in directive 91/441/EEC issued by the Council of ministers of European Community in June 1991 (EU Official Journal L242, 1991). The directive 91/441/EEC which was an amendment to the directive 70/220/EEC, established evaporative emission limits based on tests similar to the SHED test procedure (Faiz, A., et al, 1996).

4.2 Remote Sensing Method

The search for a better way to measure on-road vehicle emissions data which gives a true representation of actual driving conditions led to the development of a technology in 1987 by the University of Denver (Frey, H.C. and Eichenberger, D.A., 1997), which remotely measures vehicle emissions on the road. The technology involves the use of an infra-red source shown in figure 4.2 which continuously directs an infrared beam directly across a lane of traffic to a detector. A vehicle passing through the infra-red beam triggers the receiver to collect transmission data on the exhaust plume of the passing vehicle. A video camera placed alongside the detector records each vehicle's license plate information, which is stored together with emissions data in a computer. The license number of the vehicle can be used to retrieve information such as the age, type and perhaps the mileage of the vehicle from vehicle registration records. The primary use of the remote sensing technology was to facilitate vehicle Inspection and Maintenance programs, by identifying high emitting vehicles on the road so they can be targeted for testing and repairs.

Figure 4.2 Schematic Diagram of the Remote Sensing Technology



Source: U.S.EPA 1995; Faiz, A., et al 1996

The first generation remote sensing emissions measuring method used an infra-red source and a series of filters to isolate specific wavelengths that are absorbed by the CO, HC and CO_2 in the vehicle exhaust (Bishop, G. A. et al, 1989; Zhang, Y. et al, 1993; Wenzel, T. et al, 2000). However, modern remote sensing emission measurement uses a computer to analyze the data and determines the effective percentage of each pollutant, including NO and other emissions gases such as ammonia (Zhang,Y et al, 1996; Jimenez, J.L et al, 1999b; Popp, P.J el at, 1997; Wenzel, T. et al, 2000).

The remote sensing emission measuring technology measures emissions in terms of pollutant ratios such as CO/CO_2 and HC/CO_2, but cannot measure absolute concentrations because the amount of exhaust dilution is not known. However, since more than 90% of fuel Carbon atoms are emitted as CO, HC, or CO_2, the emissions ratios can be combined with known fuel properties (example fuel carbon content) to calculate the mass of each pollutant emitted per gallon of fuel burned (Bishop, G.A et al, 1989; Zhang, Y. et al, 1993; Wenzel, T. et al, 2000).

The advantage of the remote sensing method is that it measures emissions from a large number of vehicles quickly and cheaply. However, it has some technical limitations, the problem of sampling across multiple lanes of traffic can create conspicuous structures which can cause a safety hazard, and also the method has some degree of measurements errors. Another problem associated with the use of the remote sense emissions measuring technology is that the technology is weather sensitive, and it is most effective on dry pavement. Rain, snow or very wet pavement could cause scattering of the infra-red beam, which can lead to error readings (Rouphail, N.M. et al, 2000).

4.3 On-Board System Method

The idea to obtain emissions data that is directly representative of actual traffic conditions and driving patterns, led to the development and test of a number of on-board systems. One such technology was developed by the Flemish Institute of Technological Research (Faiz, A. et al, 1996), the technology comprised a miniature Constant Volume Sampler (CVS), gas analyzers, a sensor and measuring system for fuel consumption, an optical sensor to measure vehicle speed and distance traveled and a data processor on a laptop computer for online collection, with real-time processing and evaluation of data. It was designed to measure exhaust emissions from any Carbon based fueled vehicle. Pollutants normally covered include Carbon monoxide, Hydrocarbons, and Nitrogen oxides, and each pollutant is expressed as grams per second or grams per kilometer.

Another on-board system technology which has the potential to contribute important information about vehicle emissions is the on-board diagnostic (OBD) computer system, which has been installed in every vehicle in the U.S year model after 1995 (Wenzel,T. et al, 2000). This OBD technology does not measure exhaust emissions directly, it rather predicts when exhaust emissions are likely to exceed standards, based on extensive monitoring of engine and emissions control parameters.

The OBD systems were designed to monitor over 50 parameters of vehicle and engine operations. The OBD works on this principle: if the on-board computer detects malfunctions or operations that would lead to exhaust emissions greater than 1.5 times the certification standard, the system stores a Diagnostic Trouble Code (DTC) or "fault" code corresponding to the malfunction in the computer and turns on a Malfunction Indication Light (MIL) on the dashboard to alert the driver.

Regulations requiring on-board diagnostic systems in vehicles have been in effect in California for some time and have been adopted and strengthened by the U.S EPA over the years, listed regulations requirement have shifted from OBD I to OBD II and now OBD III (Wikipedia Encyclopedia, 2006). In Europe, the use of OBD systems in vehicles was enforced after the introduction of the Euro three vehicle emission standards (ADB 2003). The intent of the OBD regulations is twofold: to encourage vehicle owners to bring their vehicle for inspection and repair as soon as problems are detected and to record engine parameters to assist mechanics in diagnosing and repairing malfunctions. Also, the regulations have encouraged manufacturers to design better and more durable engine and emissions controls, including more extensive monitoring and backup systems.

4.4 Vehicle Emissions Estimation

One application of the vehicle emissions measurement methods (i.e. the dynamometer, remote sensing, and the on-board system) discussed earlier in this chapter is the use of the data obtained from the methods to develop or update computer models that estimates vehicle emissions rates. Computer emissions models are normally developed by using thousands of emissions tests performed on both new and used vehicles. In addition to standard testing conditions such as in the Federal Testing Procedures or New European Drive Cycle, many of these vehicles are subjected to varying temperatures, grades of fuel under different driving cycles. Data compiled from these tests are then used to generate emissions factors for vehicles at varying emissions control levels, ranging from no control to projections of future low-emissions vehicle fleet.

Vehicle emissions factors also known in some literature as "Base Emissions Rates" are estimates of vehicle emissions produced per kilometer or mile traveled by a vehicle of a given class. Estimates of vehicle emissions are then obtained by multiplying the distance traveled by a given class of vehicle by an appropriate emission factor (Faiz, A., et al, 1996). Because of the many variables that influence vehicle emissions, computer models have been developed using emissions factors to estimate vehicle emissions under any combination of conditions such as speed, ambient temperature, vehicle technology, and other variables. (Lenaers, G., 1994). Thus emissions estimates may be combined in various ways to give for example emissions from all vehicles of a certain type, all traffic in a defined area or all traffic on a particular type of road.

4.4.1 Calculation Principle Used in Vehicle Emissions Estimation

Generally, total emissions from road vehicle can be envisaged as the sum of exhaust emissions (cold start emission and hot emissions) and evaporative emissions. Thus this can be represented mathematically as:

$$E=E_{hot}+E_{cold}+E_{evaporative}+E_{abrasion,dust,\ \&\ resuspension}$$

Where E is the total emissions

E_{hot} is the total emissions when the engine is hot

E_{cold} is the total emissions when the engine is cold

$E_{evaporative}$ is the total emissions by evaporation.

$E_{abrasion,dust,\ \&\ resuspension}$ is the total emissions in the form of abrasion, dust and resuspensions

Each of these contributors to the total emissions also, depends on an emission factor and one or more parameters relating to the operation of the vehicle, so that in general

$E_x = e_x\ a$

Where E_x is one of the contributors of total emissions

e_x is an activity related emissions factor

a is the amount of traffic activity relevant to this type of emission.

The parameters e_x and a are themselves functions of other variables, for example in the case of hot exhaust emissions, the activity related emission factor, e_{hot} is expressed primarily as a function of the average speed of the vehicle modification factors (which also depends on other variables). This therefore allows corrections to be made for features such as the road gradient or the load carried by a vehicle

In the case of cold start emissions, which occur during the early part of a journey, the emissions values are expressed as an amount produced per trip, and not over the total distance traveled. The emissions factor, e_{cold} is therefore calculated as a function of the average vehicle speed, the engine temperature, the length of the trip and the length of the cold part of the trip. For evaporative emissions, there are a number of different emissions factors, $e_{evaporative}$, depending on the type of evaporative emission. Generally, these factors are a function of the ambient temperature and the fuel volatility. Similarly, a number of activity data are also needed, including total distance traveled and number of trips according to the temperature of the engine at the end of the trip.

These principles apply, with exceptions, to some pollutants, and vehicle types, because different classes of vehicle behave differently and relationships between emissions and operating characteristics vary for each pollutant. An estimate of emissions from a mixed traffic must therefore be computed as a summation of emissions from each homogeneous vehicle class in the traffic, and if the computation applies to an area where there are different roads with different traffic behavior, this must also be taken into account and done separately for each pollutant.

4.5 Concluding Remarks

The role of vehicle emissions testing can play a vital role in a country’s goal to mitigate Greenhouse Gas emissions, by ensuring a reasonable level of maintenance and proper functioning of emissions control devices installed in vehicles. Considering the variation in vehicle emissions due to the difference in operating conditions, a consistent and replicable test procedure is required if a country’s emissions regulations are to be enforceable.

Thus, to ensure improvement in emissions, vehicle testing procedures should be representative of in-used conditions. For a country, such as Ghana, where vehicles used are imported from the US, Europe and Asia will require relevant information, such as the testing procedures discussed in this chapter, to formulate a comprehensive Inspection and Maintenance (I/M) program. For example, vehicle testing procedures in Ghana can be separated based on the model year, mode of vehicle with more stringent inspections on motorbikes, and commercial vehicles such as buses, minibuses, taxis and trucks that are known to account for large share of vehicle emissions in developing countries. The formulation of such a comprehensive I/M program for Ghana may require a huge capital investment, which can be a drawback, however, the benefits such as reduction in emissions and fuel consumption, which will be derived from such a program in the long term, will be cost effective.

In the next chapter, the methodology of the two software used in computations, i.e. the COPERT software, which was used for all vehicle emissions and fuel consumption computation and the QUESTOR model, which was used to predict the likely future traffic growth and pattern, will be discussed. More importantly, the assumptions and limitations of these software will be highlighted.

Chapter 5

5.0 Software Used Methodology

In the context of United Nations Commission on Climate Change (UNFCC) reporting guidelines for emissions inventory, all emissions inventories are required to be documented or reported with some degree of transparency. Thus the assumptions and methodologies used for an inventory need to be clearly explained to facilitate replication and assessment of the inventory by users of the reported information (UNFCCC, 2004).

Therefore, the purpose of this chapter is to explain the two main software used in the research i.e. the COPERT and the QUESTOR software. Description, references and sources of information of the specific methodologies and assumptions underlying the sources of information, emission factors and activity data will be explained. The IPCC book on good practice guidelines and the COPERT software user manual version 2.1 (Ntziachristos, L. et al, 2000), the COPERT software description (Bel, S. et al., 2005) and the COPERT technical report (Kouridis, C. et al, 2000) are used as guidelines.

5.1 The COPERT Software

The computer software COPERT was employed in the computation of road transport emissions in Ghana, and emissions estimated were distinguished in three sources: Emissions produced during engine start from ambient temperature (cold-start and warming-up effects) and Hydrocarbon emissions due to fuel evaporation. The total emissions are calculated as a product of vehicle activity data and speed-dependent emissions factors incorporated in the COPERT software.

As explained earlier in chapter 4.4, emissions factors describe the amount of pollutants emitted by a vehicle per kilometer, hence the software uses two types of emissions factors i.e. cold emissions and hot emissions factors in its computations. These emissions factors make it possible to compute the total hot or cold emissions that a vehicle emits in a year i.e. by simply multiplying these factors by the number of kilometers made by the vehicle in either the cold or hot conditions as explained earlier in chapter 4.4.

The COPERT software is designed to estimate emissions of all regulated air pollutant in Europe, Carbon monoxide CO, Nitrogen oxides NO_x Volatile Organic Compound VOC and Particulate matter produced by different vehicle categories (Passenger Cars, Light Duty Vehicle, Heavy Duty Vehicle, Mopeds, and Motor Cycles) as well as Carbon dioxide CO_2 on the basis of fuel consumption. Furthermore, the software can also be used to calculate some non-regulated pollutants such as, methane CH_4, Nitrous oxides N_2O, ammonia NH_3 and Sulphur dioxide SO_2.

Hot emissions factors used in the COPERT software were derived from vehicle empirical data such as, engine parameters, year of production, driving mode and average speed, after CORINAIR emissions inventory studies in 1985 (Eggleston, H.S. et al, 1989) and 1993 (Eggleston, H.S. et al, 1993), EU COST 319 (Joumard, R. (ed), 1999) and MEET projects (Hickman, A.J. et al, 1999) and European Commission's Auto Oil II program (Ntzuachristos, L. and Samara, Z., 1999b) studies were carried out in some European cities. The resultant hot emission factors generated were also combined with average monthly maximum and minimum temperatures to derive the cold start emission factors.

5.2 Data Needed For Emissions Inventory

The computation of vehicle emission inventory using the COPERT software requires the sampling of statistical data such as, Vehicle population, Vehicle activity data and Fuel consumption. In subsequent sections of this chapter, these statistical data and the methods or procedures used in sampling these data are discussed.

5.2.1 Vehicle Population

The COPERT software requires the splitting of vehicle population into the following main categories:

- Passenger cars (cars with weight less 2.5 tons)
- Light Duty Vehicles LDVs (vehicles with weight above 2.5 tons but less than 3.5 tons)
- Heavy Duty Vehicles HDVs (vehicles with weight above 3.5 tons)
- Buses (urban and coaches)
- Mopeds (2 stroke vehicles, three and two wheelers) and
- Motorcycles (2 strokes and 4 strokes

These main vehicle population groupings also requires a further split into sub-groupings according to the type of fuel used, the engine capacity and technology or according to the UN-ECE legistration in force for each vehicle. The final detailed vehicle population requirement thus, needed for vehicle emissions computation by the COPERT software is shown in table 5.2.1

Table 5.2.1Vehicle Category Split

Vehicle Type	Class	Legislation
Passenger Cars	Gasoline <1,4l	PRE ECE
		ECE 15/00-01
		ECE 15/02
		ECE 15/03
		ECE 15/04
		Improved Conv.
		Open Loop
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	Gasoline 1,4 - 2,0l	PRE ECE
		ECE 15/00-01
		ECE 15/02
		ECE 15/03
		ECE 15/04
		Improved Conv.
		Open Loop
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	Gasoline >2,0l	PRE ECE
		ECE 15/00-01
		ECE 15/02
		ECE 15/03
		ECE 15/04
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	Diesel <2,0l	Conventional
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	Diesel >2,0l	Conventional
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	LPG	Conventional
		Euro I - 91/441/EEC
		Euro II - 94/12/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
	2 Stroke	Conventional
Light Duty Vehicles	Gasoline <3,5t	Conventional
		Euro I - 93/59/EEC
		Euro II - 96/69/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005

Vehicle Type	Class	Legislation
Light Duty Vehicles	Diesel <3,5t	Conventional
		Euro I - 93/59/EEC
		Euro II - 96/69/EC
		Euro III - 98/69/EC Stage 2000
		Euro IV - 98/69/EC Stage 2005
Heavy Duty Vehicles	Gasoline >3,5t	Conventional
	Diesel <7,5t	Conventional
		Euro I - 91/542/EEC Stage I
		Euro II - 91/542/EEC Stage II
		Euro III - 1999/96/EC
		Euro IV - COM(1998) 776
		Euro V - COM(1998) 776
	Diesel 7,5 - 16t	Conventional
		91/542/EEC Stage I
		91/542/EEC Stage II
		Euro III - 1999/96/EC
		Euro IV - COM(1998) 776
		Euro V - COM(1998) 776
	Diesel 16-32t	Conventional
		91/542/EEC Stage I
		91/542/EEC Stage II
		Euro III - 1999/96/EC
		Euro IV - COM(1998) 776
		Euro V - COM(1998) 776
	Diesel >32t	Conventional
		91/542/EEC Stage I
		91/542/EEC Stage II
		Euro III - 1999/96/EC
		Euro IV - COM(1998) 776
		Euro V - COM(1998) 776
Buses	Urban Buses	Conventional
		91/542/EEC Stage I
		91/542/EEC Stage II
		Euro III - 1999/96/EC
		Euro IV - COM(1998) 776
		Euro V - COM(1998) 776
	Coaches	Conventional
		91/542/EEC Stage I
		91/542/EEC Stage II
		Euro III - 1999/96/EC
		Euro IV - COM(1998) 776
		Euro V - COM(1998) 776
Mopeds	<50cm³	Conventional
		97/24/EC Stage I
		97/24/EC Stage II
Motorcycles	2 Stroke >50cm³	Conventional
		97/24/EC
	4 stroke 50 - 250cm³	Conventional
		97/24/EC
	4 stroke 250 - 750cm³	Conventional
		97/24/EC
	4 stroke >750cm³	Conventional
		97/24/EC

Source: Ntziachristos, L et al., 2000

5.2.2 Vehicle Activity Data

Another vital statistical data needed by the COPERT software for the computation of vehicle emissions inventory are vehicle activity data. The three main vehicle activities needed are the average annual distance covered in kilometres by each vehicle category, the proportion each category of vehicle spent on the three major road types i.e. urban, rural and highway. The third vehicle activity data needed is, the average speed of each of these vehicle categories on each of these major road types.

In addition to these statistical vehicle activity data, the COPERT software also requires one technical data i.e. the average trip length, the default value assigned in the software is 12.4 km which was derived from available data obtained in some selected European countries however, the value of I_{trip} for annual vehicle circulation in Europe ranges between 9-17 km (Andre, M. et al., 1998) as shown in table 5.2.2 below. These values were used in the COPERT1990 vehicle emissions inventories by the different European member states.

Table 5.2.2 Average Trip Length for Some European Countries

Country	Trip Length [km]	Country	Trip Length [km]	Country	Trip Length [km]
AT	12	GR	12	NL	13,1
B	12	H	12	P	12
DK	9	IRL	14	PL	10
D	14	I	12	SLO	13
E	12	L	15	UK	10
F	12	LT	14		
FIN	17	M	18		

Source: Ntziachristos, L et al., 2000

5.2.3 Fuel Consumption Data

Another major statistical data needed by the COPERT software for vehicle emissions computation is, the total annual fuel consumed by vehicle fleet in the country, in addition country specific fuel information such as the chemical and physical properties shown in table 5.2.3 are also needed for computations.

Table 5.2.3 Properties of Fuel Needed for Emission Computation

Gasoline	Diesel
E100 [%v/v]	PCA [%v/v]
E150 [%v/v]	Cetane Number CN
Aromatics [%v/v]	T95
Oxygenates [% O_2]	Sulphur
Olefins [%v/v]	
Benzene [%v/v]	
Reid Vapor Pressure RVP [mBar]	
Sulphur	

Also fuel chemical properties such as: Lead content, Hydrogen to Carbon ratio, Cadmium content, Copper, Chromium, Nickel, Zinc and Selenium contents can be altered in the COPERT software to suit country specific information.

Finally, statistical data on the monthly minimum and maximum temperatures for the entire year in a country are needed by the COPERT software for the computation of evaporative emissions. The COPERT software also makes provision for advance technical adjustment for load and road slope, this makes the software easy for adaptation in different countries even though it was primary designed to be used in Europe.

5.3 Data Sampling Procedures

The main input data to the COPERT software, vehicle population can easily and cheaply be obtained in a country if there exist a mandatory vehicle registration and deregistration (in the case of scrapping, sales etc) in that country, more importantly the vehicle registry should include the compilation of vehicle details such as: Name of vehicle manufacturer, model or model year, engine size, date of registration, transmission type, type of fuel used, air condition and catalytic converters availability. More often than not the deregistration processes in most developing countries are ineffective, thus creating data gaps in the vehicle registries. Another possible problem that might arise with the use of the national vehicle registries is incomplete vehicle details, because some countries registrations do not compile all the vehicle details needed by the COPERT software. In case of such eventuality such as data gaps, lack of vehicle details or both, the national vehicle registry need to be supplemented with vehicle field count survey.

Vehicle activity data needed for vehicle emissions computation can be sampled through the use of Combined Global Positioning Satellite (CGPS) modules with microprocessors. The unit is normally placed in a vehicle and the vehicle made to drive on a predetermined route with normal flow of traffic. The CGPS module unit collects information about the location, speed and altitude on a second by second basis. This procedure need to be carried out for all categories of vehicles and on the three different road types (urban, highway, and rural), using different vehicle drivers.

Another instrument that can complement the readings of CGPS module is the digital video camera, the camera is normally positioned along the roadside or above the road to capture images of oncoming vehicles. The videotaping is done at the same time and location where the CGPS is monitoring the driving pattern. The video tapes are later reviewed to sample vehicle detail data such as, the license plate (in some case that will be enough to retrieve other data from the national vehicle registry database), size and type of vehicle. The use of the digital camera allow driving speeds and patterns determined from the CGPS units to be correlated with traffic counts taken from the digital video camera.

The use of the CGPS unit and the digital video camera for vehicle activity data sampling however, have some shortfalls because the identification process using digital video cameras does not collect all the necessary information required to completely identify the vehicle technology. Therefore, it is important to supplement video data with visual inspection through vehicle parking surveys. The parking survey usually requires the services of an experienced mechanic to help identify some vehicle details such as engine size, engine air-fuel control and emission technology control, which are in most cases not detailed on the vehicle and thus require some identification techniques. The survey can also help sample other vehicle details such as model year, odometer readings (distance traveled), type of transmission, and availability of air conditioning. Vehicle observations are normally done at car parks provided at grocery stores and shopping centers, industrial parking lots and roadside parking lots close to the CGPS and video coverage study area. However, in cases where the CGPS module unit and digital camera are absent the parking lot survey can be used as a reasonable representative of vehicular activity in the area, and a number of these representatives data can be extrapolated together with the national vehicle registry data to give a true representation of vehicle details in the entire country. The vehicle parking survey covers a wide range of vehicle details data but sometimes the sampling process could be tedious or limited especially with transmission, air-conditioning and odometer data, where observations are done through the vehicle windows which may not be visible enough to take readings. Some vehicles are equipped with digital odometers, which are only visible when the vehicle is in operation.

5.4 Advantages and Limitations of the COPERT Software

Comparing the COPERT software with (considering the geographical scale of application, the generic model type, the nature of emissions calculation approach) other emissions models such as the US MOBILE software, the COPERT software can be said:

- To be extremely flexible and easy to use.

- More appropriate for large scale application (good for national and regional emissions inventories).
- Able to handle large number of measurements.

Despite all these advantages of the COPERT software, the software has some limitations, for example, the software cannot account for the variability in driving dynamics at particular speeds and also with new vehicles, average speed is not a reliable indicator for the high amount of emissions during short peaks (Mahmod and van Arem, 2008).

5.5 The QUESTOR Model

To achieve the second and third objectives of this research the software model QUESTOR was employed. The QUESTOR model designed through a Ghana government consultancy project (QUESTOR model project) was conducted jointly by the DHV consultancy in the Netherlands and their counterpart in Ghana, the Municipal Development Collaborative (MDC) (Ltd) Ghana.

The QUESTOR model was designed after studies were carried out in six local government areas in Ghana in 2004. Basically, the towns and cities in Ghana are divided into metropolitan (with population exceeding 250,000), municipal (with population exceeding 95,000 but less than 250,000) and district assemblies (with population exceeding 75,000 but less than 95,000) for local governance and planning. Thus the study covered towns and cities within the following local government areas:

- Greater Accra Metropolitan,
- Tema Municipal Assembly
- Ga District Assembly
- Shama Ahanta East Metropolitan Assembly (Sekondi-Takoradi)
- New Juaben Municipal Assembly (Koforidua) and
- Capecoast Municipal Assembly

According to the 2000 population censors, over 40% of Ghanaians lives in urban areas of which 18% of the total population are concentrated in areas where the study was undertaken.

The results of the QUESTOR traffic model was applied in forecasting the future traffic growth for the year 2010 and 2020, secondly, the trip analysis in the model was used in predicting future vehicular activities for the scenarios created for the forecast years 2010 and 2020.

5.5.1 The QUESTOR Methodology

The formulation of the QUESTOR model was done through the input of information and data using the following procedural steps:

- Collection of all necessary data for the base year
- Calculation of the synthetic Origin and Destination (OD) matrices for the base year
- Calibration and validation of these matrices for an optimal fit to traffic counts
- Collection of all necessary data for the forecast year
- Calculation of the synthetic OD matrices for the forecast year.
- Correction of the OD matrices in the same way as was necessary for the base year

The proceeding section of this chapter gives detail description of these procedural steps numerated above.

5.5.2 Collection of Data for the Base Year

Input data and information used in the QUESTOR model were obtained through household survey, vehicle activity observations, and passenger interviews. However, the household survey was limited to only four of the study areas.

5.5.3 Analysis of Households Survey

The household survey was applied mainly in estimating people's behaviour on trip generation, modal split and travel time. To give a true representation of the people in the study areas or in the larger sense, urban and town dwellers in Ghana, respondents were selected from different types of houses spread equally over the entire study area as shown in table 5.5.3.

Table 5.5.3 Number of Dwelling in Survey

Type of Houses	Survey	Number of Households	Number of Persons	Households /houses	Persons/ Household
Compound	845	4146	14220	4.9	3.4
Apartments	81	222	892	2.7	4.0
Semi-Detached	169	384	1271	2.3	3.3
Detached	393	400	2167	1.0	5.4
Total	1488	5152	18550	11	16

Sources: Adapted from UTP&TM Project Report 2005

For each of the house chosen for the survey, a person each was selected to answer questions on behalf of the entire household, weight factors depending on the number of people in the house represented were then assigned to each person interviewed. To ensure fairness and balance to representation, selection of persons for the survey was done taking into consideration age, gender, occupation, driving license holders and vehicle ownership.

5.5.4 Access to Public Transport

The QUESTOR model project also investigated how long it takes to get to the closest public transport stop/terminal and the time it takes to get to wait for the transport at the stops/terminals. In all 513 interviews were conducted with public transport passengers at various terminal within Accra, Tema, Ga and Sekondi-Takoradi study areas, table 5.5.4 summaries the results of the interview which was incorporated into the QUESTOR model.

Table 5.5.4 Waiting and Travel Time (minutes) by Mode and Area

Mode	Accra		Tema		Ga		Sekondi-Takoradi	
	Wait	Travel	Wait	Travel	Wait	Travel	Wait	Travel
Taxi	16	24	19	34	16	38	5	11
Trotro[†]	15	32	19	40	17	35	13	15
Private Car	-	-	-	-	-	-	-	-
Private Bus	-	-	-	-	-	-	21	52
Govt Bus	55	56	10	38	-	-	-	-
Train	-	-	-	-	-	-	-	-
Walk	-	-	-	-	-	-	-	-
Other	-	-	15	38	-	-	25	53
Average	19	32	19	39	17	35	12	21

Sources: Adapted from UTP&TM project Report 2005

[†] Commercial mini buses operating in Ghanaian cities, with average seating capacity of 12 passengers

5.5.5 Trip Analysis

The household survey also investigated and analyzed the purpose for making trips and the mode of vehicle used, respondents were therefore, made to write the reasons for making trips instead of choosing from a list of possible trips purpose. These led to a wide range of different purpose, for simplicity these purposes were re-categorized into 5 main groups as: Home-Work, Home-Shopping, Home-School, Work-Work (Business) and Others (including private errands). Also, sampled for the trip analysis were the departure and duration of trips within the early morning peak traffic hours (07:00-09:00), the evening peak traffic hours (16:00-18:00) and the rest of the day. The results of the trip analysis survey data were grouped into an Origin-Destination (O-D) matrix.

5.5.6 Validation of O-D Matrix for the Base Year

To give a true representation of the data and information collected the data for the Origin-Destination O-D was normalized using vehicle counts and passenger observation within the cordons (boundaries) of the study areas. The end results of the validate O-D Matrix was used to generate trip distribution function in the QUESTOR model which converts persons trips into vehicle trips, based on this results the daily vehicle trip per kilometer for each mode of vehicle can be calculated. The daily vehicle trip per kilometer was necessary in this research to convert vehicle activity input data which is in trips, to vehicle kilometer which is needed by the COPERT software for the computation of emissions and fuel consumptions for the various scenarios created. This will be further elaborated in the next chapter (refer to Chapter 6.6 for details).

5.6 Traffic Model Forecast

The traffic model forecast in the QUESTOR model was generated through the application of the following data and information:

- Projected number of households per zone
- Average number of persons per household
- Change in economic activities in each zone
- Growth in average car ownership
- Relative change in household income

The proceeding sections of this chapter give detail description and assumptions used in the procedural steps numerated above.

5.6.1 Projected Number of Households per Zone

The projection of households growth within the various zonal areas was done through a classification system where zones were categorized into five different groupings depending on the available building space in each zone, the characteristics of the ground and the attractiveness of the area compared to its surroundings. The following defined classifications were used:

1. Zero growth: Areas with minimal growth due to unavailability of land.
2. Low growth: Areas with low population growth due to inability to put up more houses.
3. Median growth: Areas with average increase in population
4. Above average: Areas with fast increase in population due to the availability of land for development but without infrastructure.
5. High growth: Areas potential for increase in population due to availability of land and infrastructure.

Natural growth as well as immigration within the study areas for the forecast years was also analyzed, this gave an indication to the average growth rate for the number of households in the entire study areas. However, the household size over the projected period was derived using the household growth rate, and assuming the same proportional ratio of the population to the number of households of the base year for the forecast period.

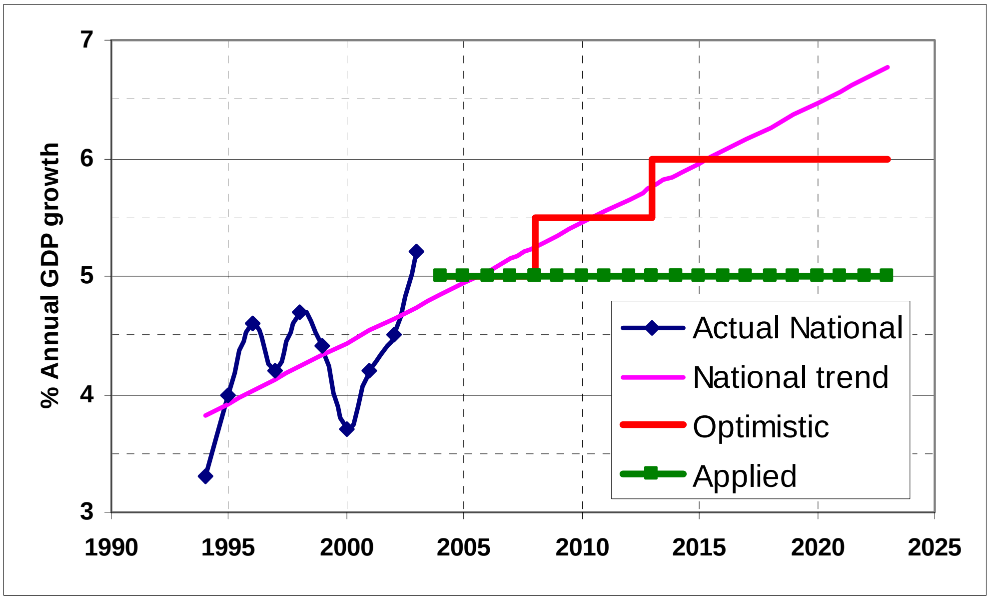
The growth in economic activities over the projected forecast period was determined using economic activity data for the various zones obtained for the base year and combining it with the percentage growth in population

The growth rate for car ownership for the forecast years was determined through the use of vehicle statistical data obtained from the office of Ghana Drivers Vehicle and Licensing Authority (DVLA). From the vehicle statistics data the annual historical growth rates for car ownership (i.e. cars/1000 populations) were computed, since car ownership depends on the Gross Domestic Product (GDP) and personal income. The historical car ownership growth rate were then adjusted for the GDP and income growth rate, since the GDP growth rate figures for the various study areas were absent the QUESTOR project team adapted the national values. Projection for the forecast years were therefore, based on the following assumptions and information obtained from the ministry of finance (Ghana):

- The downward trend of reducing interest rate
- Government policy to cut down on national expenditure to reduce budget deficit
- Stability of world crude oil price
- Continuous downward trend in inflation and
- Increases in exports

On the basis of these assumptions, together with the trend in GDP growth shown in figure 5.6.1, the QUESTOR project team assumed an economic growth of 5% to reflect the uncertainty of continuous Government policies and world crude oil prices for the entire forecast period.

Figure 5.6.1 Estimated Economic Growth Rate in Ghana



Sources: Adapted from UTP&TM project Report 2005

Finally, with the GDP growth rate, population growth rate, personal income growth and projections of car growth using the national vehicle registry data, the QUESTOR model computed the car ownership rate for the various study areas (see table 5.6.1a) as well as the rate of increase for the various mode of vehicle in Ghana (table 5.6.1b). Table 5.5.1b was thus, used in this research to compute vehicle fleet for the forecast year 2010 and 2020 in the next chapter (see chapter 6.1)

Table 5.6.1a Estimation of Car Ownership Rates

	GAMA[‡]	SETA[§]	Cape Coast	Koforidua
Car ownership rate 2004 (vehicles / 1000 pop)	**81**	**33**	**62**	**112**
2004-2008				
Car ownership elasticity	6.00%	5.04%	4.97%	2.66%
GDP annual growth rate	5.0%	5.0%	5.0%	5.0%
GDP growth factor	1.22	1.22	1.22	1.22
Population growth rate	4.4%	2.7%	1.4%	2.5%
Population growth factor	1.19	1.11	1.06	1.10
Personal income growth	1.02	1.09	1.15	1.10
Car ownership growth	1.292	1.330	1.396	1.223
Car ownership rate 2008	**105**	**44**	**86**	**137**
2008-2013				
Car ownership elasticity	6.00%	5.04%	4.97%	2.66%
GDP annual growth rate	5.0%	5.0%	5.0%	5.0%
GDP growth factor	1.28	1.28	1.28	1.28
Population growth rate	3.6%	2.5%	1.3%	2.3%
Population growth factor	1.19	1.13	1.07	1.12
Personal income growth	1.07	1.13	1.20	1.14
Car ownership growth	1.431	1.442	1.525	1.298
Car ownership rate 2013	**150**	**63**	**131**	**178**
2013-2023				
Car ownership elasticity	3.00%	5.04%	2.49%	1.33%
GDP annual growth rate	5.0%	5.0%	5.0%	5.0%
GDP growth factor	1.63	1.63	1.63	1.63
Population growth rate	2.8%	2.0%	1.0%	1.9%
Population growth factor	1.32	1.22	1.11	1.20
Personal income growth	1.24	1.34	1.47	1.36
Car ownership growth	1.661	2.185	1.878	1.547
Car ownership rate 2023	**248**	**138**	**246**	**275**

Sources: Adapted from UTP&TM project Report 2005

Table 5.6.1b Rate of Increase of Vehicle Fleet in Ghana

Vehicle	Annual increase from 2005-2012 (%)	Annual increase from 2013-2023 (%)
Cars	10.45%	6.02%
Taxis	3.11%	1.56%
Light Duty Vehicles (LDV)	4.75%	1.77%
Minibus (Trotro)	2.03%	0.93%
Heavy trucks	4.75%	1.77%
Large/medium buses	2.03%	0.93%
Articulated trucks	4.75%	1.77%
Medium trucks	4.75%	1.77%
Light trucks	4.75%	1.77%
Motorcycles	4.59%	2.03%

Sources: Adapted from UTP&TM project Report 2005

‡ GAMA represents Greater Accra, Ga and Tema combined study areas

§ SETA represents Sekondi-Takoradi study area

5.7 Concluding Remarks

The accuracy in using software and models in any empirical research depends heavily on the reliability of the software or model, and the application of best practice used to sample data and information for the computation. The choice of the COPERT software for this research was based on two main reasons. First, due to the reliability of the software, as data used for its design was sampled from a number of European countries, where the types of fleet of vehicles used are similar to that of the study area, Ghana. Secondly, the software allows adjustment to suit vehicle operating conditions in the study area. In the case of the QUESTOR model, it was purposely designed for the study area, even though, it was designed to reflect urban passenger trips behaviour in Ghana, it can be approximated to reflect the passenger trip behaviour in the entire country since, a chunk of trip activities are concentrated within the urban centres in Ghana.

In the case of data sampling, owing to the large logistics required to sample such data with the best methods discussed in this chapter, not all the best method required could be applied in this research. However, to minimise errors in sampling, technical advice and support was seek out from the Ghana Ministry of Transport. Details of data sampled and the methodology used in the sampling process will be discussed in the next chapter.

Chapter 6

6.0 Input Data Computations

One of the objectives of this research work is the computation of road vehicle emissions in Ghana using the computer software COPERT III. Some data sampled for the vehicle emissions computation are however not in the form or structure required by the COPERT III software and therefore need to be converted or structured. In this chapter, all input data used for the computation of vehicles emissions in Ghana for the base year 2005 and the forecast years 2010 and 2020 will be described, stating the sources, conversions, limitations as well as the computations.

6.1 Vehicle Fleet Input Data

Vehicle fleet data used in the emissions computation was obtained from the Ghana Drivers, Vehicle and Licensing Authority (DVLA), an institution responsible for vehicle registration and driver licensing in Ghana. Data obtained from the DVLA (See Appendix I) however did not include vehicles registered by the security services such as the Ghana Armed Forces, the Ghana Police and the Ghana Prison Services. The vehicle fleet data obtained from the DVLA (Appendix I) was slightly adjusted in structure to fit into the COPERT III software. Thus, private motor vehicles with engine capacity < 2000cc were combined with commercial vehicles < 2000cc to form a new column, Passenger vehicles with engine capacity <2000cc. Also, all rigid cargo trucks weighing up to 22 tons and above were combined with Articulator trucks weighing up to 32 tons to form a new column heavy truck with weight between 16-32 tons. Finally, off road vehicles were eliminated from the fleet data, because the focus of the research was on on-road vehicles.

The final vehicle fleet structure used in the emissions computation for the base year 2005 is shown in table 6.1a.

Table 6.1a On-Road Vehicle Fleet Registered in Ghana by Category

Year	Motor Cycle	Pass. MV up to 2*l*	MV Above 2*l*	Buses& Coaches	Heavy Trucks Up to 16 tons	Heavy Trucks From 16-32 tons	Heavy Trucks above 32 tons
1995	4908	2941	6	10387	5130	2353	3
1996	29551	149466	1067	42501	13794	10256	988
1997	7930	29624	26	9114	2546	2387	266
1998	6064	27562	71	11443	3770	2469	252
1999	6623	36438	6249	9843	3454	1369	262
2000	6440	32656	5196	5469	1428	1049	126
2001	6058	23521	5343	2676	861	988	122
2002	6430	24527	7143	2601	1044	920	168
2003	8777	25674	7778	2916	914	1181	510
2004	14462	27975	7189	4882	2065	1868	489
2005	15136	29635	8715	5585	2457	1888	454
Total as at Dec 2005	**112376**	**427267**	**48783**	**107417**	**37463**	**26728**	**3640**

Source: Adapted from DVLA, 2005

- Motor Cycle : Motor Cycles of all categories
- Pass. MV up to 2*l*: Passenger motor vehicles up to 2*l* capacity
- MV above 2*l*: Motor vehicles above 2*l* capacity
- Buses & coaches: Buses & Coaches of all kinds
- Heavy Trucks up to 16 tons: Rigid cargo trucks up to 16 tons
- Heavy Trucks 16-32 tons: Rigid cargo trucks and articulated trucks from 16-32 tons
- Heavy Trucks above 32 tons: Heavy articulated trucks above 32 tons

The vehicle fleet data (see table 6.1b) used for emissions computation for the forecast years 2010 and 2020 were derived using the base year 2005 values and the yearly growth rate (see table 5.5.1b in chapter 5) obtained from the QUESTOR model project.

Table 6.1b Forecast Vehicle Fleet 2005-2020

Year	Motor Cycle	Pass MV<2l	MV>2l	Buses& Coaches	Heavy Duty Vehicles		
					Wt.<16t	Wt. 16-32t	Wt. >32t
2005	112376	427267	48783	107417	37463	26728	3640
2006	117534	464730	51100	109598	39243	27998	3813
2007	122928	505885	53528	111822	41107	29328	3994
2008	128571	551110	56070	114092	43059	30721	4184
2009	134473	600823	58733	116409	45104	32180	4383
2010	**140645**	**655486**	**61523**	**118772**	**47247**	**33708**	**4591**
2011	147101	715609	64446	121183	49491	35309	4809
2012	153853	781755	67507	123643	51842	36987	5037
2013	160914	854544	70713	126153	54304	38744	5276
2014	164181	900409	71965	127326	55266	39429	5370
2015	167514	948947	73239	12860	56244	40127	5465
2016	170914	1000320	74535	129705	57239	40837	5562
2017	174384	1054695	75854	130911	58252	41560	5660
2018	177924	1112253	77197	132129	59283	42296	5760
2019	181536	1173182	78563	133358	60333	43045	5862
2020	**185221**	**1237686**	**79954**	**134598**	**61401**	**43806**	**5966**

The vehicle population input data were split according to the type of fuel used in the following proportions shown in table 6.1c

Table 6.1c Percentage of Vehicles in Ghana According to the Type of Fuel used

Category	Type of Fuel Used		
	Gasoline (%)	**Diesel (%)**	**LPG (%)**
Motor Cycles	100		
Private Cars & Taxis	70	29.95	0.05
Light Duty Vehicles	70	29.95	0.05
Heavy Duty Vehicles	-	100	-

Source: (Kanyoke, E. L, 2004; The Ghana DVLA, 2004)

The technologies of the different categories of vehicles applied in the emissions computation were based on information obtained from the World Bank-Ghana Energy Foundation (GEF) project report (GEF, 2006) and a research on the impact of automotive emissions on the level of lead and platinum in Accra (Kylander M.E. et al, 2003). From the GEF and Kylander research, passenger cars, buses and Light Duty Vehicles (LDVs) in Ghana were on the average 13 years old, whilst Heavy Duty Vehicles (HDVs) on average were 18 years old. Based on these ages, passenger cars, buses and LDVs were assumed to be of Euro II standards, whilst HDVs were classified into Euro I for the emissions computations.

6.2 Fuel Input Data

On-road vehicles in Ghana run on unleaded gasoline, diesel and liquefied petroleum gas (LPG), Fuel input data and information, Appendix II (Total Annual Petroleum Product Consumed) and Appendices III, IV and V (Physical and Chemical Properties for Gasoline, Diesel and LPG respectively), used for the emissions computation were obtained from the Ghana Ministry of Energy and the Tema Oil Refinery (TOR), a company that refines petroleum products for use in Ghana. However, the data obtained for the total annual fuel consumption were given in litres for gasoline and diesel, and in kilograms for LPG, which do not fit into the COPERT software, and thus needed to be converted to metric tonnes, the required unit needed by the COPERT software.

From Appendix II
The total annual Gasoline consumed = 726,024l
The total annual Diesel consumed = 1,045,569,250l
The total annual LPG consumed = 70,460,665 kg

From Appendix III, the density of Gasoline is given as 725-790 kg/m^3
Therefore the average density = (725+790)/2 kg/m^3 converting to *tons/litre* x 10^{-6} $m^3 tons/kgl$
Therefore the total annual Gasoline consumed in tons = 726,024,190l x (725+790)/2 kg/m^3 x 10^{-6} m^3 *tons/kgl*

= <u>549,963 *tons*</u>

From Appendix IV, the density of Diesel is given as 830-880 kg/m^3

Similarly, the total annual Diesel consumed =1,045,569,250*l* x (830+880)/2 (Average Density) kg/m^3 x 10^{-6} m^3 *tons/kgl*

= <u>861,958 tons</u>

Converting the total annual LPG consumed from kilograms to tons:

LPG =70, 460,665 *kg* x 10^{-3} *tons/kg*

=70,461 *tons*

Fuel chemical and physical properties conversions: Only the fuel volatility Reid Vapour Pressure (RVP) of gasoline was changed from kg/cm^2 to Kilopascals (*Kpa*)

From Appendix III, the value given for the RVP is 0.65kg/cm^3.

RVP=0.65 kg/cm^2 x $10^5 cm^2/s^2 m$ = 65,000 $kg/s^2 m$ = 65 x10^3 N/m^2

=65*Kpa*

6.3 Annual Vehicle Kilometres travelled Input Data

The annual vehicle kilometre input data used for the emissions computation were obtained from interviews with Drivers of the various categories of vehicles, also obtained from the same interview were the driving share each category of vehicle drive on the three different road types (Urban, Rural and Highway). Outcome of the interview is summarised in table 6.3a and table 6.3b.

Table 6.3a Annual Vehicle km traveled by Different Vehicle Categories in Ghana

	Max. Vehicle Km Travelled	Min. Vehicle Km Travelled	Average Vehicle Km Travelled
Passenger cars & LDVs	25,000 km	20,000 km	22,500 km
HDVs & Buses	15,000 km	13,000 km	14,000 km
Motor Bikes	12,500 km	11,000 km	11,750 km

Table 6.3b Driving Shares of vehicles in Ghana on the 3 main road types

	Urban Roads	Rural Roads	Highways
Passenger Cars	60%	10%	30%
LDVs	30%	20%	50%
Buses	40%	10%	50%
HDVs	30%	20%	50%
Motor Bikes	35%	60%	5%

6.4 Average Velocity Input Data

The average velocity input data used in the COPERT III software for the vehicle emissions computations for the base year and forecast years were obtained through a vehicle speed survey conducted on the three road types in Ghana (Urban, Highway and Rural roads). The results of the vehicle speed survey are summarised in table 6.4.

Table 6.4 Vehicle Speeds Distribution in Ghana

Urban Roads Vehicle Speeds(km/h)				
	Pass. Cars & LDVs	HDVs	Buses	Motor Bikes
	53	30	38	55
	49	35	41	35
	38	32	42	33
	40	30	43	40
	42	29	37	37
	46	27	40	39
	48	30	36	40
	48	31	40	42
	35	27	43	41
	53	32	41	40
Average Speed(km/h)	**45.2**	**30.3**	**40.1**	**40.2**

Rural Roads Vehicle Speeds(km/h)				
	Pass. Cars & LDVs	HDVs	Buses	Motor Bikes
	78	68	55	51
	80	66	56	52
	65	61	57	48
	70	58	50	50
	76	57	49	51
	77	55	53	50
	73	60	55	48
	75	60	58	52
	76	60	59	50
	80	58	60	52
Average Speed(km/h)	**75**	**60.3**	**55.2**	**50.4**

Highway&Motorway Vehicle Speeds (km/h)				
	Pass. Cars & LDVs	HDVs	Buses	Motor Bikes
	95	80	84	71
	106	80	83	72
	108	77	77	73
	110	78	76	71
	106	85	78	70
	100	82	83	69
	90	83	82	64
	95	81	84	70
	100	76	78	70
	94	80	79	70
Average Speed(km/h)	100.4	80.2	80.4	70

6.5 Vehicle Emissions and Fuel Consumption Factors Input Data

Emission factors for Carbon monoxide CO, Nitrogen oxides NO_x, Volatile Organic Compounds (VOC), Ammonia (NH_3), Methane (CH_4) and Nitrous oxides (N_2O) pollutants as well as fuel consumption factors were computed for the different vehicle categories and road types. The vehicle emissions and fuel consumption factors used in the formulation of the COPERT III software, are strictly based on vehicle average speeds, thus, the computations of these factors for this research was calculated using the average speeds data i.e. table 6.4 and formulas provided in the COPERT III software technical report (Ntziachristos et al, 2000). The choice of formula for each factor calculated is based on the type of vehicle technology used in Ghana (Refer to chapter 6.1), however, some formulas given in the technical report did not correspond directly to vehicle technologies used. In such instance, the methodology prescribed in the COPERT III software, require the user to choose a formula close to the technology used, and the calculated value corrected using correction factors provided in the technical report to suit the technology used. The rest of this chapter will therefore illustrate how these emissions and fuel consumption factors were calculated

6.5.1 Emissions and Fuel Consumption Factors

Emissions and Fuel Consumption Factors for Passenger Gasoline Cars (1.4l<CC<2.0l):
CO Emission factors for passenger gasoline cars are calculated using average speed from table 6.4 above and speed dependency CO emission factor formula provided in the COPERT technical report shown in Appendix IV. The passenger gasoline cars technology used in Ghana is Euro II (refer to Chapter 6.1). Therefore, the formula corresponding to Euro I with engine capacity of 1.4*l*<CC<2.0*l* shown in Appendix VI is used in the emissions factor computation and then corrected to suit Euro II technology, using percentage reduction values provided in the COPERT technical report (see Appendix VII).

Sample Calculation:

For CO emission factors the following steps are used for the calculation

From Appendix IV, formula given corresponding to Euro I with engine capacity 1.4*l*<CC<2.0*l* is $9.617 - 0.245V - 0.0017285V^2$ where V is the vehicle average speed

Therefore for Urban roads in Ghana with average speed of 45 *km/h*, the emission factor in *g/km* is:

Euro I = $9.617 - 0.245\ (45) - 0.0017285\ (45)^2 = 2.09$ *g/km*

Correcting this value for Euro II which is the technology of passenger cars used in Ghana, from the correction factor provided in the COPERT software (see Appendix VII) corresponding to Euro II for CO emissions reduction factor is 32%.

Thus, the Euro II CO emission factor = Euro I value x 68% = 2.09 x 68% = 1.42 *g/km*

The same formula in Appendix VII was used to calculate emissions factors for passenger cars on Highway and Rural roads i.e. $9.617 - 0.245\ (45) - 0.0017285\ (45)^2 = 2.09$ *g/km* using average velocity values in table 6.4 corresponding to Highway and Rural (100 and 75 *km/h* respectively).

Thus, the Euro I values calculated for Highway and Rural roads are as follows:

Euro I (Highway) = $9.617 - 0.245\ (100) - 0.0017285\ (100)^2 = 2.40$ *g/km*

Euro I (Rural) = $9.617 - 0.245\ (75) - 0.0017285\ (75)^2 = 0.96$ *g/km*

Correcting these values for Euro II using the same correction reduction factors as in the Urban calculation (32%).

Thus, the Euro II CO emission factors for the Highway and Rural are as follows:

Euro II (Highway) = 2.40 x 68% = 1.63 *g/km*

Euro II (Rural) = 0.96 x 68% = 0.66 *g/km*

Similarly, VOC, NO_x emissions and Fuel Consumption (FC) factors are calculated using the formulas in Appendices VIII, IX and X respectively and corrected appropriately with the percentage reduction factors in Appendix VII.

Passenger Diesel Cars: CO, VOC, NO_x, and Particulate Matter (PM) emissions as well as Fuel Consumption factors are calculated using average speeds in table 6.4 above and formulas in Appendix XI. The emissions factors are then corrected for improved vehicle technology using the percentage reduction factor in Appendix XII.

Liquefied Petroleum Gas (LPG): CO, VOC, NO_x, emissions and Fuel Consumption factors are also calculated using average speeds in table 6.4 and formulas in Appendix XIII. Correction for the emission factors for improved technology is done using the same correction reduction factor for Gasoline cars i.e. Appendix VII.

The calculated emissions and fuel consumption factors for passenger cars are shown in table 6.5.1a.

Table 6.5.1a Hot Emission Factors for Passenger Vehicles used for Emission Computations

Gasoline Passenger Car				
Passenger Car CO Emission Factor				
	Urban	Rural	Highway	
Speed V (km/h)	45	75	100	
Emission Factor (g/km)	2,09	0,96	2,40	
Correction for Euro II (g/km)	1,42	0,66	1,63	
Passenger Car :VOC Emission Factor				
Speed V (km/h)	45	75	100	
Emission Factor (g/km)	0,16	0,08	0,08	
Correction for Euro II (g/km)	0,03	0,02	0,02	
Passenger Car: NOx Emission Factor				
Speed V (km/h)	45	75	100	
Emission Factor (g/km)	0,32	0,37	0,53	
Correction for Euro II (g/km)	0,11	0,13	0,19	
Passenger Car Fuel Consumption Factor				
Speed V (km/h)	45	75	100	
Fuel Consumption factor (g/km)	60,47	42,89	48,04	
Diesel Passenger Car				
Speed V (km/h)	45	75	100	
CO Emission Factor (g/km	0,35	0,09	0,16	
NOx Emission Factor (g/km)	0,49	0,62	1,43	
VOC Emission Factor (g/km)	0,07	0,03	0,03	
PM (g/km)	0,05	0,04	0,07	
Fuel Consumption Factor (g/km)	49,88	42,00	47,41	
LPG Passenger Car				
Speed V (km/h)	45	75	100	
CO Emission Factor (g/km	1,19	1,66	3,56	
NOx Emission Factor (g/km)	0,33	0,28	0,30	
VOC Emission Factor (g/km)	0,20	0,06	0,08	
Fuel Consumption Factor (g/km)	47,58	45,75	54,13	

Light Duty Vehicles (LDVs): CO, VOC, NO_x, PM emissions and fuel consumption factors for LDVs with Euro I technology standards are calculated using average speeds and formulas in Appendices XIV and XVI for gasoline and diesel LDVs respectively. The emissions factors are finally corrected for Euro II, the technology used in Ghana (see chapter 6.1) by applying percentage reduction factors in appendices XV and XVII respectively to gasoline and diesel Euro I values calculated. The Euro I emissions and fuel consumption factors, as well as the corrected values for EuroII for LDVs are shown in table 6.5.1b.

Table 6.5.1b Emission and Fuel Consumption Factors for LDVs used for Emission Computations

Light Duty Vehicles (Gasoline) For Euro I					
	Urban	Rural	Highway		
Speed (km/h)	45	75	100		
CO Emission Factor (g/km)	3.152	0.827	3.977		
NOx Emission Factor (g/km)	0.4138875	0.4156875	0.521		
VOC Emission Factor (g/km)	0.1918925	0.0855125	0.0762		
Fuel Consumption Factor (g/km)	89.2875	66.7875	74.85		
Correction of Euro I Emission Factor Values For Euro II					
	Urban	Rural	Highway		
CO Emission Factor (g/km)	1.92	0.50	2.43		
NOx Emission Factor (g/km)	0.14	0.14	0.17		
VOC Emission Factor (g/km)	0.05	0.02	0.02		
Fuel Consumption Factor (g/km)	89.29	66.79	74.85		
Light Duty Vehicles (Diesel)					
Speed (km/h)	45	75	100		
CO Emission Factor (g/km)	0.36	0.38	0.71		
NOx Emission Factor (g/km)	1.08	1.00	1.25		
VOC Emission Factor (g/km)	0.12	0.10	0.11		
PM (g/km)	0.06	0.08	0.15		
Fuel Consumption Factor (g/km)	64.745	60.845	84.82		
NB: Correction Reduction Factor for Euro II Diesel LDVs is 0%					

Heavy Duty Vehicles (HDVs): CO, VOC, NO_x, PM emissions and Fuel Consumption factors for HDVs are calculated using average speeds from table 6.4 and formulas from Appendix XVIII. The values are then corrected for Euro I (HDVs technology used in Ghana) by applying the corresponding percentage reduction factors from Appendix XX. The calculated emissions and fuel consumption factors and the corrected values for HDVs are shown in table 6.5.1c and 6.5.1d respectively

Table 6.5.1c Emission and Fuel Consumption Factors for HDVs

Emission Factors for Heavy Duty Vehicles			
CO (g/km)			
	Urban	Rural	Highway
Speed (km/h)	30	60	80
Emission factor (wt.< 16t)	3.51	2.17	1.78
Emission factor (wt.16-32t)	3.51	2.17	1.78
Emission factor (wt.>32t)	3.51	2.17	1.78
NOx (g/km)			
Speed (km/h)	30	60	80
Emission factor (wt.< 16t)	7.49	4.29	4.09
Emission factor (wt.16-32t)	13.79	4.29	4.09
Emission factor (wt.>32t)	19.84	4.29	4.09
VOC (g/km)			
Speed (km/h)	30	60	80
Emission factor (wt.< 16t)	2.03	1.10	0.86
Emission factor (wt.16-32t)	2.03	1.10	0.86
Emission factor (wt.>32t)	2.03	1.10	0.86
PM(g/km)			
Speed (km/h)	30	60	80
Emission factor (wt.< 16t)	0.81	0.49	0.40
Emission factor (wt.16-32t)	0.97	0.59	0.48
Emission factor (wt.>32t)	1.03	0.64	0.52
Fuel Consumption Factor For Heavy Duty Vehicles (g/km)			
Speed (km/h)	30	60	80
Emission factor (wt.< 16t)	201.47	147.01	169.11
Emission factor (wt.16-32t)	317.72	227.04	230.74
Emission factor (wt.>32t)	420.19	311.46	297.38

Table 6.5.1d Emission and Fuel Consumption Factors for HDVs used for Emission Computations

Correcting Emission Factors for H DVs for Euro I						
		CO (g/km)				
	Urban	Rural	Highway			
Speed (km/h)	30	60	80			
Emission factor (wt.< 16t)	1.76	1.30	0.98			
Emission factor (wt.16-32t)	1.93	1.30	1.16			
Emission factor (wt.>32t)	1.93	1.30	1.16			
		NOx (g/km)				
Speed (km/h)	30	60	80			
Emission factor (wt.< 16t)	5.24	3.00	3.68			
Emission factor (wt.16-32t)	7.58	2.57	2.25			
Emission factor (wt.>32t)	7.58	2.57	2.25			
		VOC (g/km)				
Speed (km/h)	30	60	80			
Emission factor (wt.< 16t)	1.52	1.52	1.52			
Emission factor (wt.16-32t)	1.02	0.72	0.65			
Emission factor (wt.>32t)	1.02	0.72	0.65			
		PM(g/km)				
Speed (km/h)	30	60	80			
Emission factor (wt.< 16t)	0.53	0.53	0.53			
Emission factor (wt.16-32t)	0.63	0.16	0.16			
Emission factor (wt.>32t)	0.67	0.42	0.34			
		Fuel Consumption Factor For Heavy Duty Vehicles (g/km)				
Speed (km/h)	30	60	80			
Emission factor (wt.< 16t)	201.47	147.01	169.11			
Emission factor (wt.16-32t)	317.72	227.04	230.74			
Emission factor (wt.>32t)	420.19	311.46	297.38			

Buses and Coaches: CO, VOC, NO_x, PM emissions and Fuel Consumption factors for Euro I Buses are calculated using average speeds from table 6.4 and formulas provided in the COPERT software technical report shown in Appendix XIX, the values are then corrected for Euro II (Buses technology used in Ghana), using the percentage reduction factors in Appendix XX.

Motor Cycles: CO, VOC, NO_x, PM emissions and Fuel Consumption factors for conventional four stroke motor cycles with engine capacity 250-750 cm^3 are calculated using average speeds from table 6.4 and formulas provided for used by the COPERT software shown in Appendix XXI. The calculated emissions and fuel consumption factors used for Buses and Motor cycles emissions computation for the base year 2005 are shown in table 6.5.1e.

Table 6.5.1e Emission and Fuel Consumption Factors for Buses and Motor Cycles used for Emission Computations

Emission Factors for Buses and Motor Cycles			
	Urban	Rural	Highway
Speed (km/h)	40	55	80
CO Emission Factor (g/km)	3.78	2.98	2.26
NOx Emission Factor (g/km)	4.03	3.09	2.25
VOC Emission Factor (g/km)	0.98	0.70	0.48
Fuel Consumption Factor (g/km)	278.91	243.07	206.76
Correction for Euro II Buses			
CO Emission Factor (g/km)	1.5131	1.6413	1.1288
NOx Emission Factor (g/km)	1.8914	1.6979	1.4652
VOC Emission Factor (g/km)	0.6836	0.4924	0.3347
PM Emission Factor (g/km)	1.3377	0	0
Emission Factors for Motor Cycles			
Speed (km/h)	40	50	70
CO Emission Factor (g/km)	6.46	6	9.27
NOx Emission Factor (g/km)	0.19	0.23	0.31
VOC Emission Factor (g/km)	0.73	0.61	0.47
Fuel Consumption Factor (g/km)	26.10	23.35	27.34

Methane (CH_4), Nitrous oxide (N_2O) and Ammonia (NH_3) emission factors for the different categories of vehicles used for the vehicle emissions computations are calculated using formulas provided for used by the COPERT software shown in Appendices XXII, XXIII and XXIV respectively. The calculated values for the methane emission factors are then corrected using the VOC correction reduction factors in

Appendices VII for passenger gasoline cars, XII for passenger diesel cars, XV for gasoline LDVs, XVII for diesel LDVs and XX for both Buses and HDVs. The calculated emission factors for methane are tabulated in table 6.5.1f with the corrected values for Euro II in table 6.5.1g below, the calculated emission factor values for nitrous oxide and ammonia used in the COPERT vehicle emissions computation are shown in table 6.5.1h, and 6.5.1i respectively.

Table 6.5.1f Calculated Methane Emission factors for the Different Class of Vehicles

Emission Factors (Methane)			
Passenger Cars (mg/km)			
	Urban	Rural	Highway
Speed (km/h)	45	75	100
Gasoline < 2l Emission Factor	34.22	15.74	15.71
Diesel < 2l Emission Factor	3.85	5.37	9.24
LPG Emission Factor	80	35	25
LDV (mg/km)			
Speed (km/h)	45	75	100
Gasoline Euro I and on	33.30	16.66	20.62
Diesel	5	5	5
HDV (mg/km)			
wt. < 16t	85	23	20
wt. 16-32t	175	80	70
wt. > 32t	175	80	70
Buses & Coaches (mg/km)			
Buses	175	0	0
Motor Cycle (mg/km)			
Motor Cycle > 50cc 4 stroke	200	200	200

Table 6.5.1 g Corrected Methane Emission factors

Emission Factors (Methane)			
	Passenger Cars (mg/km)		
	Urban	Rural	Highway
Speed (km/h)	45	75	100
Gasoline <2l Emission Factor Correction for Euro II	7.19	3.31	3.30
Diesel <2l Emission Factor for Euro II	3.85	5.37	9.24
LPG Emission Factor for Euro II	16.8	7.35	5.25
LDV (mg/km)			
Gasoline Euro II	7.99	4.00	4.95
Diesel Euro II	5	5	5
Buses & Coaches (mg/km)			
Buses(Euro II)	140	140	140
Motor Cycle (mg/km)			
Motor Cycle >50cc 4 stroke	200	200	200

Table 6.5.1hCalculated Nitrous oxide Emission factors for the Different Class of Vehicles

Nitrous Oxides (N2O) Hot and Cold Emission Factors				
Passenger Cars				
Gasoline EuroI and on (mg/km)	53	16	35	
Diesel (mg/km)	27	27	27	
LPG (mg/km)	15	15	15	
Light Duty Vehicles				
Gasoline (mg/km)	53	16	35	
Diesel (mg/km)	17	17	17	
Heavy Duty Vehicles				
wt.<16t (mg/km)	30	30	30	
wt.16-32t (mg/km)	30	30	30	
wt.<32t (mg/km)	30	30	30	
Buses & Coaches				
Buses (mg/km)	30	0	0	
Motor Cycle				
Motor Cycle>50CC 4Strokes (mg/km)	2	2	2	

Table 6.5.1i Calculated Ammonia Emission factors for the Different Class of Vehicles

Ammonia (NH3) Hot and Cold Emission Factors			
Passenger Cars			
	Urban	Rural	Highway
Gasoline EuroI and on (g/km)	70	100	100
Diesel (g/km)	1	1	1
LPG (g/km)	0	0	0
Light Duty Vehicles			
Gasoline (g/km)	70	100	100
Diesel (g/km)	1	1	1
Heavy Duty Vehicles			
wt.<16t (g/km)	3	3	3
wt.16-32t (g/km)	3	3	3
wt.<32t (g/km)	3	3	3
Buses & Coaches			
Buses (g/km)	3	0	0
Motor Cycle			
Motor Cycle>50CC 4Strokes (g/km)	2	2	2

6.6 Scenario Input Data

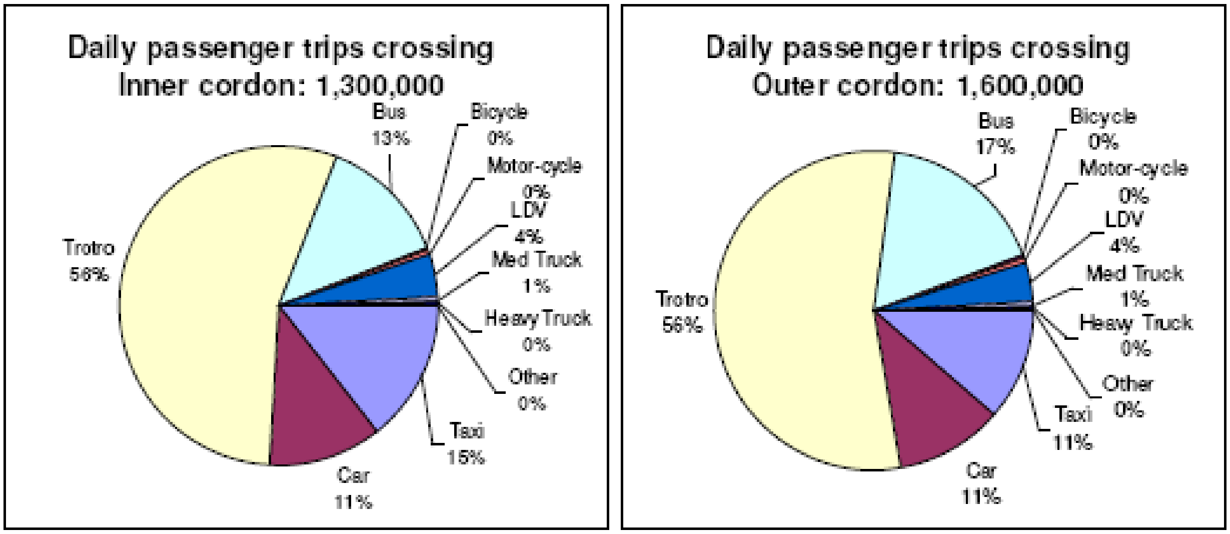
A key socio-economic problem facing Ghana is the inadequacy of road infrastructure in the face of growing population combined with increasing rates of private car ownership. Results from the QUESTOR model reveals, for example, on a typical urban road in Ghana the percentage of low occupancy mode of transport i.e. cars and taxis uses about 55% of road space whilst carrying only 24% early morning peak passengers, in contrast, high occupancy mode of transport which uses only 32% of road space carries about 68% of the passengers (UTP&TM project Report, 2005). A key solution to this problem therefore, is to maximize the use of road space, thus, using the most efficient mode of road transport (buses). This solution will not only solve the road traffic congestion in Ghana but will help reduce emissions and energy consumption associated with road transport.

To investigate how much, in terms of emissions and energy consumption that will be avoided or saved if passenger trips made using private cars are shifted to the more efficient modes, such as buses, this research computed on-road vehicle emissions and fuel consumption for some selected scenarios for the forecast years 2010 and 2020. Considering over 20% illiteracy rate in Ghana, policies targeting such a switch in road transport mode for travel can realistically achieve a target rate between 10-20%. On this basis, two separate scenarios were created i.e. a 10% and a 20% daily passenger trips shift using passenger car mode to bus mode, for each of the forecast year 2010 and 2020.

Therefore, the only input data changed in the computation of vehicle emissions and fuel consumption for the scenarios, was the annual vehicle kilometer traveled for the two modes of transport i.e. passenger cars and that of buses. To determine the annual vehicle kilometer traveled for these scenarios, a relation between vehicle kilometer travel and passenger trip in Ghana was derived using results from the QUESTOR model project.

From the QUESTOR model project, out of 10,000 vehicles observed within the cordon (boundaries) of a study area, the number of passenger trips distributed according to the mode of vehicle used within the inner and outer cordon of the study area is shown in Figure 6.6a

Figure 6.6a Urban Passenger Trips Distribution

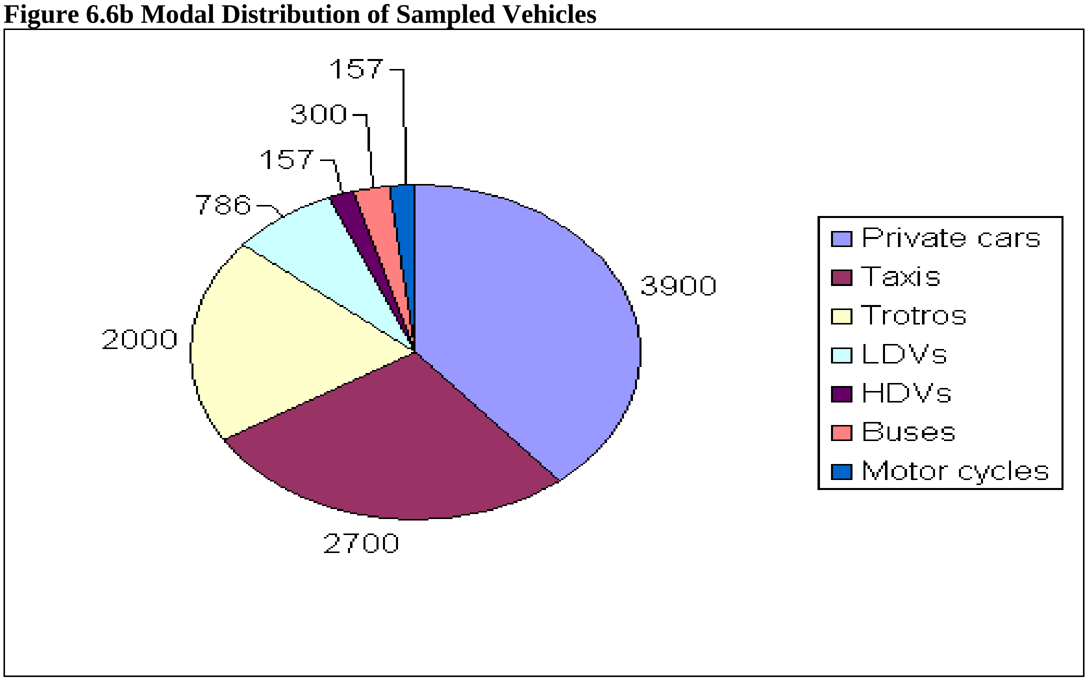


Source: UTP&TM project Final Report 2005

NB: Trotro refer to commercial mini buses operating in Ghanaian cities with an average seating capacity of 15 passengers

The 10,000 vehicles observed are also distributed according to the different modes in the following proportions shown in figure 6.6b

Figure 6.6b Modal Distribution of Sampled Vehicles



Source: Adapted from the UTP&TM project Final Report 2005

For purposes of vehicle fleet classification used in the COPERT software, the passenger trip analysis is done, by combining private cars and taxis and analysed as passenger cars, similarly, trotros and buses are combined and analysed as buses

Thus, from figure 6.6a:

Total Daily Passenger Trips = 1,300,000+1,600,000

= 2,900,000 trips

$$\text{Average Daily \% Passenger Car Trips} = \frac{\text{taxis and private cars (inner trips + outer trips)}}{2}$$

$$= \frac{26+22}{2}$$

$$= 24\%$$

Therefore, number of Daily Passenger trips using Passenger cars = 24% x 2,900,000

= 696,000 trips

From figure 6.6b these trips were made using 6,600 Passenger cars

Therefore, Daily Passenger trip/Passenger car = 696,000/6,600 = 106 trips/car

$$\text{Average Daily \% Buses Trips} = \frac{\text{trotros and buses (inner cordon + outer trips)}}{2}$$

$$= \frac{(69+73)}{2} = 71\%$$

Therefore, number of Daily trips using Buses = 71% x 2,900,000

= 2,059,000 trips

From figure 6.6b these trips were made using 2,300 buses

Therefore, Daily Passenger trip/Bus used = 2,059,000/2,300 = 895 trips/bus

Converting passenger trips to vehicle kilometer traveled:

From table 6.3a the Annual vehicle km travel for a Passenger car = 22,500 km
And the Annual vehicle km travel for a Bus = 14,000 km
Therefore, Daily vehicle km travel for a Passenger car = 22,500 km/365
Similarly, Daily vehicle km travel for Buses = 14,000km/365
Number for km/trips for a Passenger car = 22,500/(365 x 106) = 0.6 km/trip
Number of km/trips for Buses = 14,000/(365 x 895) = 0.04 km/trip

Scenario 1: In the first Scenario, analysis is based on a 10% shift from Passenger car trips to buses trips i.e. a 10% decrease in passenger car trips and a 10% increase in buses trips, therefore from the QUESTOR project survey (refer to figure 6.6a and 6.6b), the average daily % Passenger car trips will decrease from 24% to 14% (406,000 trips per day) and that of buses will increase from 71% to 81% (2,349,000 trips per day).

Therefore in Scenario 1 the new annual vehicle km traveled for Passenger cars and Buses will be as follows:
Total Annual vehicle km traveled for the 6,600 Passenger cars = 406,000 trips/day x 0.6 km/trip x 365 days = 88,914,000 km
Therefore new Annual vehicle km travel for a Passenger car = 88,914,000/6,600 km
= **<u>13,472 km</u>**

Similarly, total Annual vehicle km traveled for the 2,300 Buses = 2,349,000 trips/day x 0.04 km/trip x 365 days = 34,295,400 km
Therefore, new Annual vehicle km travel for a Bus = 34,295,400/2,300
= **<u>14,911 km</u>**

Scenario 2: In the second Scenario, a analysis is based on a 20% shift from Passenger car trips to buses trips i.e. a 20% decrease in passenger car trips and a 20% increase in buses trips, therefore from the QUESTOR project survey (refer to figure 6.6a and 6.6b), the average daily % Passenger car trips will decrease from 24% to 4% (116,000 trips per day) and that of buses will increase from 71% to 91% (2,639,000 trips per day).
Therefore in Scenario 2 the new annual vehicle km traveled for Passenger cars and Buses will be as follows:

Total Annual vehicle km traveled for the 6,600 Passenger cars = 116,000 trips/day x 0.6 km/trip x 365 days = 25,404,000 km
Therefore new Annual vehicle km travel for a Passenger car = 25,404,000/6,600 km

= **3,849 km**

Similarly, total Annual vehicle km traveled for the 2,300 Buses = 2,639,000 trips/day x 0.04 km/trip x 365 days = 38,529,400 km
Therefore, new Annual vehicle km travel for a Bus = 38,529,400/2,300

= **16,752 km**

6.7 Concluding Remarks

Sampling data for this research was carried out in June, 2006 and since emissions inventory requires annual data, the research therefore, based the vehicle emissions computations for the base year on 2005 data, thus, 2005 was set as the base year. The computation of vehicle emissions for the forecast year 2010 and 2020 was based on vehicle fleet data using the growth rate derived from the QUESTOR model project. Since, fuel consumption data for the forecast years was not available, the fuel consumption data used was adjusted to balance the calculated value obtained from the COPERT software. However, due to unavailability of data, all other input data used in the computation was assumed unchanged, and thus the 2005 data was used. The Scenario created for the forecast year 2010 and 2020 emission computation, also assumed all input data used for the 2010 and 2020 respectively except the vehicle kilometre input data which, was adjusted for passenger cars and buses.

In the next chapter, the results of the computation of vehicle emissions in Ghana using the COPERT software will be presented. To give a true representation of the impact each pollutant contributes to global warming, the results of the pollutants are converted to Carbon dioxide equivalent using the Global Warming Potential (GWP) values for each pollutant.

7.0 Presentation and Analysis of Results

Emissions results computed using the COPERT III software of pollutants (Nitrogen oxides NO_X, Carbon dioxide CO_2, Carbon monoxide CO, Nitrous oxide N_2O, and Methane CH_4), for the different categories of vehicles in Ghana are presented for the base year 2005, forecast years 2010, 2020 and the two scenarios for each of the forecast years. As it was discussed in chapter 2, these pollutants have different degree of effect on health and the environment, thus to assess the effect of the results on global warming, the total emissions for each pollutant was normalized. The normalization was done by multiplying the results of total emissions of each pollutant by its Global Warming Potential (GWP) value.

The GWP of a Greenhouse Gas (GHG) is a measure of the potential for global warming per unit mass relative to Carbon dioxide over a period of time. The GWP values are determined by the Inter-Governmental Panel on Climate Change (IPCC), because of the dynamics of the radiative effect of the GHG, the GWP values are constantly modified by the IPCC. The GWP values quoted by the IPCC are normally calculated based on the time span for which the potential is effective, thus different values for different time horizon. In this research a 100- year period time span was assumed and the GWP based on the IPCC guidelines for the Third Assessment Report (IPCC, 2001), for CO and NOx, the GWP values for indirect GHG were used. Thus, the following GWP values were used:

GHG	100-year GWP
CO_2	1
CO	2
CH4	23
NO_x	40
N_2O	296

The results of mostly regulated vehicle Greenhouse Gas emissions computations in metric tonnes obtained from the use of the COPERT software are detailed in Appendices

XXV-LIX. However, the total emissions for each pollutant converted to CO_2 equivalent after multiplying the values by the corresponding GWP value, is presented in this chapter. Also presented, alongside the emissions values are the total fuel consumption patterns.

7.1 Business As Usual (BAU) Results

To simplify the analysis of results, the results of the base year 2005, forecast year 2010 and 2020 are classified as Business As Usual (BAU), depicting a situation where, there will be no major changes to the trend in policies or economic determinants that meet the transport and energy demand in Ghana. The results of the BAU emissions and energy consumption results are summarized in tables 7.1a to 7.1f, after which the interpretation and analysis of these results are made.

Table 7.1a Business As Usual 2005 Total Emissions [tCO2e]

Business As Usual 2005 Total Emission [t CO2e]			
Pollutants	[t]	[t CO2e]=GWP(gas) x [t]	% Contribution
NOX	11064	442560	9,62
CO2	3819739	3819739	83,04
CO	90669	181338	3,94
N2O	483	142968	3,11
CH4	545	13353	0,29
Total	**3922500**	**4599958**	**100,00**

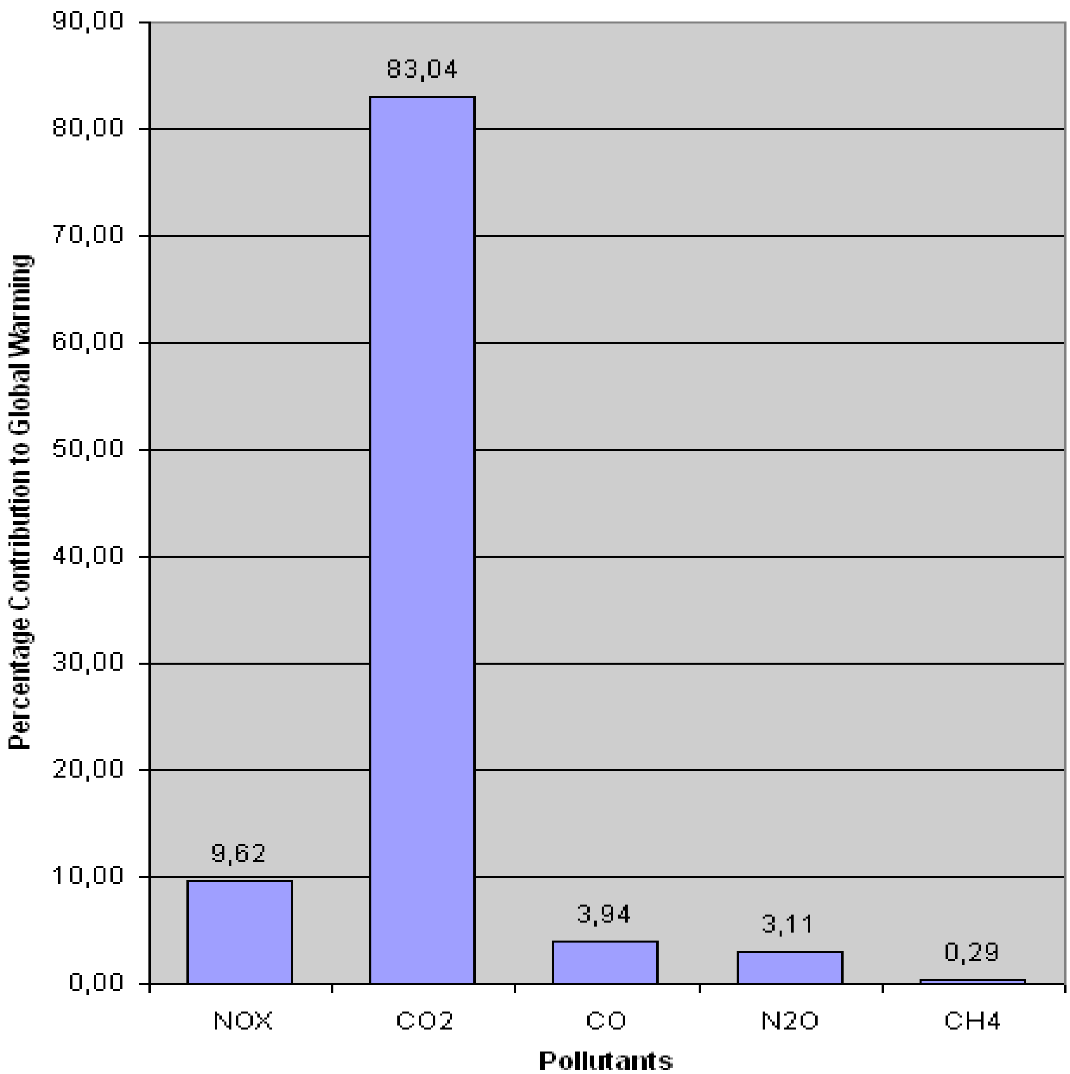


Table 7.1b Business As Usual 2005 Fuel Consumption Pattern[t]

2005 Fuel Consumption Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Diesel			
Passenger Cars	**139217**	**5024**	**144241**
Diesel < 2.0l	139217	5024	144241
Light Duty Vehicles	**24328**	**745**	**25073**
Diesel <3.5t	24328	745	25073
Heavy Duty Vehicles	**190864**	**0**	**190864**
Diesel 7.5 -16t	85754	0	85754
Diesel 16 - 32t	89042	0	0
Diesel >32t	16067	0	16067
Buses	**359795**	**0**	**359795**
Urban Buses	359795	0	359795
Total:	**714204**	**5769**	**719973**
Liquefeid Petroleum Gas			
Passenger Cars	**237**	**13**	**250**
LPG	237	13	250
Total:	**237**	**13**	**250**
Unleaded Gasoline			
Passenger Cars	**370006**	**23999**	**394005**
Gasoline 1.4 - 2.0l	370006	23999	394005
Light Duty Vehicles	**59598**	**4046**	**63644**
Gasoline < 3.5t	59598	0	62644
Motorcycles	**32352**	**0**	**32352**
4-stroke 250-750 cc	32352	0	32352
Total:	**461956**	**28045**	**490001**

Table 7.1c Business As Usual 2010 Total Emissions [tCO2e]

Business As Usual 2010 Total Emission [t CO2e]			
Pollutants	[t]	[t CO2e]=GWP(gas) x [t]	% Contribution
NOX	14580	583200	9,34
CO2	5190147	5190147	83,11
CO	124230	248460	3,98
N2O	700	207200	3,32
CH4	704	16192	0,26
Total	**5330361**	**6245199**	**100,00**

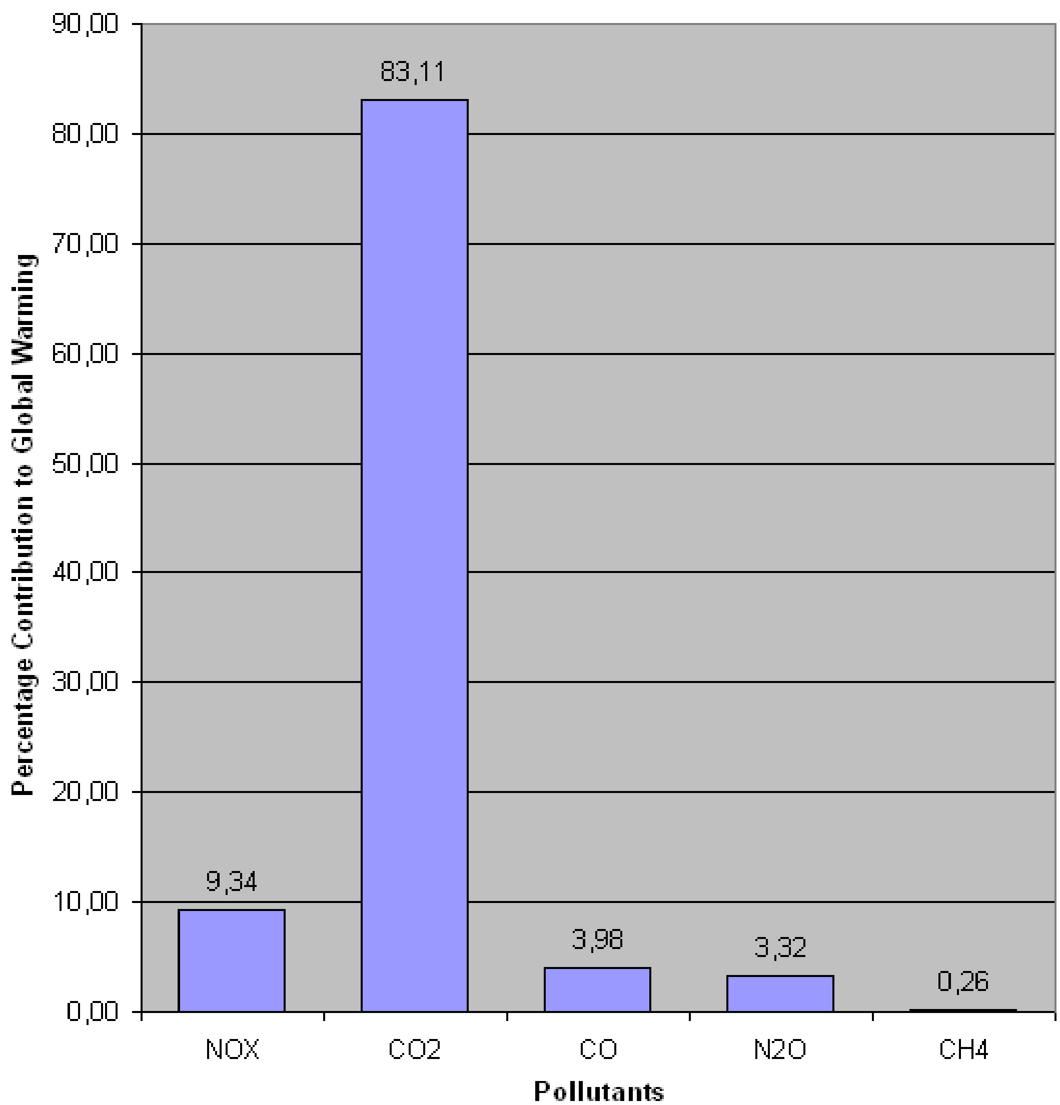


Table 7.1d Business As Usual 2010 Fuel Consumption Pattern [t]

2010 Fuel Consumption Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Diesel			
Passenger Cars	**210013**	**6794**	**216807**
Diesel < 2.0l	210013	6794	216807
Light Duty Vehicles	**30732**	**843**	**31575**
Diesel <3.5t	30732	843	31575
Heavy Duty Vehicles	**257904**	**0**	**257904**
Diesel 7.5 -16t	115876	0	115876
Diesel 16 - 32t	120316	0	120316
Diesel >32t	21713	0	21713
Buses	**426246**	**0**	**426246**
Urban Buses	426246	0	426246
Total:	**924895**	**7637**	**932532**
Liquefeid Petroleum Gas			
Passenger Cars	**358**	**18**	**376**
LPG	358	18	376
Total:	**358**	**18**	**376**
Unleaded Gasoline			
Passenger Cars	**558166**	**32451**	**590617**
Gasoline 1.4 - 2.0l	558166	32451	590617
Light Duty Vehicles	**75163**	**4574**	**79737**
Gasoline < 3.5t	75163	4574	79737
Motorcycles	**40491**	**0**	**40491**
4-stroke 250-750 cc	40491	0	40491
Total:	**673820**	**37025**	**710845**

Table 7.1e Business As Usual 2020 Total Emissions [tCO2e]

Business As Usual 2020 Total Emission [t CO2e]			
Pollutants	[t]	[t CO2e]=GWP(gas) x [t]	% Contribution
NOX	20260	810400	8,29
CO2	8145046	8145046	83,34
CO	211520	423040	4,33
N2O	1251	370296	3,79
CH4	1077	24771	0,25
Total	**8379154**	**9773553**	**100,00**

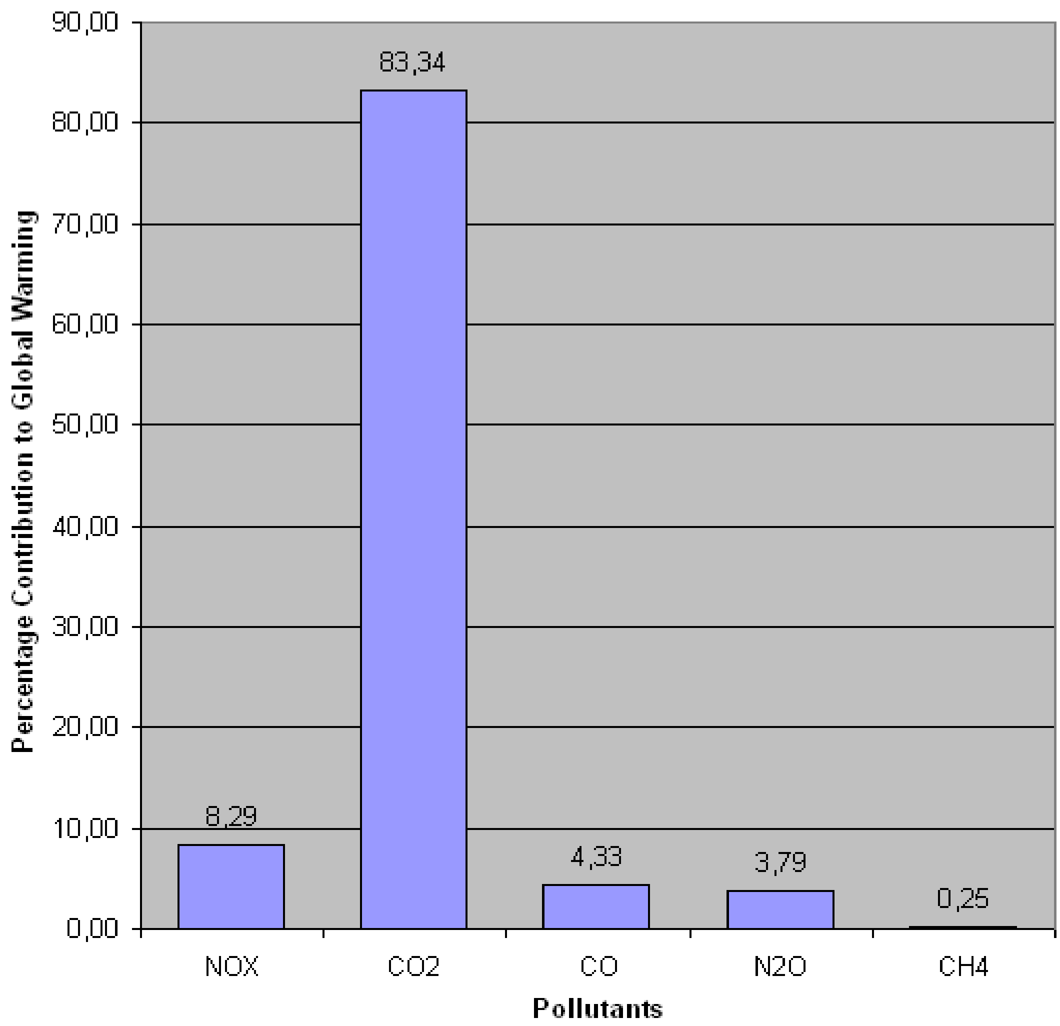


Table 7.1f Business As Usual 2020 Fuel Consumption Pattern [t]

2020 Fuel Consumption Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Diesel			
Passenger Cars	**403278**	**14554**	**417832**
Diesel < 2.0l	403278	14554	417832
Light Duty Vehicles	**39938**	**1222**	**41160**
Diesel <3.5t	39938	1222	41160
Heavy Duty Vehicles	**335164**	**0**	**335164**
Diesel 7.5 -16t	150589	0	150589
Diesel 16 - 32t	156360	0	156360
Diesel >32t	28216	0	28216
Buses	**483041**	**0**	**483041**
Urban Buses	483041	0	483041
Total:	**1261421**	**15776**	**1277197**
Liquefeid Petroleum Gas			
Passenger Cars	**687**	**39**	**726**
LPG	358	18	376
Total:	**687**	**39**	**726**
Unleaded Gasoline			
Passenger Cars	**1071814**	**69518**	**1141332**
Gasoline 1.4 - 2.0l	1071814	69518	1141332
Light Duty Vehicles	**97681**	**6631**	**104312**
Gasoline < 3.5t	97681	6631	104312
Motorcycles	**53324**	**0**	**53324**
4-stroke 250-750 cc	53324	0	53324
Total:	**1222819**	**76149**	**1298968**

The results of the BAU as shown in tables 7a-7f, shows almost a consistent pattern in terms of the percentage, each pollutant emits, with CO_2 contributing the largest with about 80% and NO_x, CO, N_2O, and CH_4 in a decreasing order. In terms of the quantity emitted, projection for the year 2010 indicate that the total emissions expressed in million tonnes of CO_2 equivalent (Mt CO_2e) will increase by 36% i.e. from the base year figure of 4.6 to 6.25 Mt CO_2e in 2010, whilst the projection for 2020 will over double the base year figure to 9.77 Mt CO_2e. This is as a result of anticipated increases in travel demand and the number of vehicles coupled with the ineptitude of policies to reduce vehicle emissions in Ghana.

The fuel consumption results for the base year 2005, shows a slight change in value as compared to the input fuel data (refer to chapter 6.2). This was due to the fact that the input value used in computations was the total Gasoline and Diesel consumed in Ghana for the year 2005, i.e. including off-road vehicles, machinery and equipments and also vehicles used by the security services in Ghana, which were excluded in this research. Hence Gasoline and Diesel consumption results for 2005 shown in figure 7.1b accounted for 90% and 84% respectively of the input fuel consumption data, this implies the remaining 10% and 16% of gasoline and diesel consumption respectively accounts for off-road vehicles, machinery, equipments and vehicles used by the security services in Ghana.

For the same reasons contributing to increases in total emissions, fuel consumptions for the forecast year 2010 and 2020, also showed an upward trend in results, the increases pattern can be seen in the percentage changes as shown in table 7.1g

Table 7.1g BAU Total Fuel Consumption Pattern

Total Fuel Consumption Results Pattern			
	2005	2010	2020
Gasoline[t]	490,001.20	710,845	1,298,968
% Change		45	165
Diesel [t]	719,973	932,532	1,277,197
% Change		30	77
Liquefied Petroleum Gas [t]	250	376	726.5
% Change		50	191

7.2 Scenario Results for 2010 and 2020

A summarized result of the total emissions in metric tonnes of CO_2 equivalent and energy consumptions for the two different scenarios created for each of the forecast year 2010 and 2020 are presented in tables 7.2a to 7.2g. Finally, a comparative analysis of emission results between the BAU and the two scenarios are made.

Table 7.2a Scenario 1 2010 Total Emissions [tCO2e]

Scenario 1 2010 Total Emission [t CO2e]			
Pollutants	[t]	[t CO2e]=GWP(gas) x [t]	% Contribution
NOX	13236	529440	10,53
CO2	4154315	4154315	82,62
CO	94856	189712	3,77
N2O	474	140304	2,79
CH4	615	14145	0,28
Total	**4263496**	**5027916**	**100,00**

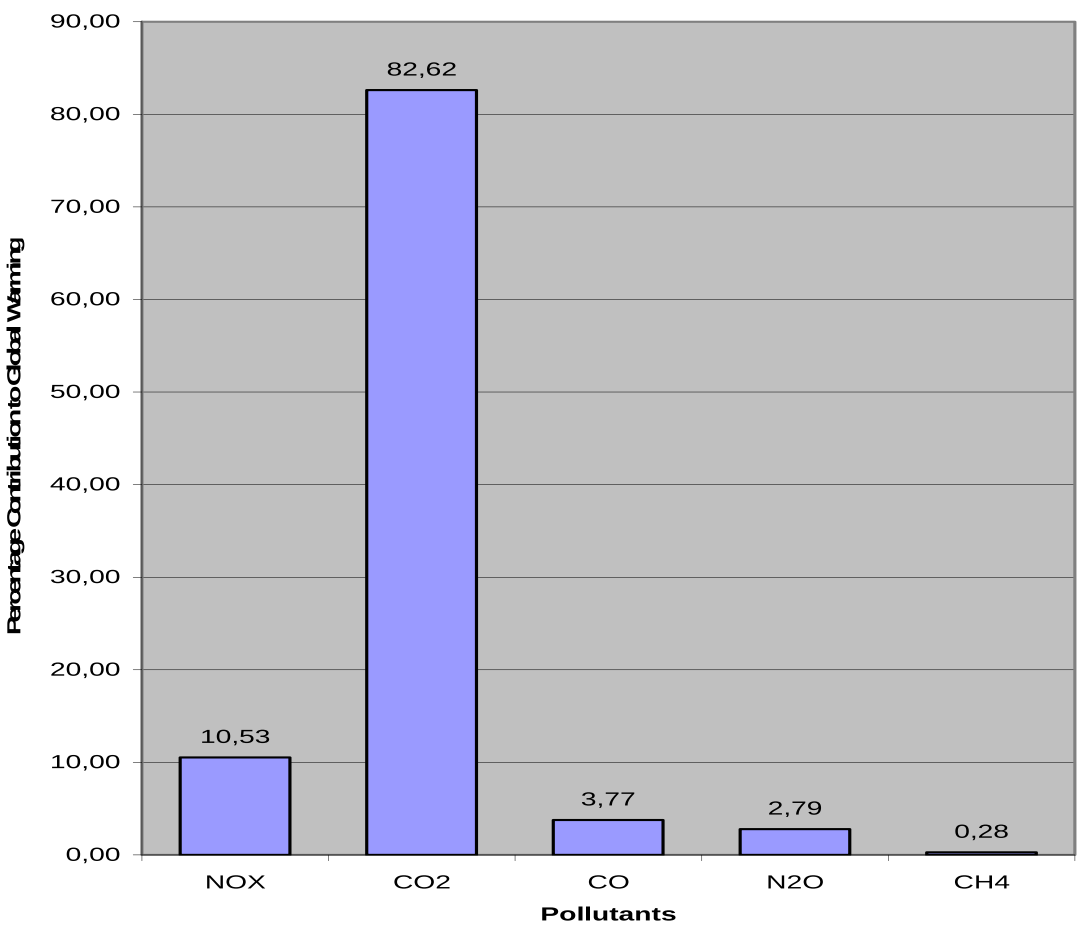


Table 7.2b Scenario 1 2010 Fuel Consumption Pattern [t]

Scenario1 2010 Fuel Consumption Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Diesel			
Passenger Cars	**125747**	**4068**	**129815**
Diesel < 2.0l	125747	4068	129815
Light Duty Vehicles	**30732**	**843**	**31575**
Diesel <3.5t	30732	843	31575
Heavy Duty Vehicles	**257904**	**0**	**257904**
Diesel 7.5 -16t	115876	0	115876
Diesel 16 - 32t	120316	0	120316
Diesel >32t	21713	0	21713
Buses	**423717**	**0**	**423717**
Urban Buses	423717	0	423717
Total:	**838100**	**4911**	**843011**
Liquefeid Petroleum Gas			
Passenger Cars	**214**	**11**	**225**
LPG	214	11	225
Total:	**214**	**11**	**225**
Unleaded Gasoline			
Passenger Cars	**334205**	**19430**	**353635**
Gasoline 1.4 - 2.0l	334205	19430	353635
Light Duty Vehicles	**75163**	**4574**	**79737**
Gasoline < 3.5t	75163	4574	79737
Motorcycles	**40491**	**0**	**40491**
4-stroke 250-750 cc	40491	0	40491
Total:	**449859**	**24004**	**473863**

Table 7.2c Scenario 1 2020 Total Emissions [tCO2e]

Scenario 1 2020 Total Emission [t CO2e]			
Pollutants	[t]	[t CO2e]=GWP(gas) x [t]	% Contribution
NOX	17669	706760	9,52
CO2	6151140	6151140	82,82
CO	153548	307096	4,13
N2O	816	241536	3,25
CH4	891	20493	0,28
Total	**6324064**	**7427025**	**100,00**

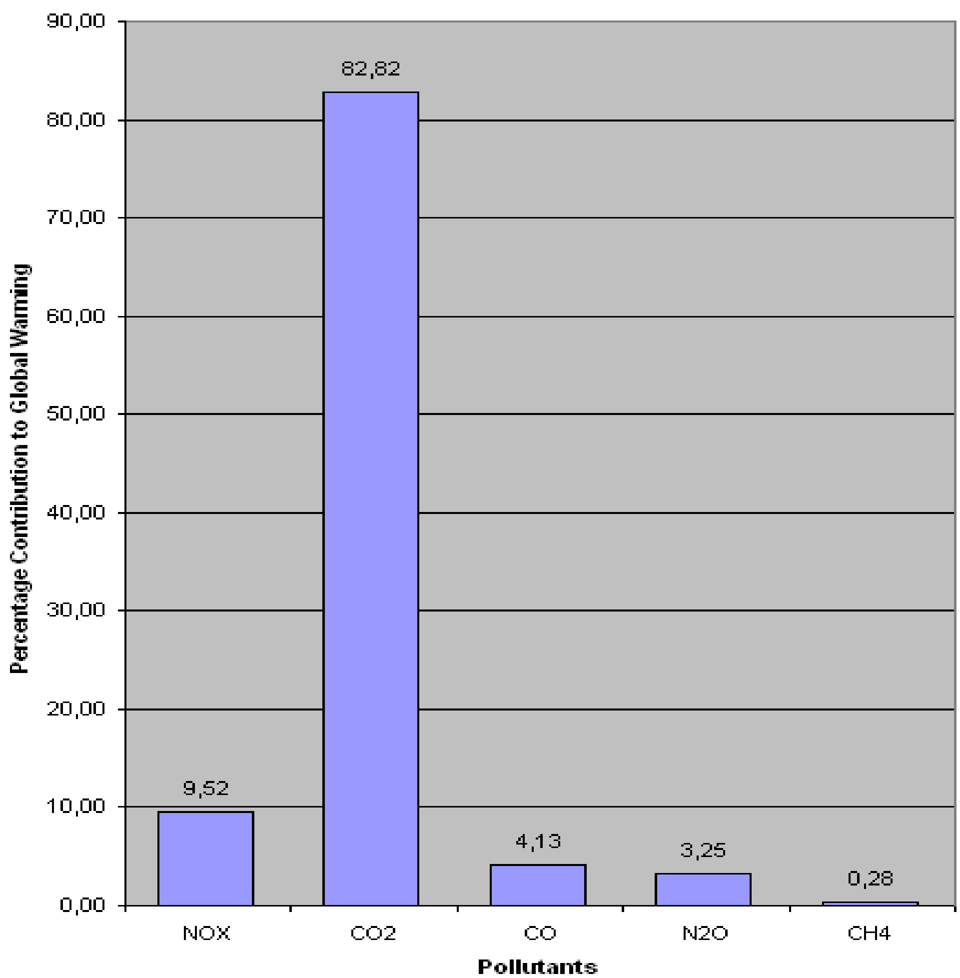


Table 7.2d Scenario 1 2020 Fuel Consumption Pattern [t]

Scenario1 2020 Fuel Consumption Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Diesel			
Passenger Cars	**241465**	**8714**	**250179**
Diesel < 2.0l	241465	8714	250179
Light Duty Vehicles	**39938**	**1222**	**41160**
Diesel <3.5t	39938	1222	41160
Heavy Duty Vehicles	**335164**	**0**	**335164**
Diesel 7.5 -16t	150589	0	150589
Diesel 16 - 32t	156360	0	156360
Diesel >32t	28216	0	28216
Buses	**480175**	**0**	**480175**
Urban Buses	480175	0	480175
Total:	**1096742**	**9936**	**1106678**
Liquefeid Petroleum Gas			
Passenger Cars	**412**	**23**	**435**
LPG	412	23	435
Total:	**412**	**23**	**435**
Unleaded Gasoline			
Passenger Cars	**641755**	**41625**	**683380**
Gasoline 1.4 - 2.0l	641755	41625	683380
Light Duty Vehicles	**97681**	**6631**	**104312**
Gasoline < 3.5t	97681	6631	104312
Motorcycles	**53324**	**0**	**53324**
4-stroke 250-750 cc	53324	0	53324
Total:	**792760**	**48256**	**841016**

Table 7.2e Scenario 2 2010 Total Emissions [tCO2e]

Scenario 2 2010 Total Emission [t CO2e]			
Pollutants	[t]	[t CO2e]=GWP(gas) x [t]	% Contribution
NOX	12431	497240	12,65
CO2	3222362	3222362	81,99
CO	63684	127368	3,24
N2O	240	71040	1,81
CH4	529	12167	0,31
Total	**3299246**	**3930177**	**100,00**

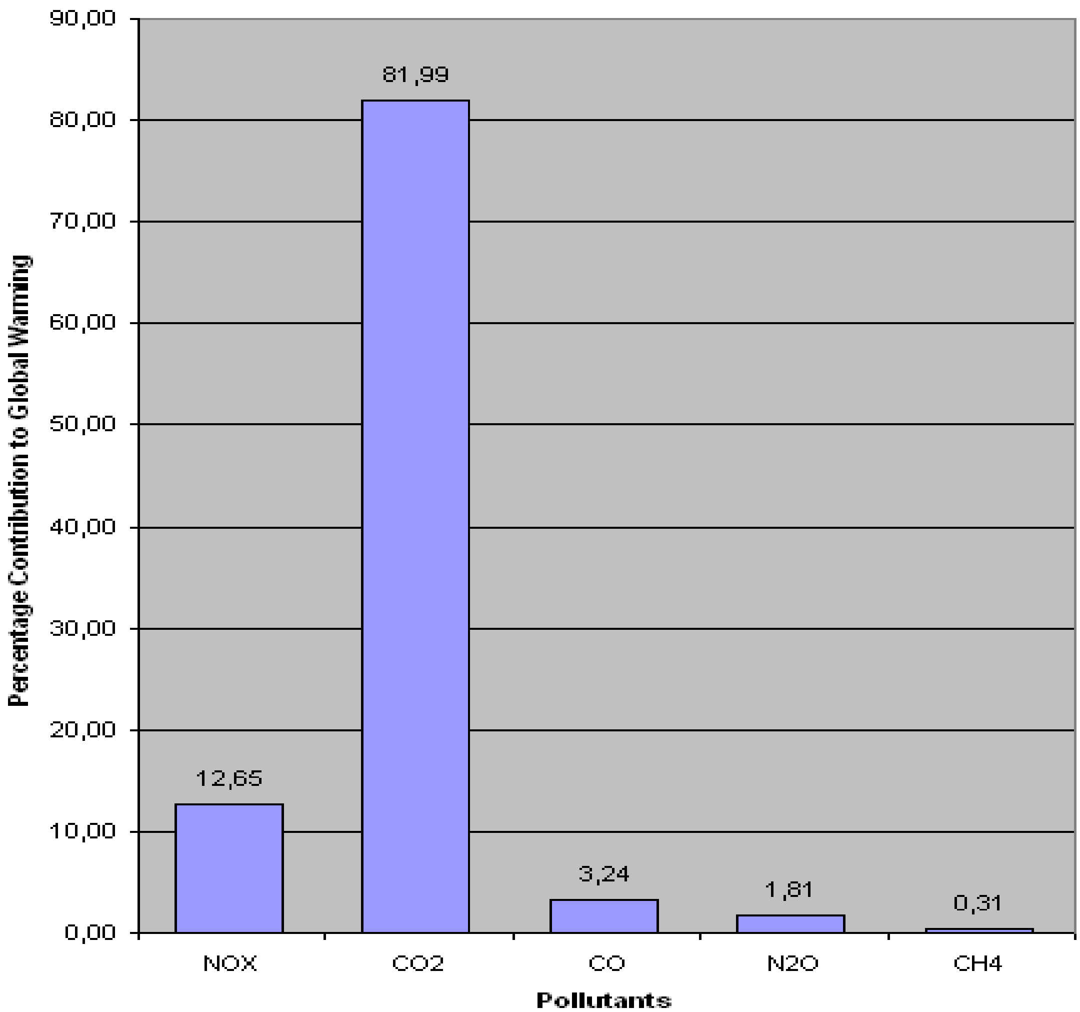


Table 7.2f Scenario 2 2010 Fuel Consumption Pattern [t]

Scenario2 2010 Fuel Consumption Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Diesel			
Passenger Cars	**35889**	**1161**	**37050**
Diesel < 2.0l	35889	1161	37050
Light Duty Vehicles	**30732**	**843**	**31575**
Diesel <3.5t	30732	843	31575
Heavy Duty Vehicles	**257904**	**0**	**257904**
Diesel 7.5 -16t	115876	0	115876
Diesel 16 - 32t	120316	0	120316
Diesel >32t	21713	0	21713
Buses	**476031**	**0**	**476031**
Urban Buses	476031	0	476031
Total:	**800556**	**2004**	**802560**
Liquefeid Petroleum Gas			
Passenger Cars	**76**	**4**	**80**
LPG	76	4	80
Total:	**76**	**4**	**80**
Unleaded Gasoline			
Passenger Cars	**95384**	**5546**	**100930**
Gasoline 1.4 - 2.0l	95384	5546	100930
Light Duty Vehicles	**75163**	**4574**	**79737**
Gasoline < 3.5t	75163	4574	79737
Motorcycles	**40491**	**0**	**40491**
4-stroke 250-750 cc	40491	0	40491
Total:	**211038**	**10120**	**221158**

Table 7.2g Scenario 2 2020 Total Emissions [tCO2e]

Scenario 2 2020 Total Emission [t CO2e]			
Pollutants	[t]	[t CO2e]=GWP(gas) x [t]	% Contribution
NOX	15619	624760	12,13
CO2	4220540	4220540	81,91
CO	91903	183806	3,57
N2O	362	107152	2,08
CH4	707	16261	0,32
Total	**4329131**	**5152519**	**100,00**

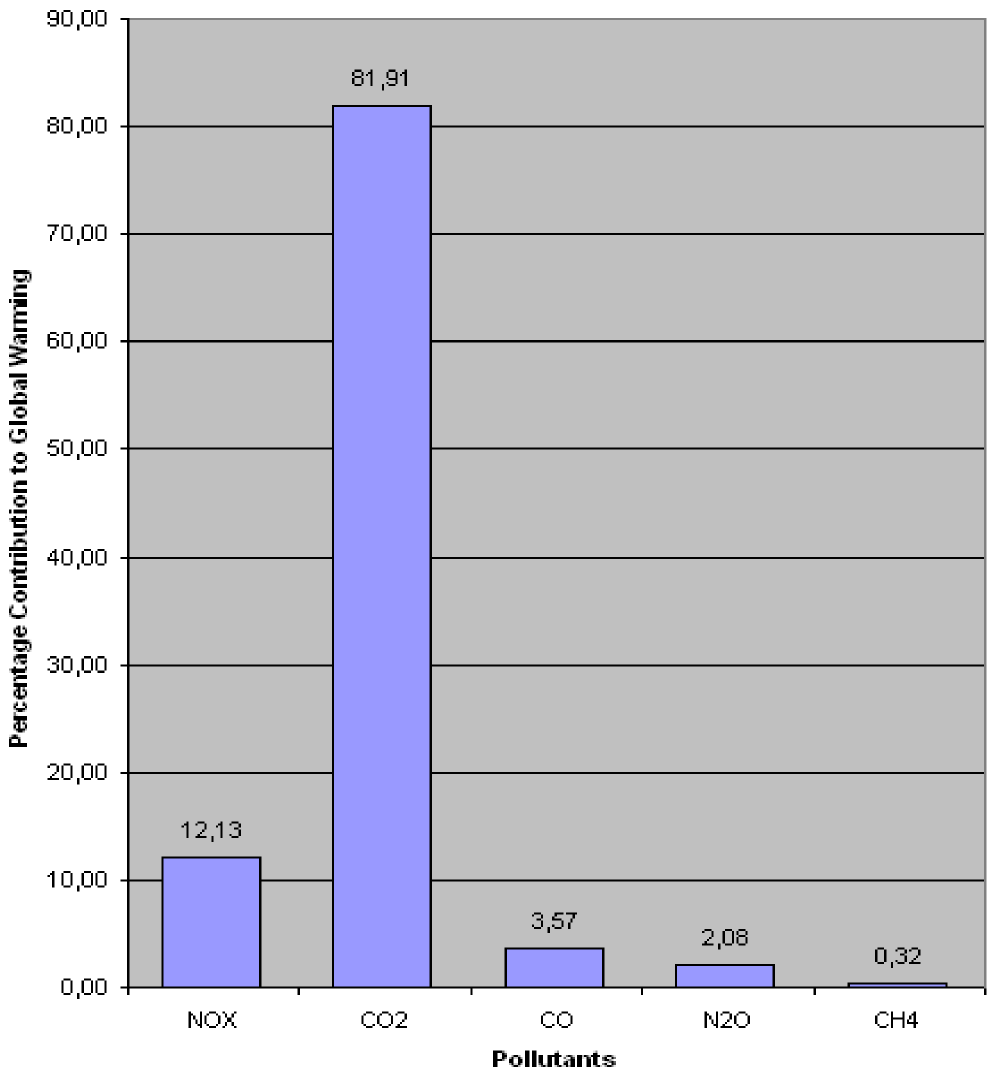
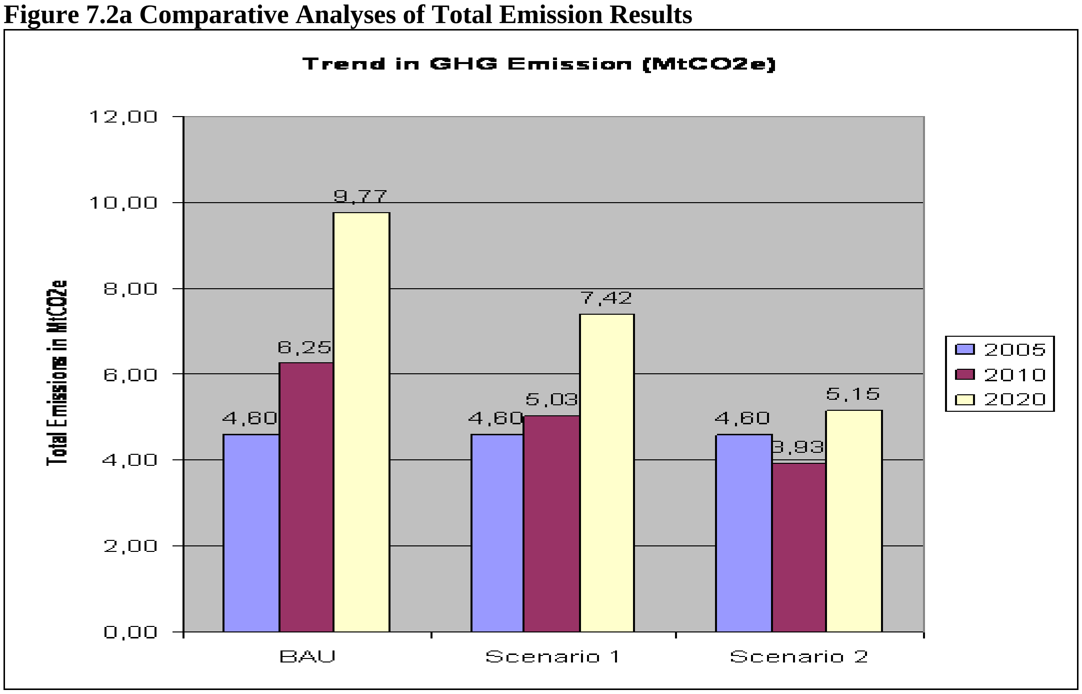


Table 7.2h Scenario 2 2010 Fuel Consumption Pattern [t]

Scenario2 2020 Fuel Consumption Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Diesel			
Passenger Cars	**68.916**	**2.487**	**71.403**
Diesel < 2.0l	68.916	2.487	71.403
Light Duty Vehicles	**39.938**	**1.222**	**41.160**
Diesel <3.5t	39.938	1.222	41.160
Heavy Duty Vehicles	**335.164**	**0**	**335.164**
Diesel 7.5 -16t	150.589	0	150.589
Diesel 16 - 32t	156.360	0	156.360
Diesel >32t	28.216	0	28.216
Buses	**539.461**	**0**	**539.461**
Urban Buses	539.461	0	539.461
Total:	**983.479**	**3.709**	**987.188**
Liquefeid Petroleum Gas			
Passenger Cars	**117**	**7**	**124**
LPG	117	7	124
Total:	**117**	**7**	**124**
Unleaded Gasoline			
Passenger Cars	**183.161**	**11.880**	**195.041**
Gasoline 1.4 - 2.0l	183.161	11.880	195.041
Light Duty Vehicles	**97.681**	**6.631**	**104.312**
Gasoline < 3.5t	97.681	6.631	104.312
Motorcycles	**53.324**	**0**	**53.324**
4-stroke 250-750 cc	53.324	0	53.324
Total:	**334.166**	**18.511**	**352.677**

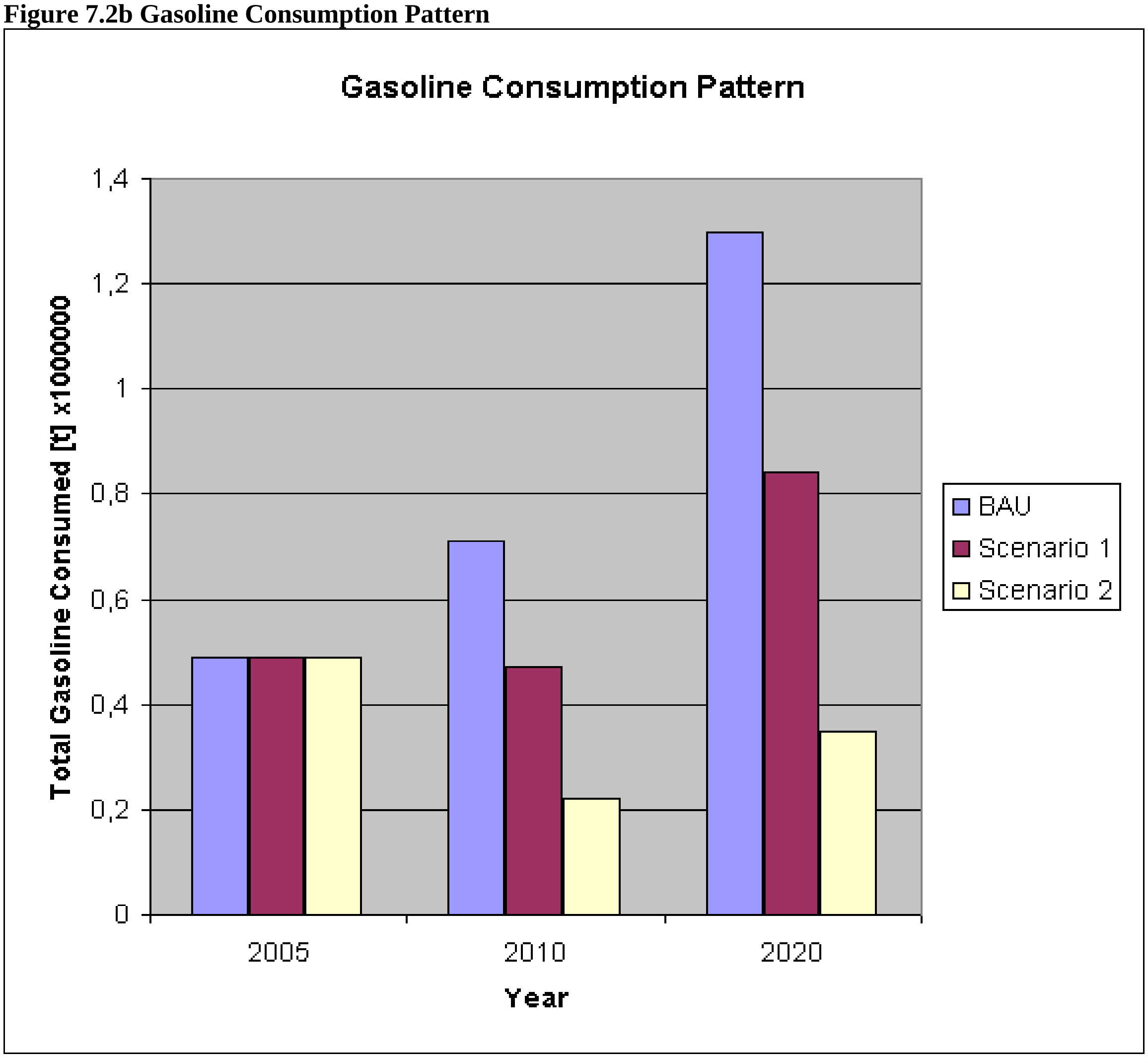
The total emissions results for the scenarios as shown in tables 7.2a to 7.2g, displays a similar pattern as BAU's results in terms of the pattern of the percentage each pollutant contributes to global warming, however the contribution of NO_x was slightly higher due to the relative increases in diesel consumption as compared to gasoline for the scenarios. This was as a result in the increases in buses activities, a chunk of which uses diesel and secondly, as a result of a decrease in passenger car use. In terms of the total quantity of emissions, figure 7.2a below gives a complete summary of the comparative results. Figure 7.2a shows that, for scenario 1, total emissions in Mt CO_2e will increase from 4.6 Mt CO_2e in 2005 to 5.03 Mt CO_2e , and 7.42 Mt CO_2e in the forecast year 2010 and 2020 respectively, however the increment are relatively small compared to the BAU increase trend shown in figure 7.2a. In Scenario 2, the total emission however, showed an irregular pattern, where it decreases to 3.93 Mt CO_2e in 2010 and rises to 5.15 Mt CO_2e in 2020, but both figures are less compared to their corresponding figures in BAU and Scenario 1.

Figure 7.2a Comparative Analyses of Total Emission Results



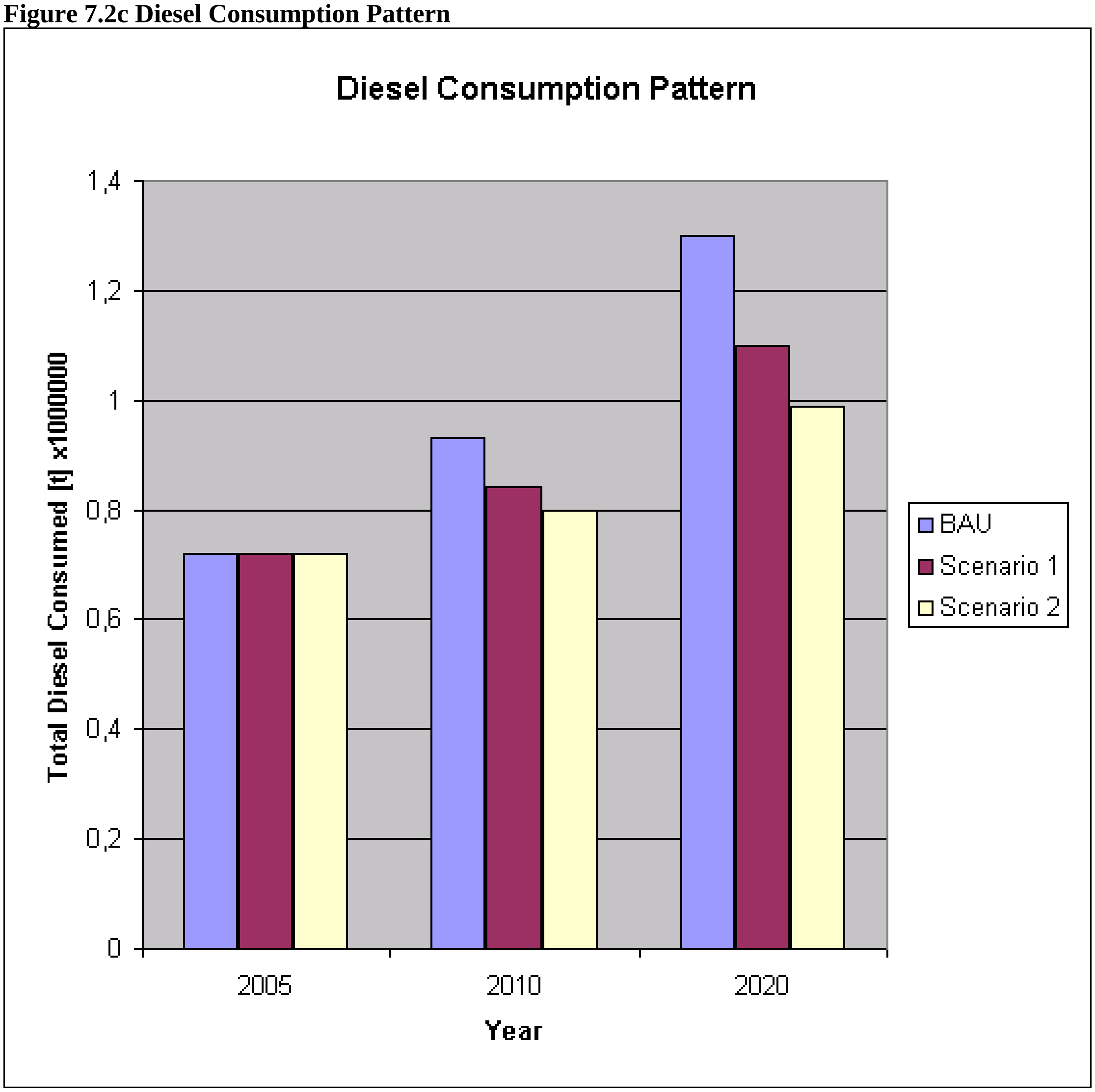
A comparative analysis of total gasoline consumed in 2010 and 2020 between the BAU and its corresponding figures in the Scenarios, shows a decreasing trend as shown in figure 7.2b, decreasing from 710,845 t to 473,863 t in 2010 and from 1,298,968 t to 841,016 t in 2020 for Scenario 1, about a 50% decrease in both cases. In the case of Scenario 2, there is a sharp decrease i.e. from 710,845 t to 221,158 t in 2010 and from 1,298,968 t to 352,677 t in 2020, over 200% decrease in both cases. These decreases in trend is as a result of the decreases in passenger car activities in these scenarios, 70% of passenger cars in Ghana are known to use gasoline hence a decrease in the use of passenger car will show a similar decreasing trend.

Figure 7.2b Gasoline Consumption Pattern



A comparative analysis of total diesel consumed in 2010 and 2020 between the BAU and its corresponding figures in the Scenarios shows a similar pattern shown in gasoline consumption i.e. a decreasing trend, however, the margin of decrease are relatively very small as can be seen in figure 7.2c. The relative small decreases in trend is as a result of the decreases in passenger car activities, however, only 30% of passenger cars in Ghana are known to use diesel, hence, the small decrease effect shown on the overall diesel consumption.

Figure 7.2c Diesel Consumption Pattern



7.3 Economic Evaluation of the scenarios if linked to the Kyoto Protocol CDM

Emissions and fuel reductions shown in the results of the scenarios generated in this research (Figure 7.2a, Figure7.2b, and Figure 7.2c) demonstrate that developing countries such as Ghana have the potential to make real meaningful and long term contributions to climate change mitigation, while generating important benefits for sustainable development. For example, a wide range of highly cost effective emissions reductions projects in the road transport sector in Ghana could be registered under the Kyoto Protocol Clean Development Mechanism (CDM) initiative to achieve the emissions and fuel reductions results in the scenarios generated in this research. Under article 12 of the Kyoto Protocol CDM (UNFCCC, 1998), countries listed as non-annex I such as Ghana could benefit from project activities resulting in emissions reductions, where for every tonne of CO_2 reduced or avoided a country is credited with a coupon called Certificate of Emission Reduction (CER) which can be traded on the international market.

7.3.1 Potential Economic Benefit

Table 7.3.1a shows the yearly rate of emissions reduction computation under scenarios1. The second and third row in the table shows total vehicle Greenhouse gas emissions in million tonnes of Carbon dioxide equivalent ($MtCO_2e$) emitted in 2005 and for the two forecast years 2010 and 2020 under the Business as Usual (BAU) and scenario1 respectively (refer to graph on figure 7.2a in the preceding section). Therefore, the total emissions that will be reduced or avoided under scenario1 are the differences in total emissions between the Business as Usual (BAU) and the corresponding scenario forecast year's values (shown in row 4 of table 7.3.1). Thus, dividing the total emissions that will be reduced by the duration (5 years i.e. between 2005 and 2010 or 15 years i.e. between 2005 and 2020) gives the yearly rate of emission reduction.

Table 7.3.1a Scenario 1 Total Emission Reduction per Year

	2005 ($MtCO_2e$)	2010 ($MtCO_2e$)	2020 ($MtCO_2e$)
Business as Usual (BAU) total emissions	4.6	6.2	9.8
Scenario 1 total emissions	4.6	5.0	7.4
Reduction in Emissions	-	1.2	2.4
Reductions in Emissions/year	-	0.24	0.16

Source based on figure 7.2a and the author's own computations

Therefore the average yearly reductions in emissions = $\frac{0.24+0.16}{2}$ $MtCO_2$

$$=0.20\ MtCO_2\ (200{,}000\ tCO_2)$$

1 tCO_2 is equivalent to 1 CER

Taking the European carbon price at the present market value and exchange rate[**]

1 CER = €22.95 ($USD 32.81)

Therefore, under Scenario 1 with a reduction of 200,000 tCO_2e per year (refer to Table 7.3.1a)

The total potential CER value = 200,000 x 32.81 (6,562,000 $USD)

The generation of foreign exchange from export earnings is a major interest to all developing countries, and CERs represent a sustainable new export option. Under the scenario1 conditions, Ghana could produce up to 200,000 coupons of CERs per year (refer to table 7.3.1), generating foreign exchange up to $USD 6.6 million a year. This is about 6.2% of total Net Foreign Direct Investment (FDI) received in 2005[††]. This extra income can help support the country's national accounts.

[**] Price of CER as at 19 October, 2007 (Source: Climate Corporation, http://www.climatecorp.com/default.asp), also using the present (19 October,2007) Euro-Dollar rate of 1.43 Dollar=1Euro (Source: Bloomberg, http://www.bloomberg.com/index_eu.html)

[††] Net FDI inflows in Ghana for 2005 was $USD 106.5 million, Source: world Development Indicators database, April 2007, http://devdata.worldbank.org/external/CPProfile.asp?CCODE=gha&PTYPE=CP

Table 7.3.1b shows a similar yearly emission reduction computation under scenario 2

Table 7.3.1b Scenario 2 Total Emission Reduction per Year

	2005 ($MtCO_2e$)	2010 ($MtCO_2e$)	2020 ($MtCO_2e$)
Business as Usual (BAU) total emissions	4.6	6.2	9.8
Scenario 2 total emissions	4.6	3.9	5.2
Reduction in Emissions	-	2.3	4.6
Total Reductions in Emissions/year	-	0.46	0.32

Source based on figure 7.2a and the author's own computations

Therefore the average yearly reductions in emissions = $\frac{0.46+0.32}{2}$ $MtCO_2$

=0.39 $MtCO_2$ (390,000 tCO_2)

Similarly, under Scenario 2 with a reduction of 390,000 tCO_2e per year (refer to table 7.3.1b)

The potential CER export that can be derived = 390,000 x 32.81 (12,795,900 $USD)

This means under Scenario 2, Ghana can generate extra foreign exchange up to about $USD 13 million forming about 12% of net total FDI inflow for 2005.

7.4 Concluding Remarks

As Ghana is set on the path of economic growth and expected to reach a middle income level in the near future, so are the transportation activities and its negative impacts expected to increase. If the current trend in policies that meet transportation and energy demand in Ghana does not change then, as shown in the results of the "Business as Usual" in figure 7.2a, not only will the traffic congestion situation compound in future but also vehicle emissions which causes health and climatic problems will over double by the year 2020.

There are policy and technology choices that could significantly lower these emissions growth rate while increasing mobility, improving air quality, reducing traffic congestion and lowering transport and energy cost in Ghana. It is also possible to reduce vehicle emissions in the absence of technology, through behavioural changes, as was demonstrated in the results (see figure 7.2a) of the scenarios created where private car owners park and use public transport for some of their daily trip activities. These mitigation options no doubt will require extra investment in the transport sector to achieve emissions reduction. Again, as demonstrated in section 7.3.1 in this chapter, the expected yearly emission reduction can fetch the country some foreign currency i.e. if investment projects needed to cause this reduction can be registered under the Clean Development Mechanism of Kyoto protocol initiative. The environmental and socio-economic benefits that will be derived are thus worth investing.

The options and opportunities associated with the implementation of vehicle emissions mitigation measures to achieve sustainable road transportation in Ghana will thus be discussed in the next chapter.

Chapter 8

8.0 Discussion

A sustainable road transportation development in any developing country such as Ghana will require a combination of measures besides the use of vehicles with high occupancy. For example, the use of vehicle emissions reduction measures such as Inspection and Maintenance (I/M), Scrappage programs and alternative fuels can further reduce vehicle emissions pollution. Though, putting these measures in place may come at a price, the socio-economic impact will in the long run will be beneficial. Thus, in this discussion section, the likely socio-economic impacts of a sustainable road transportation development in developing countries such as Ghana are examined. More importantly, a number of issues related to policy and management measures which can be identified in the context of traffic in developing countries and in the light of the results on the scenarios created for traffic emissions reduction in Ghana will be discussed.

8.1 Socio-Economic Impact

The results obtain from the scenarios generated in this research tend to reiterate the point that there are efficiency and environmental benefits of moving travellers from private cars to public transport. Many countries, faced with the threat of ever increasing traffic generated pollution and congestion, have adopted policies and strategies to encourage this shift. An obvious benefit is that public transport, with its far greater capacity for moving people, can be effectively used to support urban development policies and programs. For example, as cities grow in size, the maintenance of a strong and thriving city centre calls for daily inward and outward movement of increasingly large volumes of commuters, tourists, shoppers and others, all benefiting from the economies and necessities of central location. Public transport can more easily meet this mass access need, as compared to private cars.

Although controversy continues over the optimal pollution reduction strategy, and the distribution of action between industrialized and developing countries, it is accepted that some mitigation strategy is needed in all countries. A 'business as usual' scenario for the transport sector offers little prospect of relief. The principal components determining the level of emissions in transport are the level of activity (in tons or passenger kilometres), the modes of transport used, the energy intensity of each mode, and the mix of fuels used. The question is how to get policies adopted to achieve the best results such as the scenarios generated in this research. The suggested key to changing this situation is to link emissions pollution mitigation policy initiatives to goals that are perceived to be of immediate relevance (such as local air pollution and the potential economic benefits that contributes to the country's Balance of Payment) and to try to uncouple, or at least 'flex' the link between economic growth and emissions from the transport sector (Schipper and Marie-Lilliu, 1999).

Road based public transport tends to dominate in most cities, however, some major cities tend to have a long history for building and rail based schemes as the backbone for public transport services. Road based public transport, given adequate operational support (e.g. dedicated tracks, off-line bus stands, trunk and feeder routing, etc) is adequate to handle peak corridor flows up to about 25,000 passengers per hour, but higher flows may necessitate a rail based system which can handle higher capacity (Fouracre and Maunder, 1999).

A major task confronting countries such as Ghana, where the capital city is the main centre for economic activities in the country, is how to retain the economic benefits of city scale while limiting the deterioration of transport performance that may be associated with population size and density. In finding a solution to this dilemma, it must be recognized that cities differ greatly in economic, social and spatial characteristics. Moreover, any individual city will change its characteristics over time. Thus, a single blue print may not fit for the development of urban transport systems that is appropriate for all cities at all times. However, there are four basic road transport determinants needed in every city transportation design (Gwilliam, K., 2002).

The first factor, income determines vehicle ownership in a country. Even with rich countries where they tend to have more road infrastructure than poor countries (Ingram and Liu 1999), there is bound to be traffic congestion if traffic are not restricted. This is as a result of the likely slow growth in urban road space with income compared to traffic volume with income (Canning and Bennathan, 2000), thus traffic congestion are likely to increase with increases in income level.

The second factor, city size and its size distribution, tend to determine the average trip length of commuters, and consequently the level of traffic congestion and the environmental impact of road traffic. The third factor which normally contribute to most cities developmental planning is the historical background of the city, this shows the transition between the economic and social systems within the city. A common example is the distinction between socialist planned cities, many of which had widely dispersed pockets of high density residents served by mass transit, and those cities where market forces played a greater role in shaping land use (Dutt et al, 1994). For instance, between 1940 and 1960, driven by market forces to transport and export cocoa, diamond, bauxite and manganese, a number of cities in Ghana were linked up by a railway network. Also, some transitional economies combine rapidly increasing motorization with rapidly declining fiscal capability to support their traditionally extensive public transport systems. The fourth road transport determinant, population growth rate, is another vital indicator mostly used in cities development planning. Economic studies have shown that, generally, cities with rapid population growth rate tend to have above average car ownership rates in relation to income for the national average income level, and they tend to have below average proportions of land space devoted to circulation (Gwilliam, K., 2002). Thus, the high level of car ownership with little road space can lead to road traffic congestion if vehicles are not restricted.

The pressures on urban transport systems are increasing in most developing countries as part of the process of growth. As city population continues to grow, there is stiff competition for land space, these pressures give residents reasons to rethink about relocating outside the city centres where they are employed. This leads to trading off increased travel cost against the lower land costs (and greater availability of space and amenities) as the distance between places of residence and employment increases. As both city centre congestion and incomes increase, people are willing to pay more for space and amenities, so they travel farther to live where land is less expensive and home based movement much easier. This change in location tends to make residents more dependent on private cars, and consequently compounds the traffic congestions in the city centres.

High levels of traffic congestion in most developing countries, especially Sub-Sahara Africa, point to the problem of inadequate urban road infrastructure (Gwilliams, K., 2002). However, tackling traffic congestions in these countries by expanding the road infrastructure may solve the immediate problem i.e. traffic congestion, but will result in other problems for two main reasons. Firstly, it becomes increasingly expensive and both socially and environmentally disturbing to expand existing roads once city fabrics in these countries are established. Secondly, the expansion of roads, without the necessary steps to check the volume of traffic growth will defeat the purpose to reduce traffic congestion. These considerations have some technical implications for the appraisal of investments in extra road infrastructure. Taking the economic and environmental impact of new traffic generation into account will reduce the benefits attributed to the reduction of congestion for existing traffic, offset to some extent by the marginal benefit of the newly generated trips.

A better alternative to tackle this problem of road transport congestion, in this case will be to improve the efficiency of existing infrastructure by traffic management, restraining traffic by demand management, and shifting traffic from private to public transport use.

8.2 Technology Impact

Some technological measures such as replacement of vehicles, enforcing vehicle environmental standards, Inspection and Maintenance I/M programs and Scrappage programs, can help limit the growth in motor vehicle usage in a country, so as to maximise the benefits of motorization while minimizing its adverse impacts on environment and society.

Technological measures to reduce emissions from road transport can primarily be achieved through the replacement of vehicle stock, though this may take a longer period to accomplish, the process can complement other efforts to reduce emissions reduction. In developing countries, however, most of the change of vehicle stock is through growth, so that strategies affecting new vehicles may have a more rapid effect on emissions per unit of activity. Hence, with GDP rising, the best way to achieve a decline in emissions by transport vehicles is a combination of policy reforms in the short term and technological changes in the longer term.

In many developing countries, old and poorly maintained vehicles dominate vehicle fleets. The share of emissions is therefore not uniformly distributed over the vehicle fleet. The poorly maintained often old vehicles, thus, contributes to a large proportion of total pollution from the transport sector. If these 'high emitters' (typically, commercial vehicles and public transport vehicles, including, in some places, two and three wheeler taxis with two stroke engines) can be repaired or eliminated permanently, a considerable reduction in pollution can be achieved at relatively small cost. The implementation of such a scheme is far from simple. To be cost effective, any scheme targeting high emitters should be able to identify polluting vehicles with high annual vehicle km travelled operating in densely populated areas. Old vehicles in very poor condition may be candidates for retirement. Those that are highly polluting but are better maintained may be considered for repair or for retrofitting with more recent vehicle technology. Complicating the issue is the fact that in some cities, such as Cairo, the proportion of old, gross polluters may be very high, with the result that targeting does not leave very many vehicles out of the scope (Gwilliam, K., 2002)

8.2.1 Inspection and Maintenance Programs

To institute any vehicle environmental standards in a country it will be necessary to design appropriate vehicle inspections and maintenance programs, scrappage programs, as well as ensure that related policies are appropriate, and provide the correct incentives, including those related to domestic taxation, trade liberalization, and public expenditures.

Vehicle emissions standards and technologies are not effective without proper maintenance. Introducing effective I/M programs could be a difficult task for example, experience in Wuhan, China, showed that in a roadside testing, 93% of vehicles fell short of the standards even though 97% of these vehicles tested in the same period had passed the I/M test (Roth, 1996). Thus, wider use of spot checking equipment capable of identifying major problems from any relevant vehicle type, and of fixed I/M stations, for more thorough examination and follow up of vehicles so identified, holds promise of significant impact on the pollution problem. Also an appropriate fine and control for non-compliance could make such system self financing.

As far as off-road testing is concerned, an I/M system based on centralized, high volume inspection centres equipped with computerized emissions measurement to minimize tampering and corruption, is likely to be more effective than a decentralized system with a large number of private garages participating in the I/M (Faiz, A. et al, 1996). Besides, inspections in centralized programs tend to have better oversight, standardized training and more experienced inspection personnel. If the proper controls are in place, the private sector can be an important partner in operating effective I/M programs. At a minimum, wide public education campaigns on the social and environmental effects of using poorly maintained vehicles should be undertaken to promote cost effective practices.

8.2.2 Scrappage Programs

When emissions standards are enforced effectively, the cost of owning old vehicles actually increases, making vehicle renewal more attractive. Vehicle retirement and scrappage programs can further encourage this phenomenon as long as it is possible to identify gross emitters that are operating at a high annual rate of vehicle km and that still have reasonable remaining economic lives. Considerable care is needed in designing such schemes, since the use of age as a proxy for high emissions may not always identify the worst cases and hence other factors such as country of manufacture (indicator of standard used in manufacturing), and the frequency of vehicle maintenance need to be considered as well.

Policies that accelerate the retirement or relocation of worn-out and inefficient vehicles and vehicles not equipped with emission controls can be of value, particularly in Ghana where the high cost of vehicle replacement combined with low cost labour for repairs results in large numbers of older vehicles continuing in service well beyond their normal lifespan.

Evidence in Europe that may be relevant for some higher income developing countries suggests that, because gross emitters are typically owned by low income households that are often in no position to purchase much newer vehicles, cash for scrappage schemes may be more effective than cash for replacement schemes (ECMT, 1999). In developing countries, particularly those in which particulate emissions are the most serious pollution concern, commercial vehicles (buses, trucks, and taxis) are the greatest contributors to urban air pollution. Some countries such as Greece (1991-1993), Denmark (1994-995), France (1994-1996), and Ireland (1995-1997) have been quite successful in stimulating early replacement of these vehicles (ECMT, 1999). Developing countries, such as Ghana, can emulate a strategy that was implemented in Hungary, where cash incentives are provided to support the replacement of old buses and trucks with new vehicles complying with most recent emissions standards (Gwilliam, K., 2002).

8.2.3 The Use of Trade Liberalization

It is common for developing countries to use tariffs or trade barriers to protect domestic industry and to prevent the expenditure of scarce foreign exchange on luxury goods that are not essential to economic growth. Where either of these arguments is applied to the import of vehicles, the effect is likely to be the protection of outdated technology. Liberalization of the vehicle trade is hence an important step, particularly in countries that have automobile manufacturing facilities. The removal of barriers that hinder access to the technology available in the rest of the world would enable vehicle owners to meet tighter emissions standards at least cost. High import tariffs on new vehicles, rigid licensing schemes for imports, and quotas are all likely to slow the rate of vehicle renewal, with potentially adverse impacts on air quality (pollution).

Free trade in used cars raises the question of 'environmental dumping'. Among the largest recipient markets for used cars are Cyprus, Jamaica, Peru, Sri Lanka, the Russian Federation, and Sub-Sahara Africa while Japan remains the largest identifiable single source of used car exports (Gwilliam, K., 2002). As EU and other industrialized countries emissions standards and regulations become more stringent, the exports of used cars to developing countries are likely to grow with international free trade policies.

In the interest of environmental protection, governments may limit the age of vehicles imported, either by outright banning the importation of vehicles above a certain age or by placing high tariffs on these old vehicles. However, the purchasing pattern of vehicle owners should be carefully balanced against the hypothetical environmental advantage of restricting the import of old vehicles. If commercial operators (and, in some of the transition economies, low income households) are in no position to buy relatively new vehicles, such an import restriction constrains the supply, and increases the price of replacement vehicles, postponing the replacement of higher emitters. However, a combination of higher general taxation on motoring and environmental standards on vehicles is always likely to reconcile restraint on car use with environmental protection better than discriminatory import taxation.

8.2.4 Fuel Economy

In developing countries, fuel economy is normally affected by what is occurring in the industrialized countries through the availability and cost of imported second hand vehicles. However, the problem goes beyond the use of second hand vehicles, developing countries tend to have special problems of their own. Fuel economy is often low because of poor vehicle maintenance, fuel adulteration, and a number of other factors. Using gasoline with an octane number that is lower than that recommended by vehicle manufacturers either because lower octane gasoline (for example 80 RON) is available and is less expensive or because gasoline is adulterated with kerosene can decrease fuel economy, lead to knocking and ultimately to engine damage, and higher emissions.

Hence, a rather different focus may be appropriate for policy on fuel economy in developing countries including Ghana. The EU, Japan, and the US lead the world in setting stringent vehicle emissions standards and fuel specifications. These countries are pursuing the best available technology for further reducing emissions from new vehicles. Although the rest of the world will probably adopt these standards and technologies some day, the issue for Ghana is how to phase in these measures cost effectively.

Moreover, there have been instances in Ghana where transport fuels are adulterated. Regular fuel quality monitoring, together with costly penalties for non compliance, could help enforce fuel standards more effectively, although preventing local adulteration is likely to remain very difficult as long as there are some financial incentives to engage in the practice.

Another problem contributing to poor quality of fuel used in many developing countries including Ghana is that refineries in most of these countries are government owned and more often are not operated economically. Revamping refineries to improve fuel mix and quality means increasing fuel prices to recoup the investment otherwise such option is likely to render them even less commercially viable. Under these circumstances, the government may resist requiring changes in fuel quality, or will embrace them only while maintaining import protection through restrictions or high tariffs. In some developing countries, the net cost to society of improving fuel quality by importing superior fuels would be lower than the costs resulting from the use of domestically manufactured fuels with less stringent specifications. A downstream petroleum sector reform through transfer of ownership from the government to the private sector, coupled with liberalization of petroleum product trade and the introduction of competition, can therefore result in improved fuel and ultimately, air quality.

8.2.5 Alternative Fuels

A range of alternative fuels considered to be cleaner than conventional fuels (gasoline and diesel) continues to be under investigation or development in the industrial countries. For alternative fuels to be attractive in developing countries including Ghana, these alternatives must be seen not only as addressing perceived environmental problems but also as an economically viable option for national development. For example, Compressed Natural Gas (CNG) is one such alternative which is economically available in abundance in many developing countries (Argentina, Thailand, Bangladesh, etc) that do not have other indigenous fuel resources (Gwilliam, K. 2002), and hence CNG can support these countries' Balance of Payment (BOP) by retrofitting gasoline and diesel fuel vehicles to use CNG, and reducing their importation of crude oil.

The on-going West Africa pipeline project, from which natural gas will be transported from Nigeria to Benin, Togo, and Ghana (EIA, 2007), can be viewed as a good opportunity to start the construction of gas transport and distribution infrastructure in Ghana. The use of CNG in vehicles may have some disadvantages, if vehicles are not properly retrofitted, may lead to methane leakages, also there are extra costs associated with CNG engine conversion, the fuel control system and fuel tanks. These together can raise the initial cost of vehicles up to 30% (Gwilliams, K. 2002). The convenience factor is also important because CNG vehicles lose significant amount of luggage and passenger space to fuel tanks.

Another viable alternative source of fuel for road transport use in most developing countries including Ghana is the use of Liquefied Petroleum Gas (LPG). Though LPG is in use in Ghana, it is saddled with some problems. The main problem since its introduction in the transport sector in Ghana has been the supply and distribution system. On the distribution side, LPG is stored under pressure both inside the vehicle and in the refuelling tanks. LPG therefore, requires special refuelling equipment to transfer the pressurized liquid from storage tanks to the vehicle without leakages during refuelling. The required investment to ensure such equipment in LPG distribution and refuelling stations were not adequately made in Ghana. Therefore, to ensure a sustainable use of LPG as an alternative source for vehicle use, the issue of storage and distribution need to be addressed.

A third alternative fuel option, which can help reduce emissions from road transport and also help reduce foreign importation of crude oil is the use of ethanol or methanol. However, it is more costly to produce and use than the conventional fuels such as gasoline and diesel. Other disadvantages include having extra cost associated with modifying vehicles to ethanol/methanol, and a smaller energy density compared to gasoline (Wikipedia, 2007). Another disadvantage that may discourage most developing countries including Ghana from venturing into such an option is the trade-off needed for the production of these alcohols (ethanol/methanol), since these alcohols production compete directly with food production. Even the sugar-ethanol program of Brazil initially appeared attractive as a means of saving foreign exchange when oil prices are their peak but has lost most of its attractiveness, the new car market in Brazil is now almost exclusively for gasoline vehicles (Gwilliam, K. 2002).

8.3 Traffic Management

Many traffic management instruments, such as traffic signal systems, can lead to increases in efficiency of transport movement with negligible adverse side effects. But traffic management policy also involves choices, for example, if priorities are pedestrians focused, the outcome of such a policy may reduce the capacity for vehicles which may also adversely affect bus operations. An integrated traffic management scheme will require compromises between the competing interests of various users of the road and traffic systems. In practice, both traffic engineers and traffic police tend to concentrate on keeping the traffic moving. As a result, roads are widened, cars receive priority, and pedestrians and bicycles get crowded out. In that process, the street system gets rearranged to benefit the generally richer car users at the cost of the generally poorer bus users, bicyclists, and walkers.

Traffic management should aim at reducing unit emissions rates without generating extra traffic to negate the benefit. Coordination of traffic lights is generally beneficial. Traffic calming devices, which slow traffic down but do not stop it, may also result in cleaner, as well as safer traffic. In major towns and cities in Ghana, road traffic congestions occurs as a result of inadequate traffic signals, traffic signals not working as a result of power cuts, the use of traffic "round-about" instead of traffic interchanges and traffic accidents due to reckless driving. Thus, using solar powered traffic signals, increasing the number of traffic signals, replacing some traffic "round-about" with conventionalized intersection and eliminating "U turns" openings on some major roads which normally result in traffic accidents, are some possible solutions which could help alleviate the traffic congestions in some developing countries such as Ghana.

8.3.1 Traffic Control

There are numerous traffic management tools, including street parking management and control, traffic circulation design, traffic signal systems, public transport (bus) priority, and the enforcement of traffic regulations. These tools can be applied not only to ease traffic congestion but also, if desired, to give priority to pedestrians, bicycles, and other Non Motorised Transports (NMT) or commercial vehicles (Aragao et al, 1998).

8.3.2 Public Transport Priority

In most cities in the developing world, buses are the backbone of the motorized public transport system and will remain so for the foreseeable future. At peak loading situation in Ghana for instance shows that a bus may carry 30 (or more) times as many passengers as a car, and only use three times the road space (UTP & TM, 2005). Therefore, a reasonable traffic management approach will be to target and improve the movement of passengers rather than just the movement of vehicles. Not only will this lead to efficient use of scarce road space but the policy will have a positive impact on poverty. Since such an approach will tend to emphasize measures to assist public transport generally and also give attention to the development of pedestrian and bicycle facilities.

8.3.3 Implementation of Traffic Management

In many cities the high rates of traffic growth may quickly catch up with the initial congestion relief of traffic management measures. Traffic management must not be seen, therefore, as a panacea for urban transport congestion, but rather as a component of a broader strategy also involving public transport and demand management. Also, it must not be seen as a one shot intervention, rather, it should be seen as a continuous process adapted and adjusted to meet the changing traffic situation. Hence, the emphasis should be on creating a favourable institutional environment for the effective operation and adaptation of traffic management measures, on fostering the technical skills to implement them, rather than merely on the financing of specific schemes.

8.3.4 Demand Management

The economic rationale for traffic demand management is that if the price directly incurred by travellers in making journeys is lower than the full cost of the journey, then some trips will impose a net cost on the community. The full costs of a journey include both the personal costs incurred by the traveller (vehicle-running costs, fuel, parking, and so on), and the social costs imposed by the traveller on the community through the journey's contribution to congestion, the increase in accident potential, and the polluting effects on the environment. As the costs imposed by a traveller on others vary by location, time and traffic conditions, so ideally, should the charges incurred by vehicle users also vary. The objective of demand management should be to secure the total level of traffic, and its distribution between modes, locations, and times of day that would exist if traffic by each travel mode were to be charged prices equal to its full marginal social cost.

In order to achieve that objective, all traffic demand management tools should aim at increasing the costs of travel, through charges such as parking, congestion, and fuel prices.

8.3.5 Parking Controls for Demand Management

Parking control and pricing are tools commonly applied in traffic demand management in both industrialized and developing countries (Gwilliam, K., 2002). At its basic, parking policy in many developing cities is limited to the control of on street parking (usually simple parking prohibitions on main roads). Though parking control measures can help avoid obstruction to moving traffic, it can also have a wider restraint potential. While parking controls may have some effect on vehicle ownership, the usual aim of restraint is to reduce car use by regulating parking space and by positive allocation of available parking space among different groups of users, usually, seeking to deter car commuting for work. The effectiveness of parking as a restraint measure in developing countries is compromised by the ability of the rich to keep their vehicles on the street with their hired drivers inside waiting.

Even more difficult problems arise in respect of private non residential parking in the ownership of private sector companies or government agencies. Withdrawing the right to use these parking areas not only creates a political problem but also legal problems in some countries, where the private non residential parking may have been constructed in response to city parking standards for construction permits. There are still many developing country cities where, even in city centres, minimum rather than maximum parking standards are set.

Despite these weaknesses, a comprehensive parking policy is likely to be the starting point for demand management in most cities in Africa. Parking fees are the least contentious of user charges, and most cities have some form or parking policy. The number, location, and price of on street parking can be controlled. Publicly available off street parking and private non residential parking capacity expansion can be limited, and charges can be regulated to prevent subsidized parking. Policies for these categories of parking consistent with general policy objectives should be included in all transport strategy plans.

8.3.6 Traffic restraint

In the industrial economies, demand for more space in lower density settlements and the vehicle ownership and use associated with it, have all proved income elastic, while at high incomes and low motoring costs, the price elasticity of demand for car travel has been low (Schipper and Marie-Lilliu, 1999). Increased vehicle fleet and mileage may therefore appear inevitable as economies develop. The use of vehicle exclusion policy as a demand management strategy, where vehicles are licensed to be used on some particular days can result in dramatic reductions in traffic volume during the first months of implementation. In the longer term, however, the schemes may be counterproductive because some households will purchase an additional vehicle or retain an old and polluting vehicle that would have otherwise been replaced, in order to avoid the effect of the restrictions.

Despite this disadvantage of vehicle exclusion, many cities such as, Athens, Bogota, Lagos, Manila, Mexico city, Santiago, Sao Paul and Seoul used this measure to some degree to solve their traffic congestion problems. The positive thing about vehicle exclusion policy is that, it is easily accepted by the public as a demonstration of commitment by government to reduce congestion and related air pollution and have proved less difficult to enforce than one might have expected (Gwilliam, K., 2002). Some cities in Ghana such as Accra and Kumasi, where traffic congestions are more pronounced can follow suit by instituting and enforcing vehicle exclusion policy as a temporal measure to examine its effectiveness.

Chapter 9

9.0 Conclusions and Recommendations

The research revealed that, the unrelenting population growth and expected increases in economic activities in Ghana will induce continuous increases in the travel activities of people and goods in Ghana and consequently, its negative effects such as air pollution, global warming, traffic congestion, and energy consumption. Results from the research for example, shows in 2005 the total Greenhouse Gas CO_2 emissions equivalent emitted from road transport in Ghana was about 4.6 Mt, consuming about 490,000 t and 720,000 t of gasoline and diesel respectively. The research reveals that if no major change in policies or economic determinants from the existing trends in meeting road transport and energy demand in Ghana, then the 2005 emissions value is expected to rise by 36% in 2010 and over double in 2020 i.e. from 4.6 Mt to 6.25 Mt and 9.77 Mt CO_2e in 2010 and 2020 respectively. The fuel consumption pattern also shows similar increases in pattern i.e. gasoline consumption increasing from 490,000 t to about 710,000 t and 1,300,000 t in 2010 and 2020 respectively and diesel consumption also increasing from 720,000 t to 933,000 t and 1,300,000 t in 2010 and 2020 respectively.

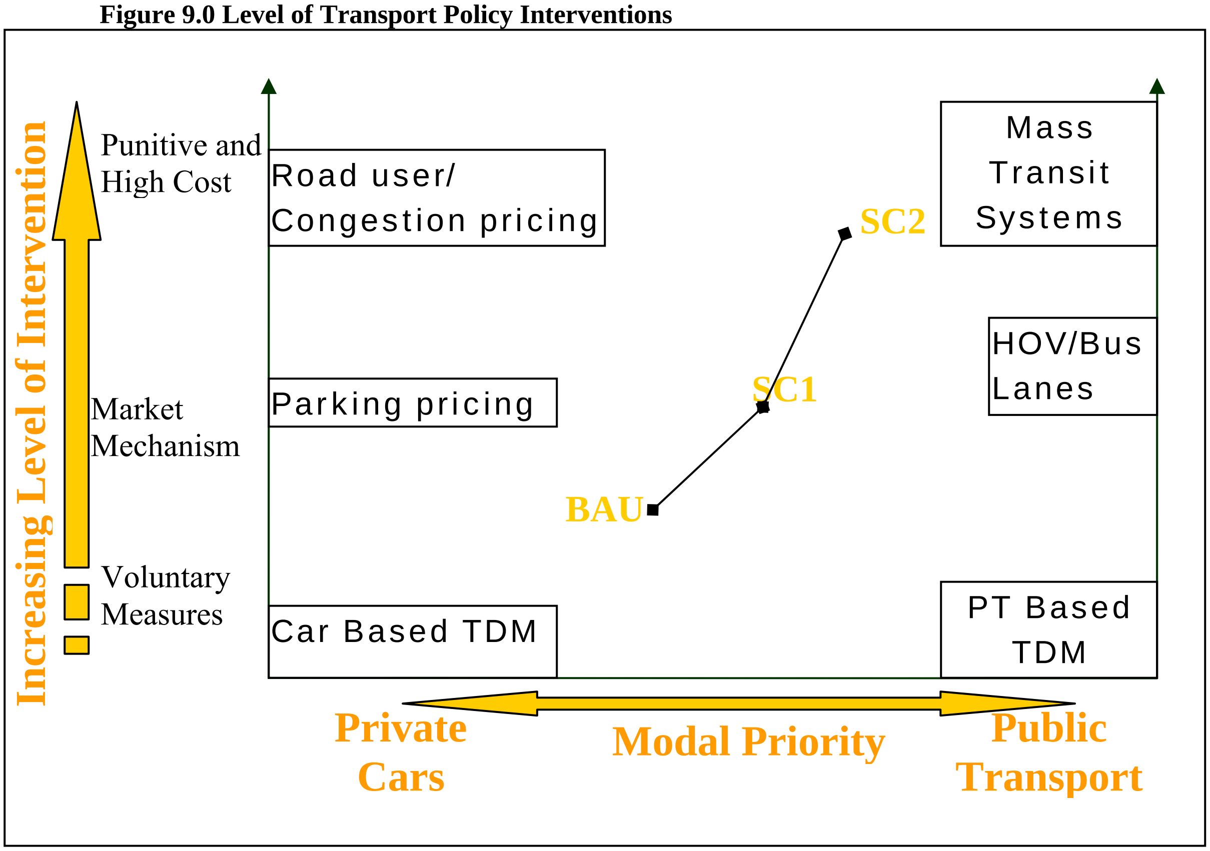
There are policy and technology choices that could significantly lower these emissions growth rate while increasing mobility, improving air quality, reducing traffic congestion and lowering transport and energy cost in Ghana. It is also possible to reduce Greenhouse gas emissions in the absence of technology, through behavioural changes, as was demonstrated by this research.

The research revealed that Greenhouse gas emissions and fuel consumptions from road transport in Ghana could be reduced, if a proportion of daily trips made by passengers could be shifted from the use of private cars to the use of public transport such as buses. Thus, for a 10% and a 20% of daily passenger trips shift that were considered for the first and second scenario, the outcome was a 0.24 MtCO_2e, and 0.46 MtCO_2e yearly emission reductions respectively.

This research also demonstrated that in addition to reduction in emissions and fuel consumption, Ghana could earn some foreign currency, i.e. if emissions reductions in these scenarios can be implemented under the Kyoto Protocol CDM initiative. Such an option, as evident in this research could earn Ghana yearly about $USD 6.6 million in the first scenario and about $USD 13 million in the second scenario.

There are a range of policy options to meet these emissions and fuel reduction targets in Ghana. However, in the context of these scenarios created in this research, policy options are only needed in two main directions, i.e. discouraging the use of single occupancy vehicles and those policies that improve the efficient operation of public transport. The levels of intervention of policy options to achieve emissions results in the scenarios can thus be illustrated with figure 9.0

Figure 9.0 Level of Transport Policy Interventions



Source: Adapted From Johannesburg Integrated Plan (UTP&TM, 2005)

TDM= Travel Demand Management

BAU= Business as Usual

SC1= Scenario 1

SC2= Scenario 2

HOV= High Occupancy Vehicle

PT= Public Transport

As can be observed from the rectangles in figure 9.0, interventions shown on the left hand side of the figure such as car based TDM, parking pricing, road user and congestion pricing are interventions necessary for discouraging the use of private cars and will result in the shift to the use of public transport. The interventions shown on the right hand side are necessary to improve the efficient operation of public transport. Again, it can be observed from figure 9 that interventions are grouped into voluntary measures, market based mechanisms, punitive or high cost measures. Thus, a possible combination of policy intervention needed to achieve emissions results in scenario 1 may require voluntary and market based measures, whilst in the case of the scenario 2, all the three measures may be required.

Based on these levels of interventions and measures discussed earlier in chapters 3 and 8, the following recommendations will be necessary to achieve results in the scenarios.

Scenario 1

Reasons/Goals	Recommended Interventions /Measures	Responsible Ministry/ Department/Agencies
Vehicle Use Restriction or Limitations	Parking Management • Restrict access and parking for private cars in the core of the CBD* during working days business hours with strict enforcement. • Discourage long stay parking in the central areas with high differential parking fees. • Enforcing one side street parking in residential areas. • Prohibit parking on primary routes within the highway network accompanied by strict enforcement of prohibition. • Peak hour on street loading should be prohibited	Ministry of Local Government and Rural Development (Metropolitan, Municipal and District Assemblies)

*CBD Central Business District

Interventions and measures recommended for scenario1 would be equally needed in scenario 2 however, the following additional measures will be needed.

Scenario2

Reasons/Goals	Recommended Interventions /Measures	Responsible Ministry/ Department/Agencies
Vehicle Use Restriction or Limitations	Parking Management • Additional off street private car parks should be provided • Provision of adequate off-street parking should be strictly enforced for new developments. • Parking fee charge for all residential street parking**	Ministry of Local Government and Rural Development (Metropolitan, Municipal and District Assemblies)
	Road User Charges • Full recovery cost (maintenance and rehabilitation) should be charged for use of all highway roads • Eliminate employee parking subsidies	Ministry of Road Transport (Ghana Highway Authority)

** These will require naming of streets and proper house numbering system

Scenario 1

Reasons/Goals	Recommended Interventions /Measures	Responsible Ministry/ Department/Agencies
Public Transport Improvement	• Separate lanes for buses and other commercial vehicles	Ministry of Local Government and Rural Development (Department of Town and Country Planning)
	• Design and implement a reliable timetable schedule for the MMT+ buses, example by increasing the frequency of buses during peak hour demand in all directions • Separate lanes for buses and other commercial vehicles • In the absence of direct route to destinations, the bus schedules should be coordinated to reduce waiting time at change over bus stops • Provision of information such as the bus routes and schedules should be made available at various bus stops. • Simplified Bus fare collection • Integrate bus fares to allow trips and transfers throughout the system for a single fare • Bus stops or shelters should be located where it is safe and convenient to passengers, and reduce boarding and alighting time • To avoid too many stops, bus stops should be located at minimum of 500 m apart	Ministry of Road Transport (Dept. of Urban Roads) Ministry of Tourism and Modernization of Capital City

+MMT Metro Mass Transit

Scenario 2

Reasons/Goals	Recommended Interventions /Measures	Responsible Ministry/ Department/Agencies
Public Transport Improvement	• Feeder bus services	Ministry of Local Government and Rural Development (Department of Town and Country Planning) and Ministry of Road Transport (Feeder Road Department)
	• Express bus services • Bus route and schedule modification	Ministry of Road Transport (Dept. of Urban Roads)
	• Midday Park and Ride Shuttles	Ministry of Tourism and Modernization of Capital City

Besides restricting vehicle use and improving public transport use, there are other measures or interventions that could help reduce road traffic congestion or reduce vehicle emissions in Ghana. The following additional measures or intervention are thus proposed for the scenarios.

Scenario1

Reasons/Goals	Recommended Interventions /Measures	Responsible Ministry/ Department/Agencies
0ther Vehicle Emissions or Road Congestion Reduction Measures	**<u>Trip Reduction Measures</u>** <u>Use of Bicycles</u> • Provision of lockers, racks, other storage facilities, and ancillary facilities (such as showers and clothing lockers)	Ministry of Local Government and Rural Development (Department of Town and Country Planning) and Ministry of Road Transport (Department of Urban Roads) and Ministry of Tourism and Modernization of Capital City
	• Driving code education, media and promotional campaigns including provision of bicycle maps	Ministry information and communication and Motor Transport and Traffic Unit of the Ghana police service
	<u>Vehicle Road Worthy Standards</u> • Specification for maximum vehicle emissions • On-road routine vehicle emission testing • On-road routine smoke test for Heavy Duty Vehicles	Ministry of Road Transport (Drivers Vehicle Licensing Authority) and Ministry of Environment (Environmental Protection Agency)

Additional Measures need for Scenario 2

Reasons/Goals	Recommended Interventions /Measures	Responsible Ministry/ Department/Agencies
0ther Vehicle Emissions or Road Congestion Reduction Measures	**<u>Trip Reduction Measures</u>** <u>Use of Bicycles</u> • Development of bicycle routes, lanes or paths	Ministry of Local Government and Rural Development (Department of Town and Country Planning) and Ministry of Road Transport (Department of Urban Roads) and Ministry of Tourism and Modernization of Capital City
	<u>Use of telephone and internet email communication</u> • Expand internet and broadband connections in most cities and towns • Encourage the opening of more Internet cafes	Ministry of information and communication.

To improve road congestion on the highways in Ghana, the following specific recommendations are proposed:

- Expansion of highway roads (Dual Carriageways)
- Coordinate traffic signals to move traffic more efficiently
- Institute a rapid response unit to deal with vehicular crashes, vehicle breakdowns and debris on highway roads
- Provision of safe alternate routes for vehicles, during road construction or maintenance
- To ensure smooth operations of vehicles during bad weather conditions such as, rains, and fog or mist, the highway road design in Ghana should have roadway illumination, pavement markings, and larger drainage areas
- Reduce the use of trucks on highway roads by reviving, extending and promoting the use of rail transportation in Ghana.

Specific Recommendation for Accra

Due to the high economic activities centered within the capital city of Ghana, Accra the worst traffic congestion situations in Ghana are mostly observed there. The most affected being the principal traffic circles (Nkrumah and Obetsebi-Lamptey circles) on the ring roads, normally carrying the highest traffic volumes with the greatest delays and higher number of accidents in the central area. Also compounding the traffic congestion in Accra is obstruction of on-street traders and pedestrians on roadways. Thus the following specific recommendations will be necessary for the capital city Accra to help achieve results in both scenarios.

- Improvement in the existing road network and to reduce the dominance of the centrally oriented movement system to a more efficient intra-city transport system linking major employment and activity centers under a more decentralized.

- An outer orbital road around the city to enable through traffic that currently uses the motorway extension to bypass the inner urban area with urban area with its associated congestion.
- Additional ring road and links to improve the efficiency of orbital movement with the link between Medina and Teshie road.
- Eliminate left and U vehicle turning movements on ring roads that cause accidents substantial intersection delays.
- Commerce a program of road markings and street naming to set the pace for a Global Position Satellite Navigation system for vehicle use in Accra.
- Replace traffic circles such as the Nkrumah and Obetsebi-Lamptey circles with signalized traffic intersections.
- Replace traffic signals with solar operated traffic signals
- Eliminate all retail activities on the streets and also relocate all commercial vehicle terminals outside the central business areas.
- Involve the private sector to strengthen mobile police tow truck services to clear immobile vehicles causing obstruction to traffic flow

Appendices

Appendix I Vehicle Fleet Registered in Ghana by Category

POPULATION OF VEHICLES REGISTERED IN GHANA BY CATEGORY

YEAR	MOTOR CYCLE	PTE MV UPTO 2000CC	COMM MV UPTO 2000CC	MV ABOVE 2000CC	BUSES AND COACHES	R/C TRUCKS UPTO 16TONS	R/C TRUCKS FROM 16-22 TONS	R/C TRUCKS ABOVE 22 TONS	ART TRUCKS UPTO 24 TONS	ART TRUCKS ABOVE 24-32 TONS	ART TRUCKS ABOVE 32 TONS	ART EQUIP	COMBINE HARVESTERS	CONS EQUIP	MINING EQUIP	PART. ID. MARK	GROSS TOTAL
1995	4908	17248	2941	6	10387	5130	1387	104	686	176	3	0	0	0	0	0	42976
1996	29551	112991	36475	1067	42501	13794	5189	1421	2243	1403	988	0	0	0	0	0	247623
1997	7930	24134	5490	26	9114	2546	981	487	531	388	266	0	0	0	0	0	51893
1998	6064	22693	4869	71	11443	3770	1085	669	396	319	252	0	0	0	0	0	51631
1999	6623	24434	12004	6249	9843	3454	590	292	196	291	262	357	10	116	30	0	64751
2000	6440	27552	5104	5196	5469	1428	395	229	120	305	126	337	30	149	1	0	52881
2001	6058	17953	5568	5343	2676	861	367	234	136	251	122	303	4	136	2	0	40014
2002	6430	18512	6015	7143	2601	1044	300	281	138	201	168	206	36	172	10	0	43257
2003	8777	20564	5110	7778	2916	914	292	326	116	447	510	158	77	46	29	14	48074
2004	14462	20333	7642	7189	4882	2065	603	442	447	376	489	510	20	56	11	21	59548
2005	15136	22949	6686	8715	5585	2457	420	543	551	374	454	140	192	68	7	142	64419
TOTAL	112379	329363	97904	48783	107417	37463	11609	5028	5560	4531	3640	2011	369	743	90	177	767067

N/B:

MOTOR CYCLE = MOTOR CYCLES OF ALL CATEGORIES:
PTE MV UPTO 2000CC =PRIVATE MOTOR VEHICLES UPTO 2000 CUBIC CAPACITY
COMM MV UPTO 2000CC =COMMERCIAL MOTOR VEHICLES UPTO 2000 CUBIC CAPACITY
MV ABOVE 2000CC =MOTOR VEHICLES ABOVE 2000 CUBIC CAPACITY
BUSES & COACHES =BUSES & COACHES OF ALL KINDS

R/C TRUCKS UPTO 16TONS =RIGID CARGO TRUCKS UPTO 16 TONS
R/C TRUCKS FROM 16 - 22 TONS =RIGID CARGO TRUCKS UPTO 16 TONS
R/C TRUCKS ABOVE 22TONS =RIGID CARGO TRUCKS ABOVE 22 TONS
ART TRUCKS UPTO 24TONS =ARTICULATOR TRUCKS UPTO 24 TONS
ART TRUCKS FROM 24-32TONS =ARTICULATOR TRUCKS FROM 24-32 TONS
ART TRUCKS ABOVE 32 TONS =ARTICULATOR TRUCKS ABOVE 32 TONS
ART EQUIP =AGRICULTURAL EQUIPMENT
COMBINE HARVESTERS =COMBINE HARVESTERS
CONS EQUIP =CONSTRUCTION EQUIPMENT
MINING EQUIP =MINING EQUIPMENT
PART.ID.MARK =PARTICULAR IDENTIFICATION MARK

NB:

The above statistics exclude vehicles registered by the security services such as the Ghana Arm Forces, the Ghana Police Service and Prison Service

Source: The Drivers Vehicle Licensing Authority, 2007

Appendix II Total Annual Petroleum Products Consumed in Ghana

NATIONAL PETROLEUM PRODUCTS CONSUMPTION

(UNITS IN LITRES, EXCEPT LPG IN KGS)

PRODUCTS	Jan-Dec 2000	Jan-Dec 2001	Jan-Dec 2002	Jan-Dec 2003	Jan-Dec 2004	Jan-Dec 2005	Jan-Aug 2006
LPG	44,999,648	42,519,123	49,954,999	56,707,826	65,666,614	70,460,665	57,872,53
Gas Oil (Diesel)	790,695,840	813,926,690	852,512,318	896,957,186	1,008,137,950	1,045,569,250	710,158,74
Premium Gasoline	707,879,250	722,377,200	769,763,190	647,761,842	777,086,900	726,024,190	453,258,10
Kerosene	83,662,286	87,326,650	92,666,660	85,154,700	90,582,050	92,025,700	66,496,05
Premix	42,187,000	37,190,667	36,922,500	39,861,089	38,004,600	43,267,500	29,484,00
Fuel Oil	63,347,700	57,722,900	57,591,990	50,689,900	50,212,750	53,126,550	41,130,11
ATK	120,005,250	94,570,500	111,997,200	111,180,450	132,993,600	147,672,710	98,607,75
GBS Export	59,569,046	39,809,812	40,734,171	40,079,790	22,233,304	44,063,658	32,558,60
Total	1,912,346,020	1,895,443,542	2,012,143,028	1,928,392,783	2,184,917,768	2,222,210,223	1,489,565,89

Year		2000/2001	2001/2002	2002/2003	2003/2004	2004/2005	2005/2006
% Change/Growth		-0.88%	6.16%	-4.16%	13.30%	1.71%	-32.97%

(% ALLOCATION OF PRODUCT CONSUMPTION)

PRODUCTS	Jan-Dec 2000	Jan-Dec 2001	Jan-Dec 2002	Jan-Dec 2003	Jan-Dec 2004	Jan-Dec 2005	Jan-Aug 2006
LPG	2.4%	2.2%	2.5%	2.9%	3.0%	3.2%	3.9
Gas Oil (Diesel)	41.3%	42.9%	42.4%	46.5%	46.1%	47.1%	47.7
Premium Gasoline	37.0%	38.1%	38.3%	33.6%	35.6%	32.7%	30.4
Kerosene	4.4%	4.6%	4.6%	4.4%	4.1%	4.1%	4.5
Premix	2.2%	2.0%	1.8%	2.1%	1.7%	1.9%	2.0
Fuel Oil	3.3%	3.0%	2.9%	2.6%	2.3%	2.4%	2.8
ATK	6.3%	5.0%	5.6%	5.8%	6.1%	6.6%	6.6
GBS Export	3.1%	2.1%	2.0%	2.1%	1.0%	2.0%	2.2

Source: Ghana Ministry of Energy, 2006

Appendix III Chemical and Physical Properties of Gasoline Fuel used in Ghana

Test	Unit	Limits	Test Method
Density @ 15°C	kg/m^3	725-790	ASTM-D-1298 or ASTM-D-4052
ASTM DISTILLATION			
10% evaporated	°C	70 max.	ASTM-D-86
50% evaporated	°C	120 max.	ASTM-D-86
90% evaporated	°C	190max.	ASTM-D-86
Final Boiling Point	°C	225 max.	ASTM-D-86
Residue	%vol	2 max.	ASTM-D-86
Total Sulphur	% wt.	0.15 max.	ASTM-D-5453
Copper Strip Corrosion (3hrs. @ 40°C)	-	1b max.	ASTM-D-130
Reid Vapour Pressure	kg/cm^2	0.65 max.	ASTM-D-323
Induction Period @ 100°C	minutes	240 min.	ASTM-D-525
Manganese (MMT)	mg/l	18 max	AAS/ICP
Octane Number (Research Method)	-	91 min.	ASTM-D-2699
Colour (Commercial)	-	Red	-
Dye Content	mg/l	4-8	-
Existent Gum	mg/100ml	5 max.	ASTM-D-381
Olefins [%v/v]	[%v/v]	About 20%	-
Benzene [%v/v]	[%v/v]	About 1.5	-
Aromatics [%v/v]	[%v/v]	About 27%	-

Source:Tema Oil Refinery, 2006

Appendix IV Chemical and Physical Properties of Diesel (Gas oil) Fuel used in Ghana

Test	Unit	Limit	Test Method
Density @ 15°C	kg/m^3	830-880 max	ASTM-D-1298 or ASTM-D-4052
Evaporated @ 360°C	% vol.	85 min.	ASTM-D-86
Total Sulphur	% wt.	1.0 max.	ASTM-D-2622
Colour (ASTM)	-	3 max.	ASTM-D-1500
Flash Point, PM (Closed Cup)	°C	55 min.	ASTM-D-93
Kinematic Viscosity @ 37.8 °C	cSt	1.6-6.5 max.	ASTM-D-445
Pour Point	°C	+15 max.	ASTM-D-97
Conradson Carbon Residue (on 10% vol. Distillation residue)	% wt.	0.20 max.	ASTM-D-189
Total Acid Number	mgKOH/g	1 max.	ASTM-D-974
Ash	% wt.	0.1 max.	ASTM-D-482
Copper Corrosion 3hrs@100°C		1b	ASTM D 130
CETANE INDEX	-	40 min.	ASTM D 4737
Water by Distillation	% vol.	0.05 max.	ASTM-D-95
Water &Sediment	%vol.	0.10max	ASTM D-96
Heat Of Combustion (Gross)	kcal/gm	Report	ASTM D-4868
T95	°C	About 360	-

Source:Tema Oil Refinery, 2006

Appendix V Chemical and Physical Properties of LPG Fuel used in Ghana

Test	Unit	Limits	Test Method
Density @ 15°C	kg/m^3	To be reported	ASTM-D-1657
Vapour Pressure @ 37.8 °C	kg/cm^2	10.0 max.	ASTM-D-1267
C5+ (Pentanes &heavier) 95% vol. Evaporated Point	%vol. OR °C	2 max +2 max.	GLC ASTM-D-1837
Free Water Content	-	Absent	Qualitative
Copper Corrossion (1hr@37.8°C)		1b max	ASTM D 1838
Hydrogen Sulphide	Qualitative	Absent	I.P. 272
Hydrogen Sulphide (as Sulphur)	%ppm	20 max	ASTM D-4294
Mercaptan (as Sulphur)	% ppm	20 max	ASTM D 3227
Total Sulphur	% ppm	200 max	ASTM-D-5453
%C1&C2	%wt.	2 max	GLC
% Propane+Propylenes etc	% wt	To be reported	G.L.C.
% n-butane+butenes	% wt	To be reported	G.L.C.
% iso-butane	% wt	To be reported	G.L.C.

Source: Tema Oil Refinery, 2006

Appendix VI Speed Dependent Formulas for CO Emission Factor Calculations (Gasoline Cars)

Vehicle Class	Engine Capacity	Speed Range [km/h]	CO Emission Factor [g/km]	R^2
PRE ECE	All capacities	10-100	$281V^{-0,630}$	0,924
	All capacities	100-130	0,112V + 4,32	-
ECE 15-00/01	All capacities	10-50	$313V^{-0,760}$	0,898
	All capacities	50-130	$27,22 - 0,406V + 0,0032V^2$	0,158
ECE 15-02	All capacities	10-60	$300V^{-0,797}$	0,747
	All capacities	60-130	$26,260 - 0,440V + 0,0026V^2$	0,102
ECE 15-03	All capacities	10-19,3	161,36 - 45,62ln(V)	0,790
	All capacities	19,3-130	$37,92 - 0,680V + 0,00377V^2$	0,247
ECE 15-04	All capacities	10-60	$260,788V^{-0,910}$	0,825
	All capacities	60-130	$14,653 - 0,220V + 0,00116386V^2$	0,613
Improved Conventional	CC < 1,4 l	10-130	$14,577 - 0,294V + 0,002478V^2$	0,781
	1,4 l < CC < 2,0 l	10-130	$8,273 - 0,1511V + 0,000957V^2$	0,767
Open Loop	CC < 1,4 l	10-130	$17,882 - 0,377V + 0,002825V^2$	0,656
	1,4 l < CC < 2,0 l	10-130	$9,446 - 0,23012V + 0,002029V^2$	0,719
EURO I	CC < 1,4 l	5-130	$9,846 - 0,2867V + 0,0022V^2$	0,133
	1,4 l < CC < 2,0 l	5-130	$9,617 - 0,245V + 0,0017285V^2$	0,145
	CC > 2,0 l	5-130	$12,826 - 0,2955V + 0,00177V^2$	0,159

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix VII Percentage Reduction for Improved Gasoline and LPG Cars Emission Factors

Engine Capacity	Gasoline & LPG Passenger Cars	CO [%]	NO_x [%]	VOC [%]
CC < 1,4 l	Euro II - 94/12/EC	32	64	79
	Euro III - 98/69/EC Stage 2000	44	76	85
	Euro IV - 98/69/EC Stage 2005	66	87	97
1,4 l < CC < 2,0 l	Euro II - 94/12/EC	32	64	79
	Euro III - 98/69/EC Stage 2000	44	76	86
	Euro IV - 98/69/EC Stage 2005	66	87	97
CC > 2,0 l	Euro II - 94/12/EC	32	64	76
	Euro III - 98/69/EC Stage 2000	44	76	84
	Euro IV - 98/69/EC Stage 2005	65	87	95

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix VIII Speed Dependent Formulas for Calculating VOC Emission Factor (Gasoline Cars)

Vehicle Class	Engine Capacity	Speed Range [km/h]	VOC Emission Factor [g/km]	R^2
PRE ECE	All capacities	10-100	$30{,}34\ V^{-0{,}693}$	0,980
	All capacities	100-130	1,247	-
ECE 15-00/01	All capacities	10-50	$24{,}99V^{-0{,}704}$	0,901
	All capacities	50-130	$4{,}85V^{0{,}318}$	0,095
ECE 15-02/03	All capacities	10-60	$25{,}75V^{-0{,}714}$	0,895
	All capacities	60-130	$1{,}95 - 0{,}019V + 0{,}00009V^2$	0,198
ECE 15-04	All capacities	10-60	$19{,}079V^{-0{,}693}$	0,838
	All capacities	60-130	$2{,}608 - 0{,}037V + 0{,}000179V^2$	0,341
Improved Conventional	CC < 1,4 l	10-130	$2{,}189 - 0{,}034V + 0{,}000201V^2$	0,766
	1,4 l < CC < 2,0 l	10-130	$1{,}999 - 0{,}034V + 0{,}000214V^2$	0,447
Open Loop	CC < 1,4 l	10-130	$2{,}185 - 0{,}0423V + 0{,}000256V^2$	0,636
	1,4 l < CC < 2,0 l	10-130	$0{,}808 - 0{,}016V + 0{,}000099V^2$	0,49
EURO I	CC < 1,4 l	5-130	$0{,}628 - 0{,}01377V + 8{,}52E{-}05V^2$	0,207
	1,4 l < CC < 2,0 l	5-130	$0{,}4494 - 0{,}00888V + 5{,}21E{-}05V^2$	0,197
	CC > 2,0 l	5-130	$0{,}5086 - 0{,}00723V + 3{,}3E{-}05V^2$	0,0433

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix IX Speed Dependent Formulas for Calculating NO_x Emission Factor (Gasoline Cars)

Vehicle Class	Engine Capacity	Speed Range [km/h]	NO_x Emission Factor [g/km]	R^2
PRE ECE & ECE 15-00/01	CC < 1,4 l	10-130	$1,173 + 0,0225V - 0,00014V^2$	0,916
	1,4 l < CC < 2,0 l	10-130	$1,360 + 0,0217V - 0,00004V^2$	0,960
	CC > 2,0 l	10-130	$1,5 + 0,03V + 0,0001V^2$	0,972
ECE 15-02	CC < 1,4 l	10-130	$1,479 - 0,0037V + 0,00018V^2$	0,711
	1,4 l < CC < 2,0 l	10-130	$1,663 - 0,0038V + 0,00020V^2$	0,839
	CC > 2,0 l	10-130	$1,87 - 0,0039V + 0,00022V^2$	-
ECE 15-03	CC < 1,4 l	10-130	$1,616 - 0,0084V + 0,00025V^2$	0,844
	1,4 l < CC < 2,0 l	10-130	$1,29e^{0,0099V}$	0,798
	CC > 2,0 l	10-130	$2,784 - 0,0112V + 0,000294V^2$	0,577
ECE 15-04	CC < 1,4 l	10-130	$1,432 + 0,0026V + 0,000097V^2$	0,669
	1,4 l < CC < 2,0 l	10-130	$1,484 + 0,013V + 0,000074V^2$	0,722
	CC > 2,0 l	10-130	$2,427 - 0,014V + 0,000266V^2$	0,803
Improved Conventional	CC < 1,4 l	10-130	$-0,926 + 0,7192\ln(V)$	0,883
	1,4 l < CC < 2,0 l	10-130	$1,387 - 0,0014V + 0,000247V^2$	0,876
Open Loop	CC < 1,4 l	10-130	$-0,921 + 0,616\ln(V)$	0,791
	1,4 l < CC < 2,0 l	10-130	$-0,761 + 0,515\ln(V)$	0,495
EURO I	CC < 1,4 l	5-130	$0,5595 - 0,01047V + 10,8E\text{-}05V^2$	0,122
	1,4 l < CC < 2,0 l	5-130	$0,526 - 0,0085V + 8,54E\text{-}05V^2$	0,0772
	CC > 2,0 l	5-130	$0,666 - 0,009V + 7,55E\text{-}05V^2$	0,0141

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix X Speed Dependent Formulas for Calculating Fuel Consumption Factor (Gasoline Cars)

Vehicle Class	Cylinder Capacity	Speed Range [km/h]	Fuel Consumption Factor [g/km]	R^2
PRE ECE	CC < 1,4 l	10-60	$521\ V^{-0,554}$	0,941
		60-80	55	-
		80-130	0,386V + 24,143	-
	1,4 l < CC < 2,0 l	10-60	$681V^{-0,583}$	0,936
		60-80	67	-
		80-130	0,471V + 29,286	-
	CC > 2,0 l	10-60	$979V^{-0,628}$	0,918
		60-80	80	-
		80-130	0,414V + 46,867	-
ECE 15-00/01	CC < 1,4 l	10-60	$595V^{-0,63}$	0,951
		60-130	$95 - 1,324V + 0,0086V^2$	0,289
	1,4 l < CC < 2,0 l	10-60	$864V^{-0,69}$	0,974
		60-130	$59 - 0,407V + 0,0042V^2$	0,647
	CC > 2,0 l	10-60	$1236V^{-0,764}$	0,976
		60-130	$65 - 0,407V + 0,0042V^2$	-
ECE 15-02/03	CC < 1,4 l	10-50	$544V^{-0,63}$	0,929
		50-130	$85 - 1,108V + 0,0077V^2$	0,641
	1,4 l < CC < 2,0 l	10-50	$879V^{-0,72}$	0,950
		50-130	$71 - 0,7032V + 0,0059V^2$	0,830
	CC > 2,0 l	10-50	$1224V^{-0,756}$	0,961
		50-130	$111 - 1,333V + 0,0093V^2$	0,847
ECE 15-04	CC < 1,4 l	10-17,9	296,7 - 80,21ln(V)	0,518
		17,9-130	$81,1 - 1,014V + 0,0068V^2$	0,760
	1,4 l < CC < 2,0 l	10-22,3	$606,1V^{-0,667}$	0,907
		22,3-130	$102,5 - 1,364V + 0,0086V^2$	0,927
	CC > 2,0 l	10-59,5	$819,9V^{-0,663}$	0,966
		59,5-130	$41,7 + 0,122V + 0,0016V^2$	0,650
Improved Conventional	CC < 1,4 l	10-130	$80,52 - 1,41V + 0,013V^2$	0,954
	1,4 l < CC < 2,0 l	10-130	$111,0 - 2,031V + 0,017V^2$	0,994
Open Loop	CC < 1,4 l	10-130	$85,55 - 1,383V + 0,0117V^2$	0,997
	1,4 l < CC < 2,0 l	10-130	$109,6 - 1,98V + 0,0168V^2$	0,997
EURO I and onwards	CC < 1,4 l	5-12,3	$329,451 - 39,093V + 1,531V^2$	0,958
		12,3-130	$98,336 - 1,604V + 0,0106V^2$	0,790
	1,4 l < CC < 2,0 l	5-13,1	$428,06 - 46,696V + 1,697V^2$	0,989
		13,1-130	$135,44 - 2,314V + 0,0144V^2$	0,777
	CC > 2,0 l	5-12,7	$605,57 - 70,09V + 2,645V^2$	0,976
		12,7-130	$181,85 - 3,398V + 0,0209V^2$	0,865

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XI Speed Dependent Formulas for Emission and Fuel Consumption Factors Calculations (Diesel Cars)

Pollutant	Engine Capacity	Speed Range [km/h]	Emission Factor [g/km]	R^2
CO	All capacities	10-120	$1,4497 - 0,03385V + 21E\text{-}05V^2$	0,550
NO_x	All capacities	10-120	$1,4335 - 0,026V + 17,85E\text{-}05V^2$	0,262
VOC	All capacities	10-130	$0,1978 - 0,003925V + 2,24E\text{-}05V^2$	0,342
PM	All capacities	10-130	$0,1804 - 0,004415V + 3,33E\text{-}05V^2$	0,294
Fuel Consumption	All capacities	10-130	$91,106 - 1,308V + 0,00871V^2$	0,526

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XII Percentage Reduction for Improved Diesel Cars Emission Factors

Diesel Passenger Cars	CO [%]	NO_x [%]	VOC [%]	PM [%]
Euro II - 94/12/EC	0	0	0	0
Euro III - 98/69/EC Stage 2000	0	23	15	28
Euro IV - 98/69/EC Stage 2005	0	47	31	55

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XIII Speed Dependent Formulas for Emissions and Fuel Consumption Factors Calculations (LPG Cars)

Pollutant	Cylinder Capacity	Speed Range [km/h]	Emission Factor [g/km]
CO	All categories	10-130	$0,00110V^2 - 0,1165V + 4,2098$
NO_x	All categories	10-130	$0,00004V^2 - 0,0063V + 0,5278$
VOC	All categories	10-130	$0,00010V^2 - 0,0166V + 0,7431$
Fuel Consumption	All categories	10-130	$0,00720V^2 - 0,9250V + 74,625$

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XIV Speed Dependent Formulas for Emissions and Fuel Consumption Factors Calculations (LDVs Gasoline)

Pollutant	Vehicle Class	Speed Range [km/h]	Emission Factor [g/km]	R^2
CO	Conventional	10-110	$0{,}01104V^2 - 1{,}5132V + 57{,}789$	0,732
	EURO I	10-120	$0{,}0037V^2 - 0{,}5215V + 19{,}127$	0,394
NO_x	Conventional	10-110	$0{,}0179V + 1{,}9547$	0,142
	EURO I	10-120	$7{,}55E\text{-}05V^2 - 0{,}009V + 0{,}666$	0,0141
VOC	Conventional	10-110	$67{,}7E\text{-}05V^2 - 0{,}117V + 5{,}4734$	0,771
	EURO I	10-120	$5{,}77E\text{-}05V^2 - 0{,}01047V + 0{,}5462$	0,358
Fuel Consumption	Conventional	10-110	$0{,}0167V^2 – 2{,}649V + 161{,}51$	0,787
	EURO I	10-120	$0{,}0195V^2 – 3{,}09V + 188{,}85$	0,723

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XV Percentage Reduction for Improved LDVs Gasoline Emission Factors

Gasoline Light Duty Vehicles	CO [%]	NO_x [%]	VOC [%]
Euro II - 96/69/EC	39	66	76
Euro III - 98/69/EC Stage 2000	48	79	86
Euro IV - 98/69/EC Stage 2005	72	90	94

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XVI Speed Dependent Formulas for Emissions and Fuel Consumption Factors Calculations (LDVs Diesel)

Pollutant	Vehicle Class	Speed Range [km/h]	Emission Factor [g/km]	R^2
CO	Conventional	10-110	20E-05V² - 0,0256V + 1,8281	0,136
	EURO I	10-110	22,3E-05V² - 0,026V + 1,076	0,301
NO_x	Conventional	10-110	81,6E-05V² - 0,1189V + 5,1234	0,402
	EURO I	10-110	24,1E-05V² - 0,03181V + 2,0247	0,0723
VOC	Conventional	10-110	1,75E-05V² - 0,00284V + 0,2162	0,0373
	EURO I	10-110	1,75E-05V² - 0,00284V + 0,2162	0,0373
PM	Conventional	10-110	1,25E-05V² - 0,000577V + 0,288	0,0230
	EURO I	10-110	4,5E-05V² - 0,004885V + 0,1932	0,224
Fuel Consumption	Conventional	10-110	0,02113V² - 2,65V + 148,91	0,486
	EURO I	10-110	0,0198V² - 2,506V + 137,42	0,422

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XVII Percentage Reduction for Improved LDVs Diesel Emission Factors

Diesel Light Duty Vehicles	CO [%]	NO_x [%]	VOC [%]	PM [%]
Euro II - 96/69/EC	0	0	0	0
Euro III - 98/69/EC Stage 2000	18	16	38	33
Euro IV - 98/69/EC Stage 2005	35	32	77	65

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XVIII Speed Dependent Formulas for Emissions and Fuel Consumption Factors Calculations (HDVs)

Pollutant	Weight Class	Speed Range [km/h]	Emission Factor [g/km]	R^2
CO	All Weight Categories	0-100	$37{,}280V^{-0{,}6945}$	0,880
NO_x	Weight<7,5t	0 - 46,7	$50{,}305V^{-0{,}7708}$	0,902
		46,7 - 100	$0{,}0014V^2 - 0{,}1737V + 7{,}5506$	0,260
	7,5<Weight<16t	0 - 58,8	$92{,}584V^{-0{,}7393}$	0,940
		58,8 - 100	$0{,}0006V^2 - 0{,}0941V + 7{,}7785$	0,440
	16<Weight<32t	0 - 100	$108{,}36V^{-0{,}6061}$	0,650
	Weight>32t	0 - 100	$132{,}88V^{-0{,}5581}$	0,894
VOC	All Weight Categories	0-100	$40{,}120V^{-0{,}8774}$	0,976
PM	Weight<7,5t	0 - 100	$4{,}5563V^{-0{,}7070}$	0,944
	7,5<Weight<16t	0 - 100	$9{,}6037V^{-0{,}7259}$	0,974
	16<Weight<32t	0 - 100	$10{,}890V^{-0{,}7105}$	0,946
	Weight>32t	0 - 100	$11{,}028V^{-0{,}6960}$	0,961
Fuel Consumption	Weight<7,5t	0 - 47	$1425{,}2V^{-0{,}7593}$	0,990
		47 - 100	$0{,}0082V^2 - 0{,}0430V + 60{,}12$	0,798
	7,5<Weight<16t	0 - 59	$1068{,}4V^{-0{,}4905}$	0,628
		59 - 100	$0{,}0126V^2 - 0{,}6589V + 141{,}18$	0,037
	16<Weight<32t	0 - 59	$1595{,}1V^{-0{,}4744}$	0,628
		59 - 100	$0{,}0382V^2 - 5{,}1630V + 399{,}3$	0,037
	Weight>32t	0 - 58	$1855{,}7V^{-0{,}4367}$	0,914
		58 - 100	$0{,}0765V^2 - 11{,}414V + 720{,}9$	0,187

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XIX Speed Dependent Formulas for Emissions and Fuel Consumption Factors Calculations (Buses & Coaches)

Pollutant	Vehicle Class	Speed Range [km/h]	Emission Factor [g/km]	R^2
CO	Urban Buses	0 - 50	$59{,}003\ V^{-0{,}7447}$	0,895
	Coaches	0 - 120	$63{,}791\ V^{-0{,}8393}$	0,978
NO_x	Urban Buses	0 - 50	$89{,}174\ V^{-0{,}5185}$	0,534
	Coaches	0 – 58,8	$125{,}87\ V^{-0{,}6562}$	0,848
		58,8 – 120	$0{,}0010\ V^2 - 0{,}1608\ V + 14{,}308$	0,073
VOC	Urban Buses	0 - 50	$43{,}647\ V^{-1{,}0301}$	0,992
	Coaches	0 - 120	$44{,}217\ V^{-0{,}8870}$	0,993
PM	Urban Buses	0 - 50	$7{,}8609\ V^{-0{,}7360}$	0,920
	Coaches	0 - 120	$9{,}2934\ V^{-0{,}7373}$	0,975
Fuel Consumption	Urban Buses	0 - 50	$1371{,}6\ V^{-0{,}4318}$	0,502
	Coaches	0 -59	$1919{,}0\ V^{-0{,}5396}$	0,786
		59 - 120	$0{,}0447\ V^2 - 7{,}072\ V + 478$	0,026

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XX Percentage Reduction for Improvd HDVs, Buses &Coaches Emission Factors

Veh. Class	Weight Class	CO			NO_x			VOC			PM		
		U	R	H	U	R	H	U	R	H	U	R	H
Euro I	Weight<7,5t	50,0	40,0	45,0	30,0	30,0	10,0	25,0	25,0	25,0	35,0	35,0	35,0
	7,5<Weight<16t	50,0	40,0	45,0	30,0	30,0	10,0	25,0	25,0	25,0	35,0	35,0	35,0
	16<Weight<32t	45,0	40,0	35,0	45,0	40,0	45,0	50,0	35,0	25,0	35,0	35,0	35,0
	Weight>32t	45,0	40,0	35,0	45,0	40,0	45,0	50,0	35,0	25,0	35,0	35,0	35,0
Euro II	Weight<7,5t	60,0	45,0	50,0	50,0	45,0	35,0	30,0	30,0	30,0	60,0	60,0	60,0
	7,5<Weight<16t	60,0	45,0	50,0	50,0	45,0	35,0	30,0	30,0	30,0	60,0	60,0	60,0
	16<Weight<32t	55,0	50,0	35,0	60,0	55,0	55,0	55,0	40,0	35,0	75,0	75,0	75,0
	Weight>32t	55,0	50,0	35,0	60,0	55,0	55,0	55,0	40,0	35,0	75,0	75,0	75,0
Euro III	Weight<7,5t	72,0	61,5	65,0	65,0	61,5	54,5	51,0	51,0	51,0	72,0	72,0	72,0
	7,5<Weight<16t	72,0	61,5	65,0	65,0	61,5	54,5	51,0	51,0	51,0	72,0	72,0	72,0
	16<Weight<32t	68,5	65,0	54,5	72,0	68,5	68,5	68,5	58,0	54,5	82,5	82,5	82,5
	Weight>32t	68,5	65,0	54,5	72,0	68,5	68,5	68,5	58,0	54,5	82,5	82,5	82,5
Euro IV	Weight<7,5t	79,6	71,9	74,5	75,5	73,1	68,2	65,7	65,7	65,7	94,7	94,7	94,7
	7,5<Weight<16t	79,6	71,9	74,5	75,5	73,1	68,2	65,7	65,7	65,7	94,7	94,7	94,7
	16<Weight<32t	77,0	74,5	66,8	80,4	78,0	78,0	78,0	70,6	68,2	96,7	96,7	96,7
	Weight>32t	77,0	74,5	66,8	80,4	78,0	78,0	78,0	70,6	68,2	96,7	96,7	96,7
Euro V	Weight<7,5t	79,6	71,9	74,5	86,0	84,6	81,8	65,7	65,7	65,7	94,7	94,7	94,7
	7,5<Weight<16t	79,6	71,9	74,5	86,0	84,6	81,8	65,7	65,7	65,7	94,7	94,7	94,7
	16<Weight<32t	77,0	74,5	66,8	88,8	87,4	87,4	78,0	70,6	68,2	96,7	96,7	96,7
	Weight>32t	77,0	74,5	66,8	88,8	87,4	87,4	78,0	70,6	68,2	96,7	96,7	96,7
Euro I	Urban Busses	50,0	40,0	45,0	30,0	30,0	10,0	25,0	25,0	25,0	35,0	35,0	35,0
	Coaches	45,0	40,0	35,0	45,0	40,0	45,0	50,0	35,0	25,0	35,0	35,0	35,0
Euro II	Urban Busses	60,0	45,0	50,0	50,0	45,0	35,0	30,0	30,0	30,0	60,0	60,0	60,0
	Coaches	55,0	50,0	35,0	60,0	55,0	55,0	55,0	40,0	35,0	75,0	75,0	75,0
Euro III	Urban Busses	72,0	61,5	65,0	65,0	61,5	54,5	51,0	51,0	51,0	72,0	72,0	72,0
	Coaches	68,5	65,0	54,5	72,0	68,5	68,5	68,5	58,0	54,5	82,5	82,5	82,5
Euro IV	Urban Busses	79,6	71,9	74,5	75,5	73,1	68,2	65,7	65,7	65,7	94,7	94,7	94,7
	Coaches	77,0	74,5	66,8	80,4	78,0	78,0	78,0	70,6	68,2	96,7	96,7	96,7
Euro V	Urban Busses	79,6	71,9	74,5	86,0	84,6	81,8	65,7	65,7	65,7	94,7	94,7	94,7
	Coaches	77,0	74,5	66,8	88,8	87,4	87,4	78,0	70,6	68,2	96,7	96,7	96,7

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XXI Speed Dependent Formulas for Emissions and Fuel Consumption Factors Calculations (Motor Cycles)

Pollutant	Cylinder Capacity	Speed Range [km/h]	Emission Factor [g/km]
CO	Conventional <250cm³	10 - 60	0,01930V² - 1,9200V + 68,30
		60 - 110	0,00170V² + 0,1210V + 9,500
	Conventional 250<cc<750cm³	10 - 60	0,01390V² - 1,4200V + 55,00
		60 - 110	0,00090V² - 0,0099V + 17,80
	Conventional >750cm³	10 - 60	0,01230V² - 1,1900V + 42,80
		60 - 110	0,00050V² + 0,1240V + 6,900
	97/24/EC All Capacities	10 - 60	0,00760V² - 0,7300V + 23,50
		60 - 110	0,00100V² + 0,0510V + 0,800
NO_x	Conventional <250cm³	10 - 60	0,00005V² - 0,0010V + 0,090
		60 - 110	0,00002V² + 0,0006V + 0,102
	Conventional 250<cc<750cm³	10 - 60	0,00005V² - 0,0009V + 0,092
		60 - 110	0,00002V² + 0,0007V + 0,104
	Conventional >750cm³	10 - 60	0,00005V² - 0,0008V + 0,100
		60 - 110	0,00002V² + 0,0008V + 0,112
	97/24/EC All Capacities	10 - 60	0,00005V² -0,0007V + 0,137
		60 - 110	0,00002V² + 0,001V + 0,143
VOC	Conventional <250cm³	10 - 60	0,00190V² - 0,2110V + 6,950
		60 - 110	0,00090V² - 0,1410V + 6,420
	Conventional 250<cc<750cm³	10 - 60	0,00150V² - 0,1640V + 5,510
		60 - 110	0,00001V² + 0,0005V + 0,860
	Conventional >750cm³	10 - 60	0,00220V² - 0,2570V + 9,280
		60 - 110	0,00010V² - 0,0310V + 3,290
	97/24/EC All Capacities	10 - 60	0,00070V² - 0,0755V + 2,630
		60 - 110	0,00007V² - 0,0152V + 1,190
Fuel Consumption	Conventional <250cm³	10 - 60	0,01890V² - 1,8740V + 67,90
		60 - 110	0,00080V² + 0,1614V + 11,50
	Conventional 250<cc<750cm³	10 - 60	0,02730V² - 2,8490V + 98,90
		60 - 110	0,00210V² - 0,1550V + 29,20
	Conventional >750cm³	10 - 60	0,02870V² - 3,1080V + 115,9
		60 - 110	0,00180V² - 0,1638V + 37,00
	97/24/EC All Capacities	10 - 60	0,02000V² - 2,0750V + 77,10
		60 - 110	0,00130V² - 0,0391V + 23,50

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XXII Speed Dependent Formulas for Calculating Methane CH_4 Emission factors

CH_4 Emission Factors [mg/km]	Speed Range [km/h]	Urban	Rural	Highway
Passenger Cars				
Gasoline Conventional	10 - 130	$0{,}0331V^2 - 5{,}73V + 268$		
Gas. Euro I CC < 1,4 l	10 - 130	$0{,}012969V^2 - 2{,}1098V + 101{,}995$		
Gas. Euro I 1,4 l<CC<2,0 l	10 - 130	$0{,}011176V^2 - 1{,}9573V + 99{,}652$		
Gas. Euro I CC > 2,0 l	10 - 130	$0{,}0093945V^2 - 1{,}8118V + 97{,}488$		
Diesel CC < 2,0 l	10 - 130	$0{,}0019V^2 - 0{,}1775V + 7{,}9936$		
Diesel CC > 2,0 l	10 - 130	$0{,}0019V^2 - 0{,}1775V + 7{,}9936$		
LPG		80	35	25
2 - stroke		150	40	25
Light Duty Vehicles				
Gasoline Conventional		150	40	25
Gasoline Euro I and on	10 - 130	$0{,}012969V^2 - 2{,}1098V + 101{,}995$		
Diesel		5	5	5
Heavy Duty Vehicles				
Gasoline > 3,5 t		140	110	70
Diesel < 7,5 t		85	23	20
Diesel 7,5 t < W < 16 t		85	23	20
Diesel 16 t < W < 32 t		175	80	70
Diesel W > 32 t		175	80	70
Urban Buses		175	-	-
Coaches		175	80	70
Mopeds and Motorcycles				
< 50 cm^3		219	219	219
> 50 cm^3 2 stroke		150	150	150
> 50 cm^3 4 stroke		200	200	200

Source: COPERT III Technical Report, Ntziachristos et al, 2000

Appendix XXIII Speed Dependent Formulas for Calculating Nitrous oxide N_2O Emission factors

N_2O Emission Factors [mg/km]	Urban	Rural	Highway
Passenger Cars			
Gasoline Conventional	5	5	5
Gasoline Euro I and on	53	16	35
Diesel CC < 2.0 l	27	27	27
Diesel CC > 2.0 l	27	27	27
LPG	15	15	15
2 - stroke	5	5	5
Light Duty Vehicles			
Gasoline Conventional	6	6	6
Gasoline Euro I and on	53	16	35
Diesel	17	17	17
Heavy Duty Vehicles			
Gasoline > 3.5 t	6	6	6
Diesel < 7.5 t	30	30	30
Diesel 7.5 t < W < 16 t	30	30	30
Diesel 16 t < W < 32 t	30	30	30
Diesel W > 32 t	30	30	30
Urban Buses	30	-	-
Coaches	30	30	30
Motorcycles			
< 50 cm^3	1	1	1
> 50 cm^3 2 stroke	2	2	2
> 50 cm^3 4 stroke	2	2	2

Source: COPERT III Technical Report, Ntziachristos et al, 2000

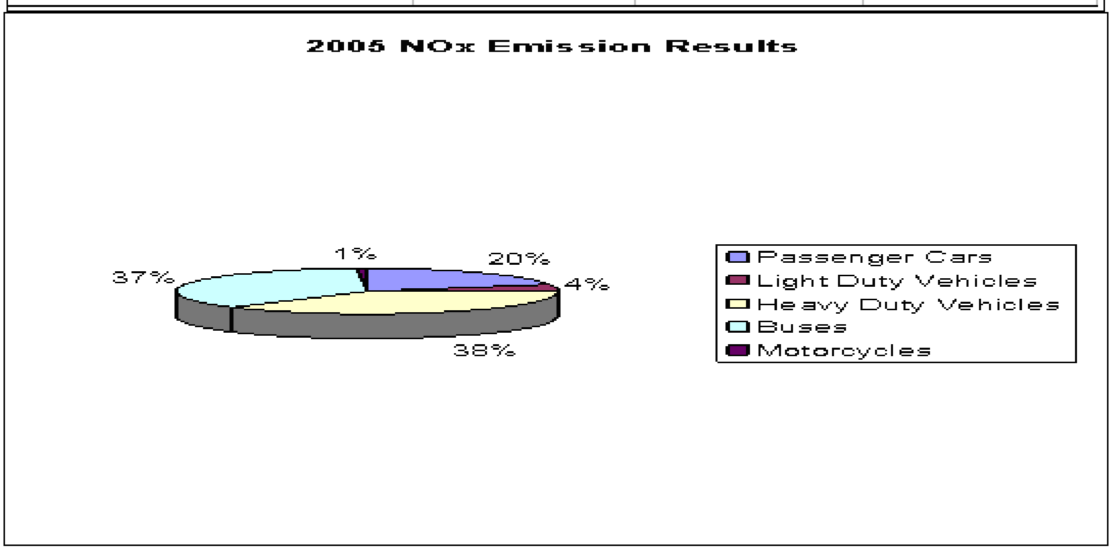
Appendix XXIV Speed Dependent Formulas for Calculating Ammonia NH_3 Emission factors

NH_3 Emission Factors [mg/km]	Urban	Rural	Highway
Passenger Cars			
Gasoline Conventional	2	2	2
Gasoline Euro I and on	70	100	100
Diesel CC < 2.0 l	1	1	1
Diesel CC > 2.0 l	1	1	1
LPG	nd	nd	nd
2 - stroke	2	2	2
Light Duty Vehicles			
Gasoline Conventional	2	2	2
Gasoline Euro I and on	70	100	100
Diesel	1	1	1
Heavy Duty Vehicles			
Gasoline Veh. > 3.5 t	2	2	2
Diesel < 7.5 t	3	3	3
Diesel 7.5 t < W < 16 t	3	3	3
Diesel 16 t < W < 32 t	3	3	3
Diesel W > 32 t	3	3	3
Urban Buses	3	-	-
Coaches	3	3	3
Motorcycles			
< 50 cm^3	1	1	1
> 50 cm^3 2 stroke	2	2	2
> 50 cm^3 4 stroke	2	2	2

Source: COPERT III Technical Report, Ntziachristos et al, 2000

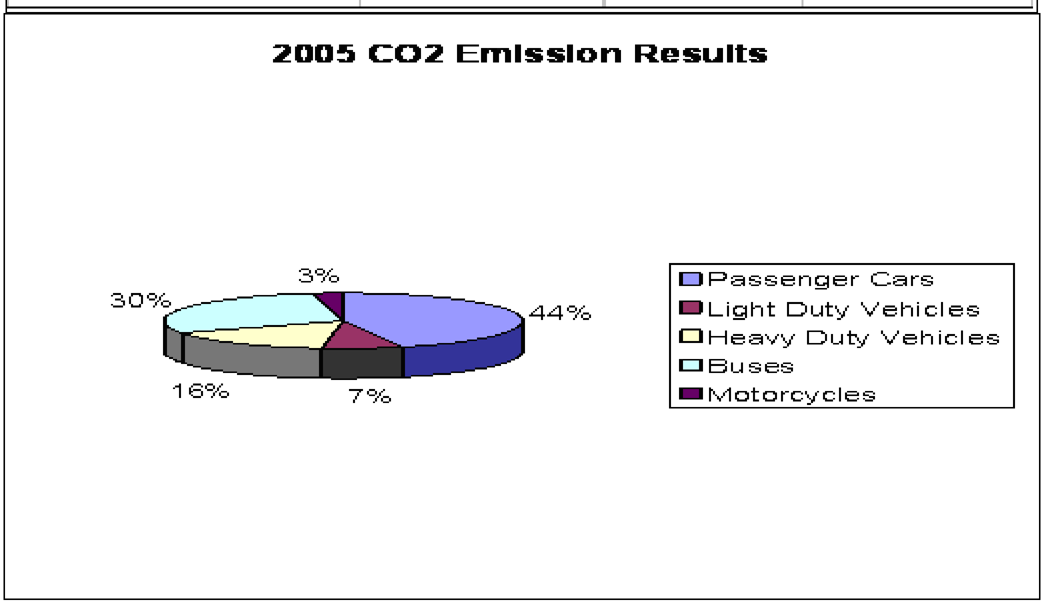
Appendix XXV 2005 BAU NOx Emission Results

2005 NOx Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**1985**	**258**	**2243**
Gasoline 1.4 -2.0l	294	258	552
Diesel < 2.0l	1390	0	1390
LPG	1	0	1
Light Duty Vehicles	**403**	**29**	**432**
Gasoline <3.5t	38	29	67
Diesel <3.5t	364	0	364
Heavy Duty Vehicles	**4238**	**0**	**4238**
Diesel 7.5 -16t	1918	0	1918
Diesel 16 - 32t	1928	0	1928
Diesel >32t	392	0	392
Buses	**4061**	**0**	**4061**
Urban Buses	4061	0	4061
Motorcycles	**90**	**0**	**90**
4-stroke 250 - 750	90	0	90
Grand Total	**10777**	**287**	**11064**



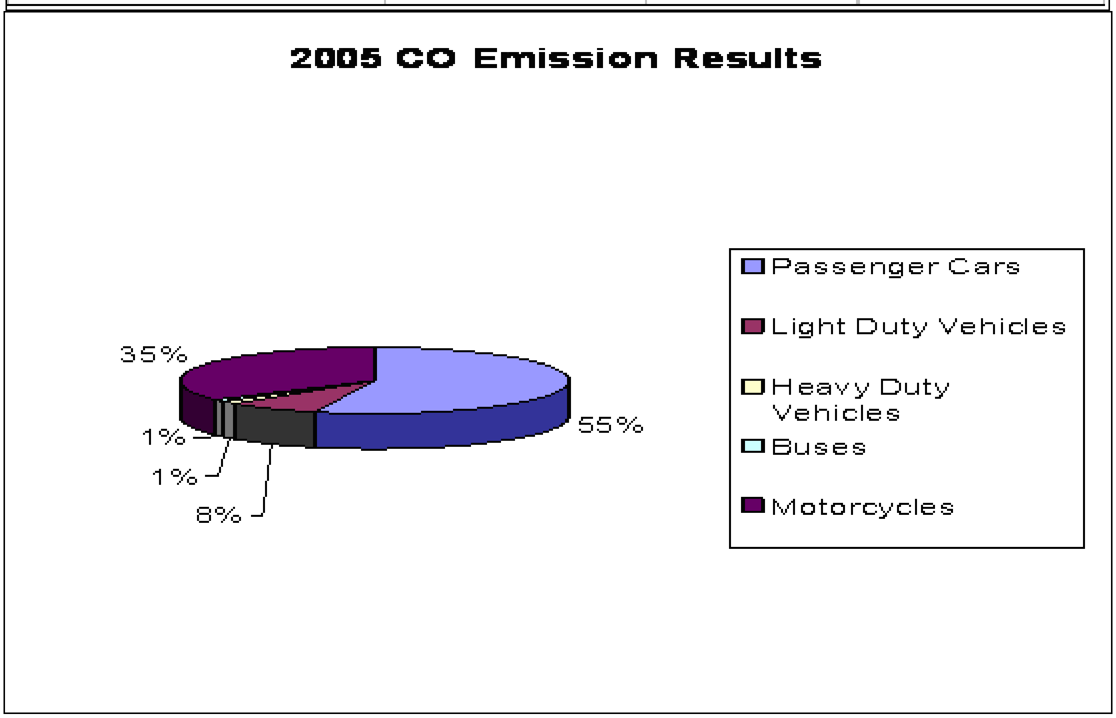
Appendix XXVI 2005 BAU CO2 Emission Results

2005 CO2 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**1615528**	**92210**	**1707738**
Gasoline 1.4 -2.0l	1177856	76396	1254252
Diesel < 2.0l	436806	15764	452570
LPG	867	49	916
Light Duty Vehicles	**266054**	**15215**	**281269**
Gasoline <3.5t	189722	12879	202601
Diesel <3.5t	76332	2336	78668
Heavy Duty Vehicles	**598852**	**0**	**598852**
Diesel 7.5 -16t	269063	0	269063
Diesel 16 - 32t	279377	0	279377
Diesel >32t	50413	0	50413
Buses	**1128891**	**0**	**1128891**
Urban Buses	1128891	0	1128891
Motorcycles	**102989**	**0**	**102989**
4-stroke 250 - 750	102989	0	102989
Grand Total	**3712314**	**107425**	**3819739**



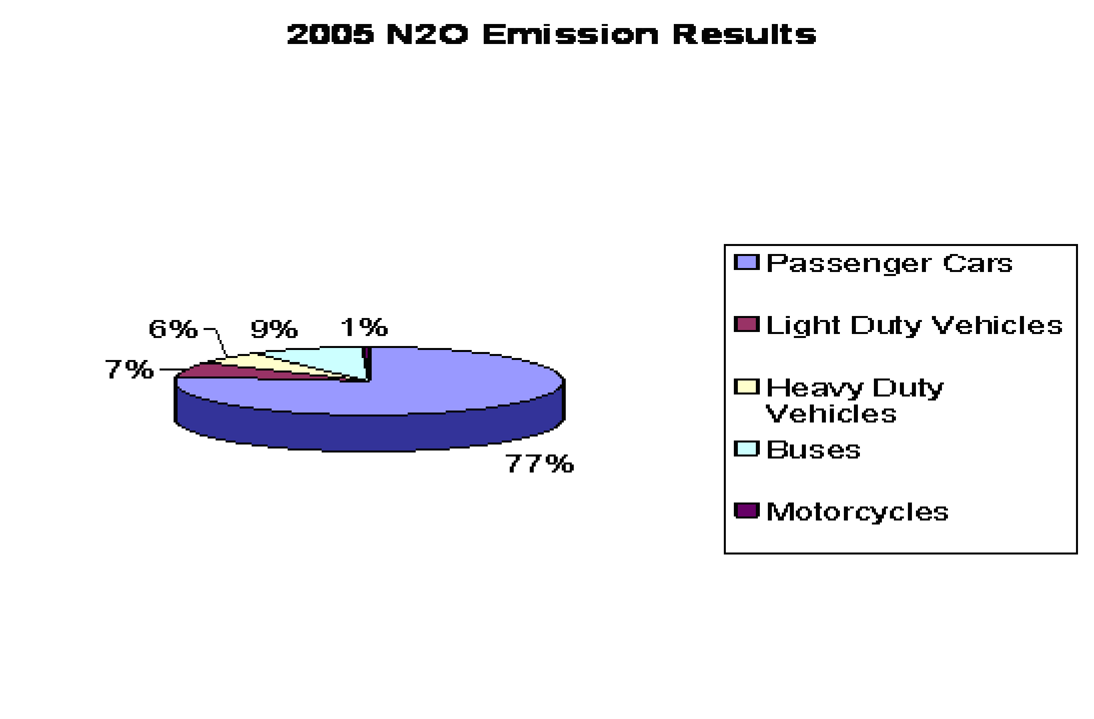
Appendix XXVII 2005 BAU CO Emission Results

2005 CO Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**36806**	**13040**	**49846**
Gasoline 1.4 -2.0l	35627	12968	48595
Diesel < 2.0l	1173	72	1245
LPG	6	1	7
Light Duty Vehicles	**5724**	**1449**	**7173**
Gasoline <3.5t	5457	1440	6897
Diesel <3.5t	266	8	274
Heavy Duty Vehicles	**1281**	**0**	**1281**
Diesel 7.5 -16t	680	0	680
Diesel 16 - 32t	529	0	529
Diesel >32t	72	0	72
Buses	**996**	**0**	**996**
Urban Buses	996	0	996
Motorcycles	**31373**	**0**	**31373**
4-stroke 250 - 750	31373	0	31373
Grand Total	**76180**	**14489**	**90669**



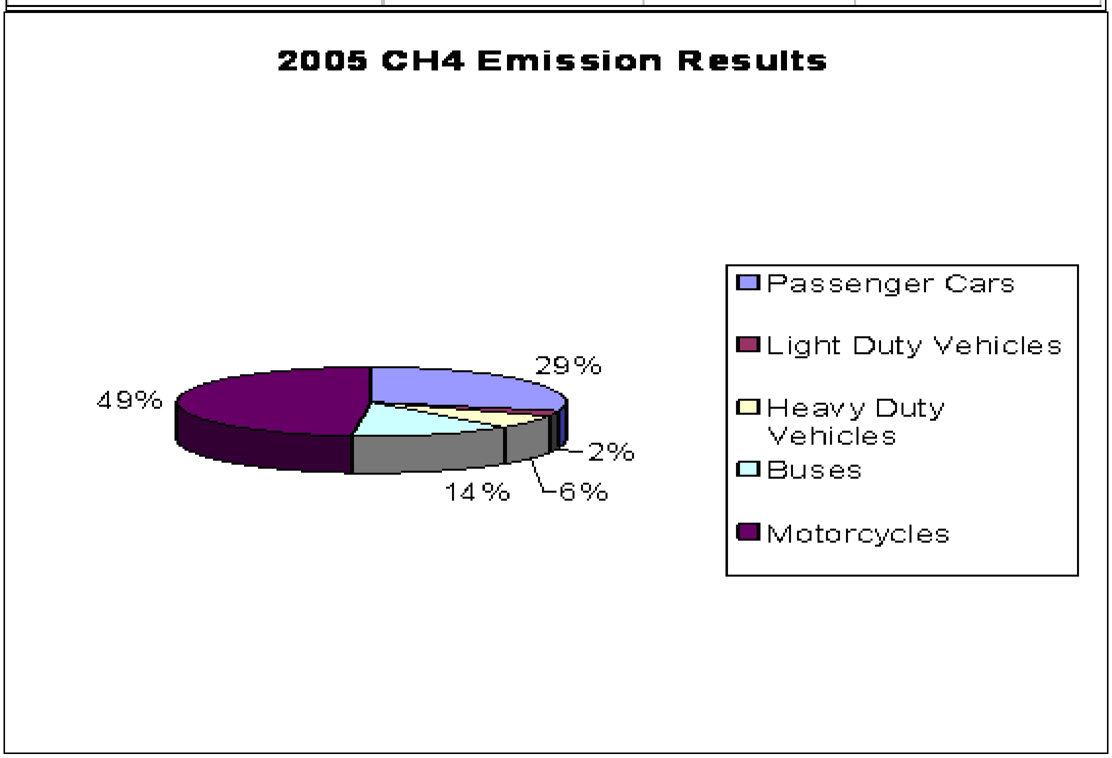
Appendix XXVIII 2005 BAU N2O Emission Results

2005 N2O Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**373**	**0**	**373**
Gasoline 1.4 -2.0l	295	0	295
Diesel < 2.0l	78	0	78
LPG	0	0	0
Light Duty Vehicles	**34**	**0**	**34**
Gasoline <3.5t	28	0	28
Diesel <3.5t	6	0	6
Heavy Duty Vehicles	**28**	**0**	**28**
Diesel 7.5 -16t	16	0	16
Diesel 16 - 32t	11	0	11
Diesel >32t	2	0	2
Buses	**45**	**0**	**45**
Urban Buses	45	0	45
Motorcycles	**3**	**0**	**3**
4-stroke 250 - 750	3	0	3
Grand Total	**483**	**0**	**483**



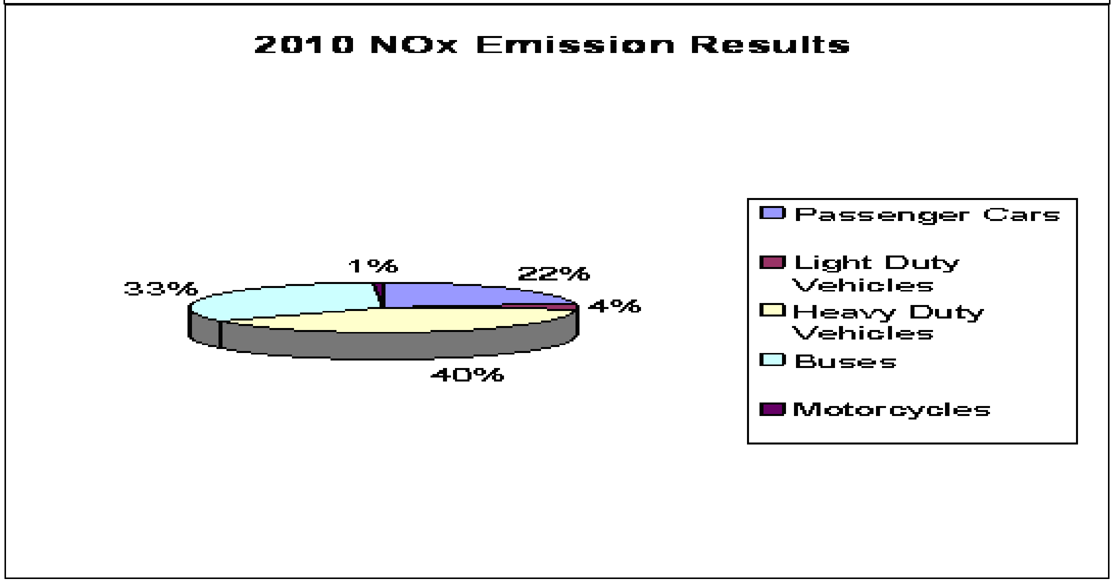
Appendix XXIX 2005 BAU CH4Emission Results

2005 CH4 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**54**	**105**	**159**
Gasoline 1.4 -2.0l	38	104	142
Diesel < 2.0l	16	0	16
LPG	0	0	0
Light Duty Vehicles	**6**	**7**	**13**
Gasoline <3.5t	4	7	12
Diesel <3.5t	2	0	2
Heavy Duty Vehicles	**35**	**0**	**35**
Diesel 7.5 -16t	11	0	11
Diesel 16 - 32t	21	0	21
Diesel >32t	3	0	3
Buses	**74**	**0**	**74**
Urban Buses	74	0	74
Motorcycles	**264**	**0**	**264**
4-stroke 250 - 750	264	0	264
Grand Total	**433**	**112**	**545**



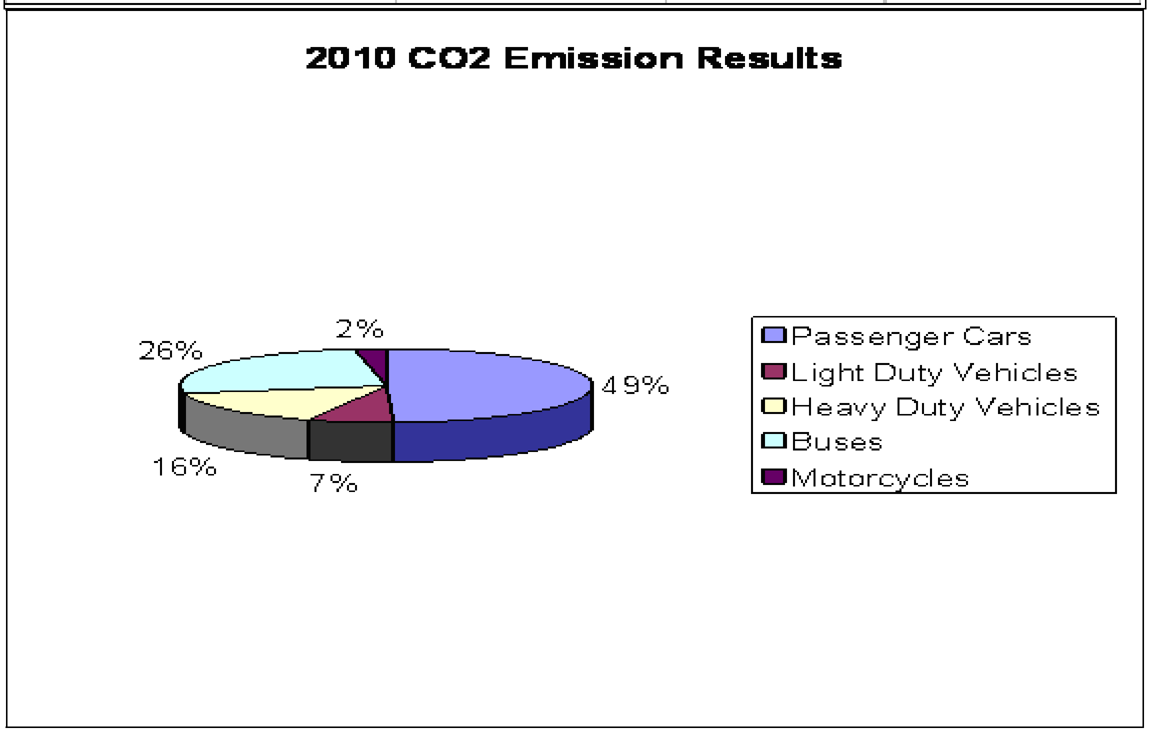
Appendix XXX 2010 BAU NOx Emission Results

2010 NOx Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**2929**	**349**	**3278**
Gasoline 1.4 -2.0l	443	349	792
Diesel < 2.0l	2485	1	2486
LPG	1	0	1
Light Duty Vehicles	**497**	**33**	**530**
Gasoline <3.5t	48	33	82
Diesel <3.5t	449	0	449
Heavy Duty Vehicles	**5793**	**0**	**5793**
Diesel 7.5 -16t	2621	0	2621
Diesel 16 - 32t	2635	0	2635
Diesel >32t	536	0	536
Buses	**4866**	**0**	**4866**
Urban Buses	4866	0	4866
Motorcycles	**113**	**0**	**113**
4-stroke 250 - 750	113	0	113
Grand Total	**14198**	**382**	**14580**



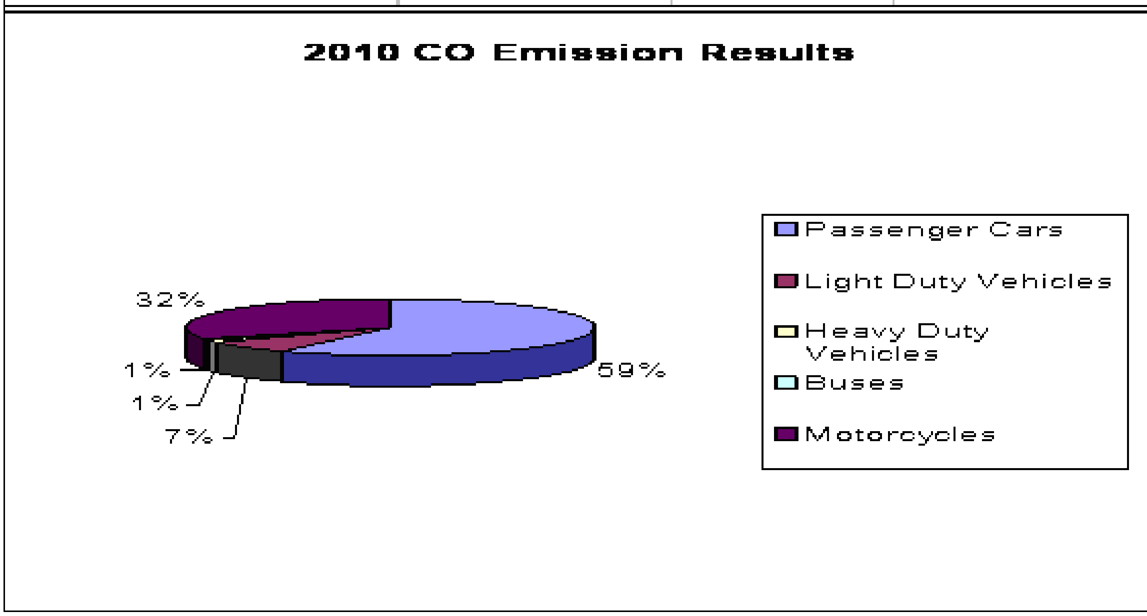
Appendix XXXI 2010 BAU CO2 Emission Results

2010 CO2 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**2437083**	**124685**	**2561768**
Gasoline 1.4 -2.0l	1776836	103302	1880138
Diesel < 2.0l	658936	21316	680252
LPG	1311	67	1378
Light Duty Vehicles	**335694**	**17205**	**352899**
Gasoline <3.5t	239270	14559	253829
Diesel <3.5t	96424	2645	99069
Heavy Duty Vehicles	**809199**	**0**	**809199**
Diesel 7.5 -16t	363570	0	363570
Diesel 16 - 32t	377503	0	377503
Diesel >32t	68126	0	68126
Buses	**1337385**	**0**	**1337385**
Urban Buses	1337385	0	1337385
Motorcycles	**128896**	**0**	**128896**
4-stroke 250 - 750	128896	0	128896
Grand Total	**5048257**	**141890**	**5190147**



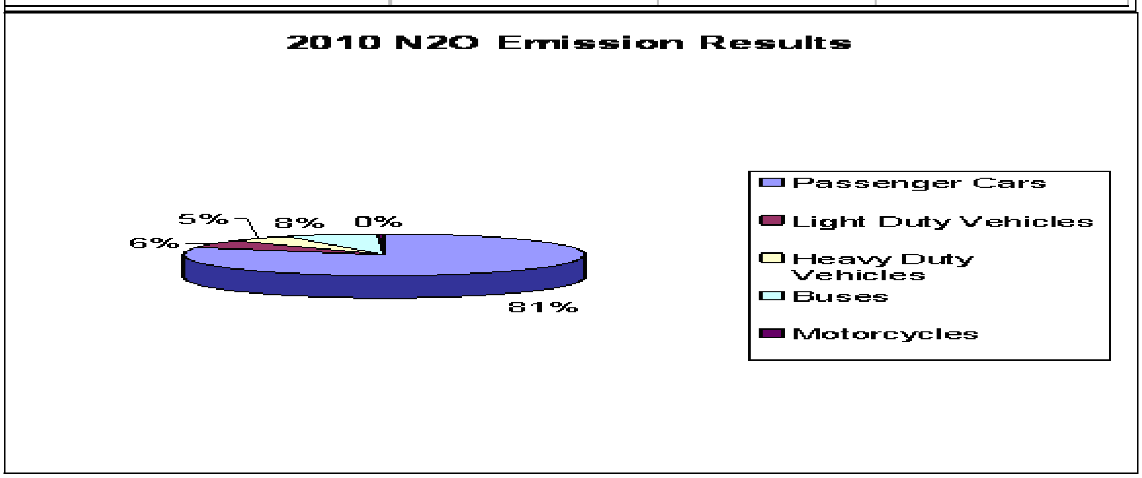
Appendix XXXII 2010 BAU CO Emission Results

2010 CO Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**55556**	**17635**	**73191**
Gasoline 1.4 -2.0l	53744	17635	71379
Diesel < 2.0l	1803	99	1902
LPG	10	1	11
Light Duty Vehicles	**7225**	**1638**	**8863**
Gasoline <3.5t	6883	1628	8511
Diesel <3.5t	343	10	353
Heavy Duty Vehicles	**1731**	**0**	**1731**
Diesel 7.5 -16t	919	0	919
Diesel 16 - 32t	714	0	714
Diesel >32t	97	0	97
Buses	**1180**	**0**	**1180**
Urban Buses	1180	0	1180
Motorcycles	**39265**	**0**	**39265**
4-stroke 250 - 750	39265	0	39265
Grand Total	**104957**	**19273**	**124230**



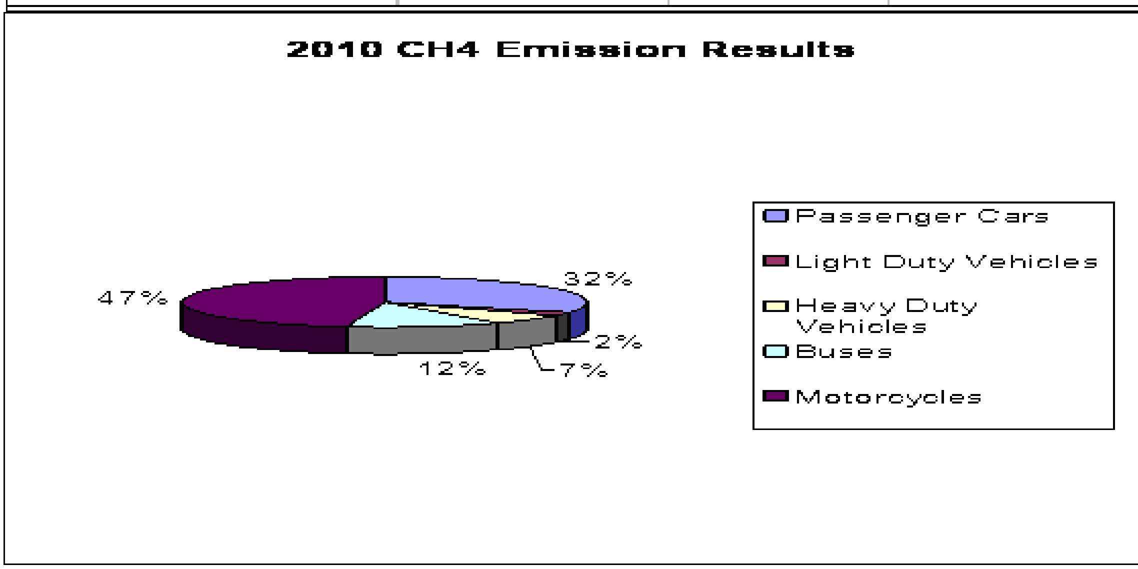
Appendix XXXIII 2010 BAU N2OEmission Results

2010 N2O Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**563**	**0**	**563**
Gasoline 1.4 -2.0l	446	0	446
Diesel < 2.0l	117	0	117
LPG	0	0	0
Light Duty Vehicles	**43**	**0**	**43**
Gasoline <3.5t	35	0	35
Diesel <3.5t	7	0	7
Heavy Duty Vehicles	**38**	**0**	**38**
Diesel 7.5 -16t	21	0	21
Diesel 16 - 32t	15	0	15
Diesel >32t	2	0	2
Buses	**53**	**0**	**53**
Urban Buses	53	0	53
Motorcycles	**3**	**0**	**3**
4-stroke 250 - 750	3	0	3
Grand Total	**700**	**0**	**700**



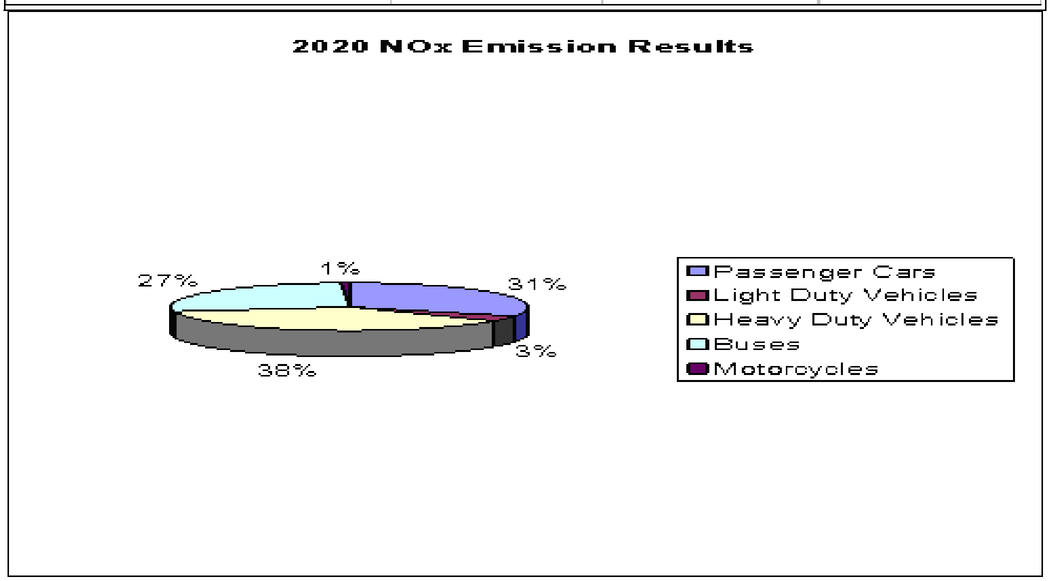
Appendix XXXIV 2010 BAU CH4 Emission Results

2010 CH4 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**82**	**141**	**223**
Gasoline 1.4 -2.0l	57	141	198
Diesel < 2.0l	24	0	24
LPG	0	0	0
Light Duty Vehicles	**8**	**8**	**16**
Gasoline <3.5t	6	8	14
Diesel <3.5t	2	0	2
Heavy Duty Vehicles	**47**	**0**	**47**
Diesel 7.5 -16t	15	0	15
Diesel 16 - 32t	28	0	28
Diesel >32t	4	0	4
Buses	**87**	**0**	**87**
Urban Buses	87	0	87
Motorcycles	**331**	**0**	**331**
4-stroke 250 - 750	331	0	331
Grand Total	**555**	**149**	**704**



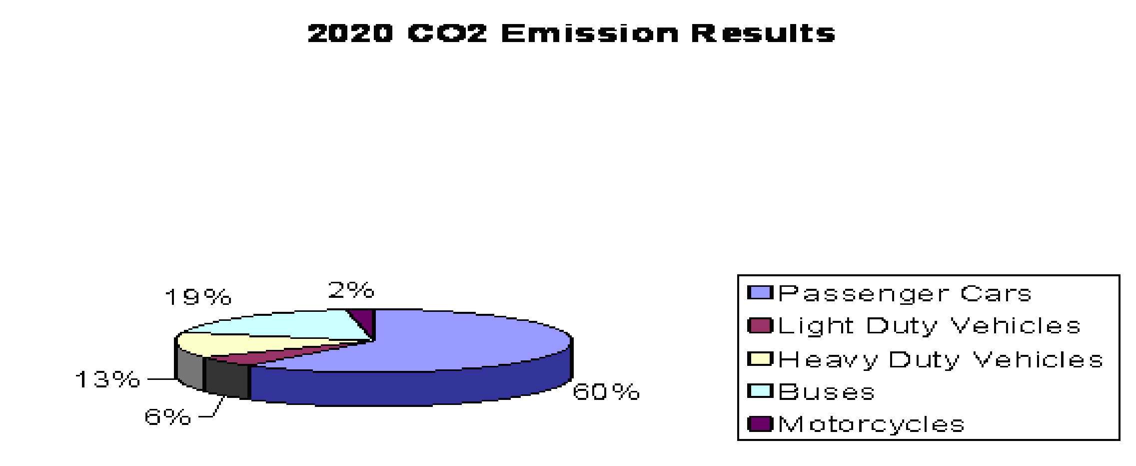
Appendix XXXV BAU 2020 NOx Emission Results

2020 NOx Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**5625**	**749**	**6374**
Gasoline 1.4 -2.0l	851	748	1599
Diesel < 2.0l	4772	1	4773
LPG	2	0	2
Light Duty Vehicles	**646**	**48**	**694**
Gasoline <3.5t	63	48	111
Diesel <3.5t	583	0	583
Heavy Duty Vehicles	**7528**	**0**	**7528**
Diesel 7.5 -16t	3407	0	3407
Diesel 16 - 32t	3425	0	3425
Diesel >32t	697	0	697
Buses	**5515**	**0**	**5515**
Urban Buses	5515	0	5515
Motorcycles	**149**	**0**	**149**
4-stroke 250 - 750	149	0	149
Grand Total	**19463**	**797**	**20260**



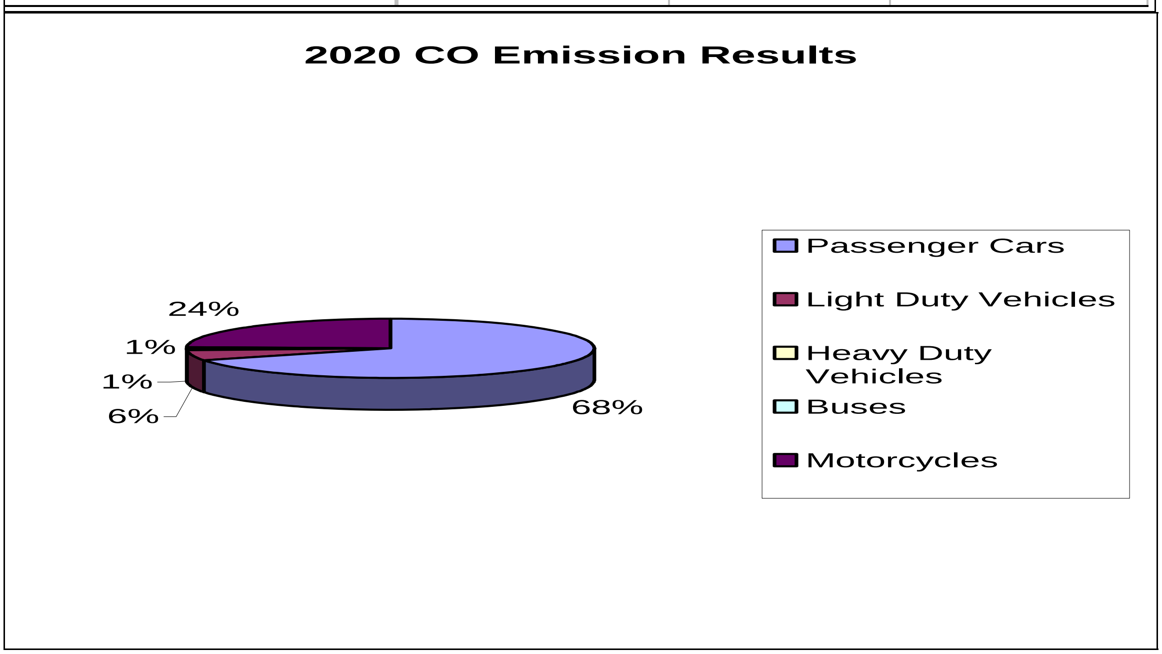
Appendix XXXVI 2020 BAU CO2 Emission Results

2020 CO2 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**4679791**	**267109**	**4946900**
Gasoline 1.4 -2.0l	3411952	221301	3633253
Diesel < 2.0l	1265321	45665	1310986
LPG	2519	143	2662
Light Duty Vehicles	**436261**	**24944**	**461205**
Gasoline <3.5t	310951	21109	332060
Diesel <3.5t	125309	3835	129144
Heavy Duty Vehicles	**1051607**	**0**	**1051607**
Diesel 7.5 -16t	472486	0	472486
Diesel 16 - 32t	490592	0	490592
Diesel >32t	88529	0	88529
Buses	**1515585**	**0**	**1515585**
Urban Buses	1515585	0	1515585
Motorcycles	**169749**	**0**	**169749**
4-stroke 250 - 750	169749	0	64033
Grand Total	**7852993**	**292053**	**8145046**



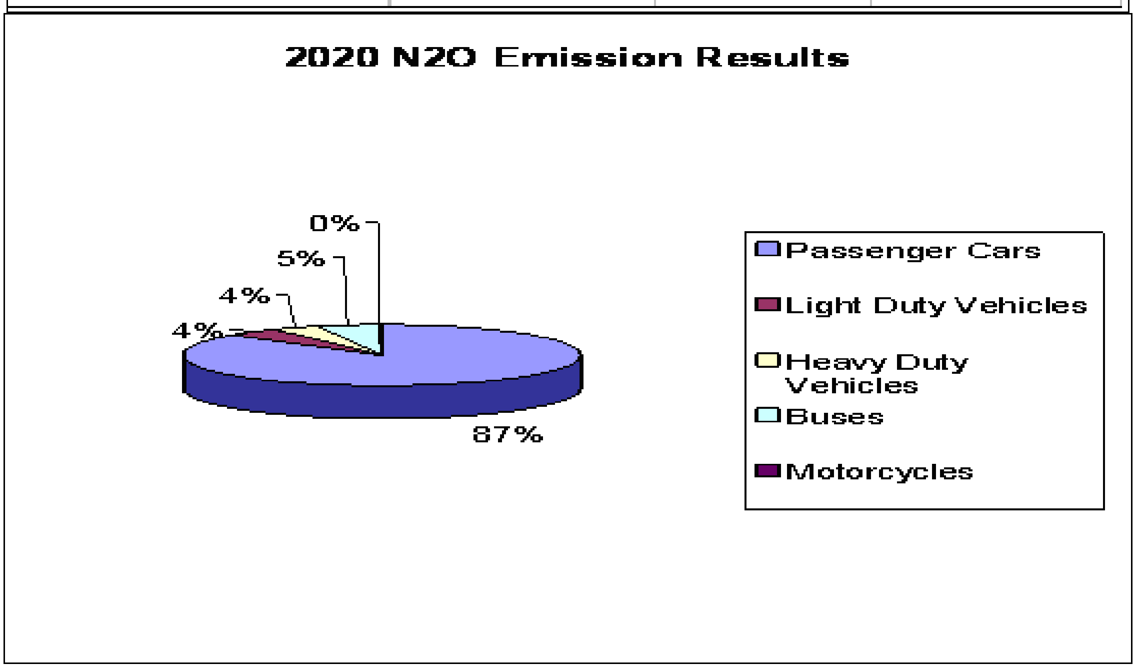
Appendix XXXVII 2020 BAU CO Emission Results

2020 CO Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**106682**	**37778**	**144460**
Gasoline 1.4 -2.0l	103202	37564	140766
Diesel < 2.0l	3462	213	3675
LPG	18	2	20
Light Duty Vehicles	**9390**	**2375**	**11765**
Gasoline <3.5t	8945	2361	11306
Diesel <3.5t	446	14	460
Heavy Duty Vehicles	**2249**	**0**	**2249**
Diesel 7.5 -16t	1194	0	1194
Diesel 16 - 32t	929	0	929
Diesel >32t	126	0	126
Buses	**1337**	**0**	**1337**
Urban Buses	1337	0	1337
Motorcycles	**51709**	**0**	**51709**
4-stroke 250 - 750	51709	0	51709
Grand Total	**171367**	**40153**	**211520**



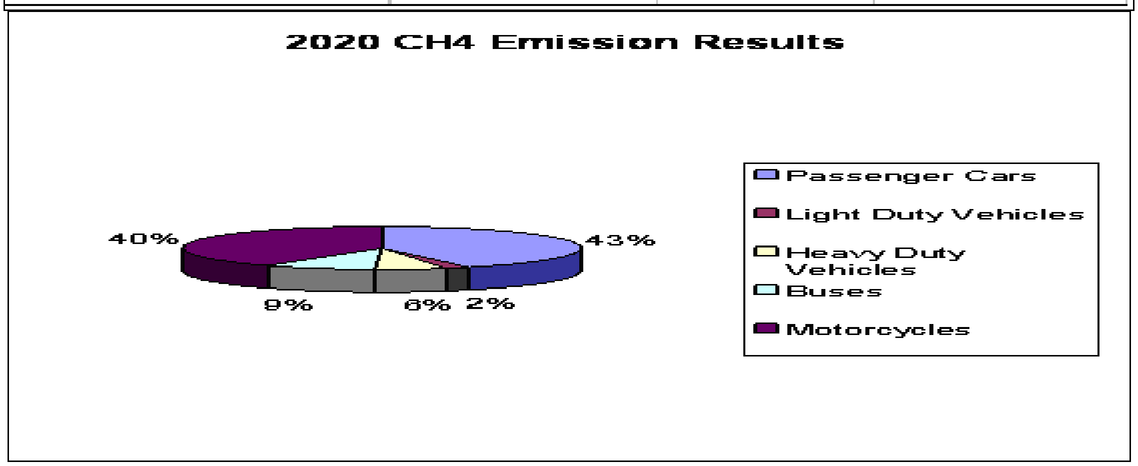
Appendix XXXVIII 2020 BAU N2O Emission Results

2020 N2O Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**1081**	**0**	**1081**
Gasoline 1.4 -2.0l	856	0	856
Diesel < 2.0l	225	0	225
LPG	0	0	0
Light Duty Vehicles	**55**	**0**	**55**
Gasoline <3.5t	46	0	46
Diesel <3.5t	9	0	9
Heavy Duty Vehicles	**50**	**0**	**50**
Diesel 7.5 -16t	28	0	28
Diesel 16 - 32t	20	0	20
Diesel >32t	3	0	3
Buses	**61**	**0**	**61**
Urban Buses	61	0	61
Motorcycles	**4**	**0**	**4**
4-stroke 250 - 750	4	0	4
Grand Total	**1251**	**0**	**1251**



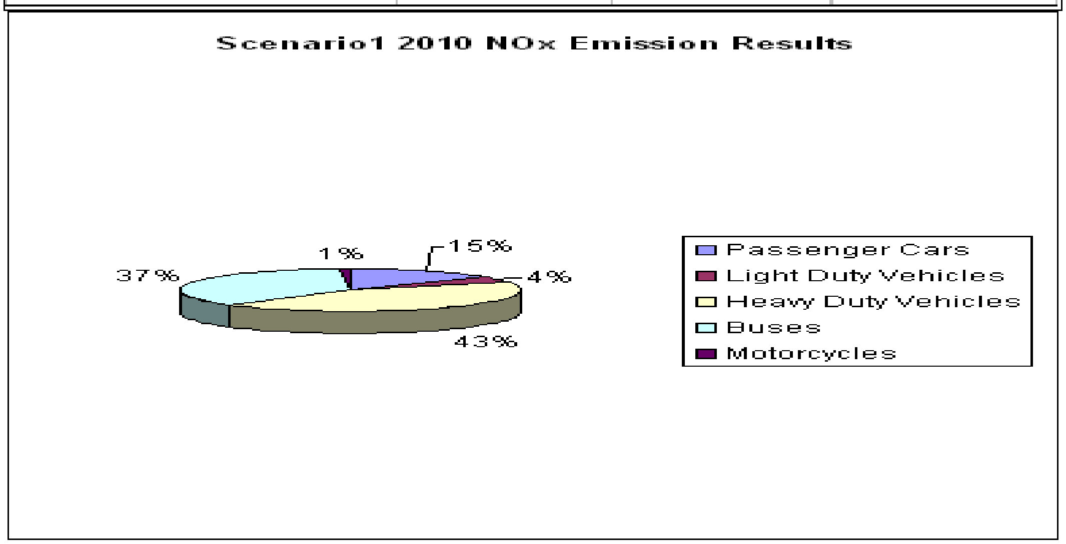
Appendix XXXIX 2020 BAU CH4Emission Results

2020 CH4 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**157**	**303**	**460**
Gasoline 1.4 -2.0l	110	303	413
Diesel < 2.0l	47	0	47
LPG	0	0	0
Light Duty Vehicles	**10**	**12**	**22**
Gasoline <3.5t	7	12	19
Diesel <3.5t	3	0	3
Heavy Duty Vehicles	**61**	**0**	**61**
Diesel 7.5 -16t	19	0	19
Diesel 16 - 32t	37	0	37
Diesel >32t	5	0	5
Buses	**99**	**0**	**99**
Urban Buses	99	0	99
Motorcycles	**435**	**0**	**435**
4-stroke 250 - 750	435	0	435
Grand Total	**762**	**315**	**1077**



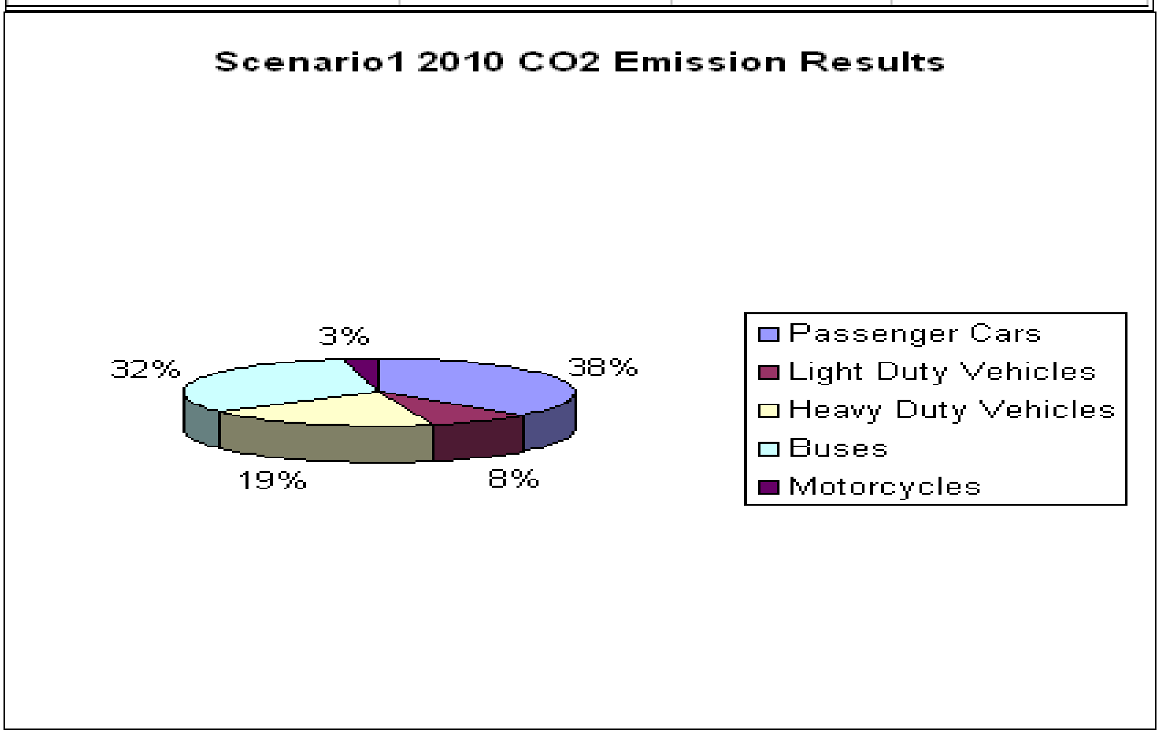
Appendix XL Scenario1 2010 NOx Emission Results

Scenario1 2010 NOx Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**1754**	**209**	**1963**
Gasoline 1.4 -2.0l	265	209	474
Diesel < 2.0l	1488	0	1488
LPG	0	0	0
Light Duty Vehicles	**497**	**33**	**530**
Gasoline <3.5t	48	33	82
Diesel <3.5t	449	0	449
Heavy Duty Vehicles	**5793**	**0**	**5793**
Diesel 7.5 -16t	2621	0	2621
Diesel 16 - 32t	2635	0	2635
Diesel >32t	536	0	536
Buses	**4837**	**0**	**4837**
Urban Buses	4837	0	4837
Motorcycles	**113**	**0**	**113**
4-stroke 250 - 750	113	0	113
Grand Total	**12994**	**242**	**13236**



Appendix XLI Scenario1 2010 CO2 Emission Results

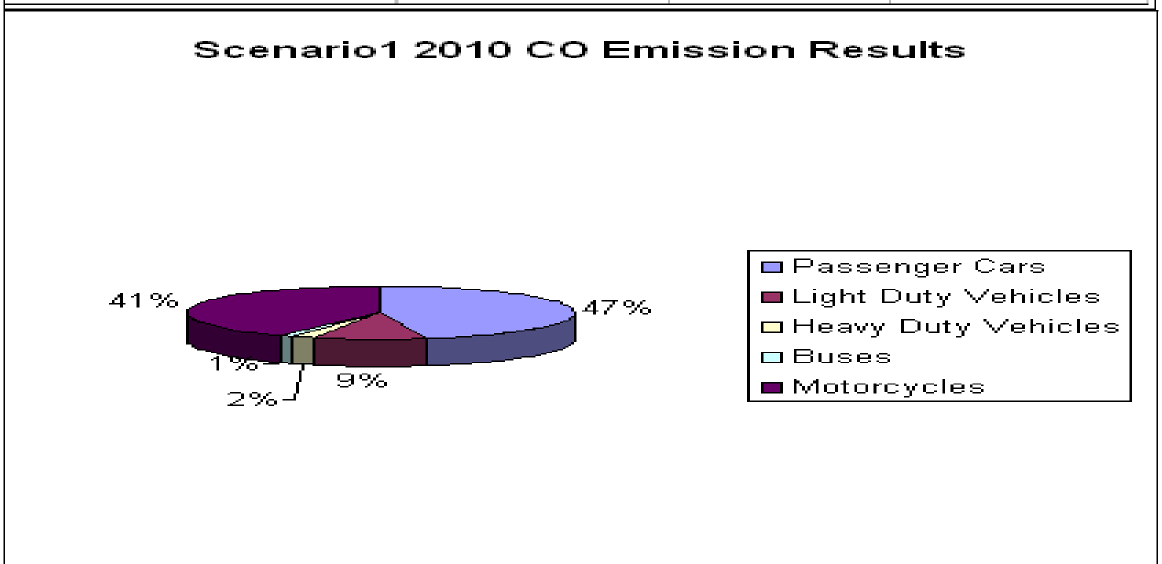
Scenario1 2010 CO2 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**1459216**	**74656**	**1533872**
Gasoline 1.4 -2.0l	1063890	61853	1125743
Diesel < 2.0l	394542	12763	407305
LPG	785	40	825
Light Duty Vehicles	**335694**	**17205**	**352899**
Gasoline <3.5t	239270	14559	253829
Diesel <3.5t	96424	2645	99069
Heavy Duty Vehicles	**809199**	**0**	**809199**
Diesel 7.5 -16t	363570	0	363570
Diesel 16 - 32t	377503	0	377503
Diesel >32t	68126	0	68126
Buses	**1329449**	**0**	**1329449**
Urban Buses	1329449	0	1329449
Motorcycles	**128896**	**0**	**128896**
4-stroke 250 - 750	128896	0	128896
Grand Total	**4062454**	**91861**	**4154315**



Appendix XLII Scenario1 2010 CO Emission Results

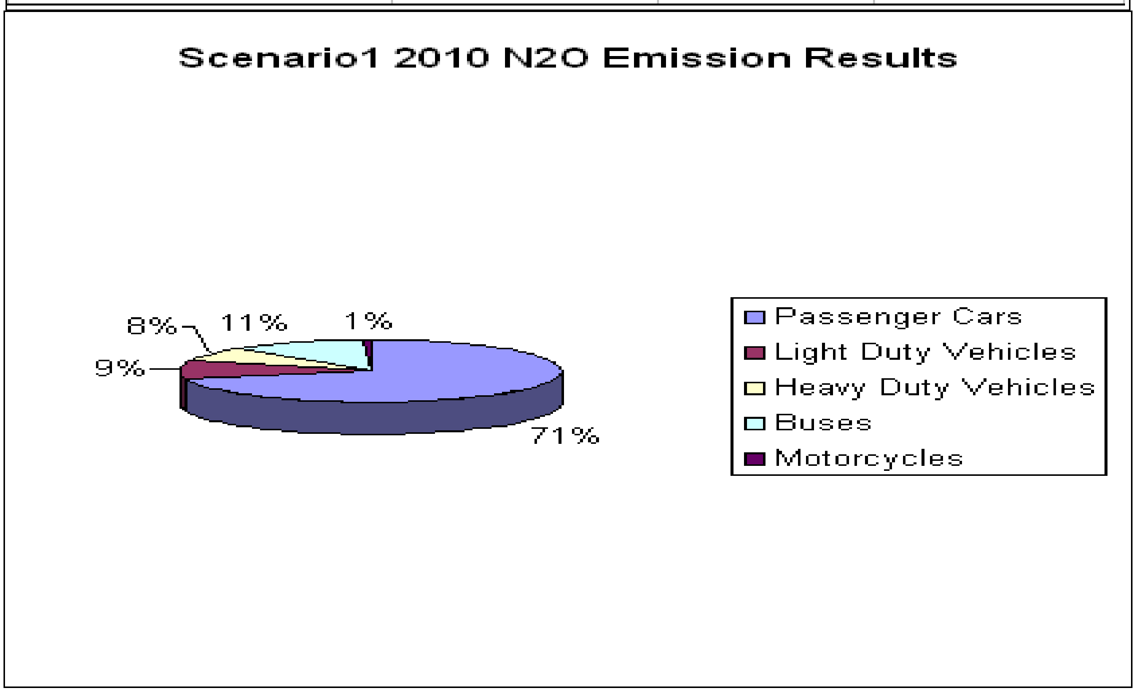
Scenario1 2010 CO Emission Results

Sector	Hot [t]	Cold[t]	Total [t]
Passenger Cars	**33265**	**10559**	**43824**
Gasoline 1.4 -2.0l	32180	10499	42679
Diesel < 2.0l	1079	59	1138
LPG	6	0	6
Light Duty Vehicles	**7225**	**1638**	**8863**
Gasoline <3.5t	6883	1628	8511
Diesel <3.5t	343	10	353
Heavy Duty Vehicles	**1731**	**0**	**1731**
Diesel 7.5 -16t	919	0	919
Diesel 16 - 32t	714	0	714
Diesel >32t	97	0	97
Buses	**1173**	**0**	**1173**
Urban Buses	1173	0	1173
Motorcycles	**39265**	**0**	**39265**
4-stroke 250 - 750	39265	0	39265
Grand Total	**82659**	**12197**	**94856**



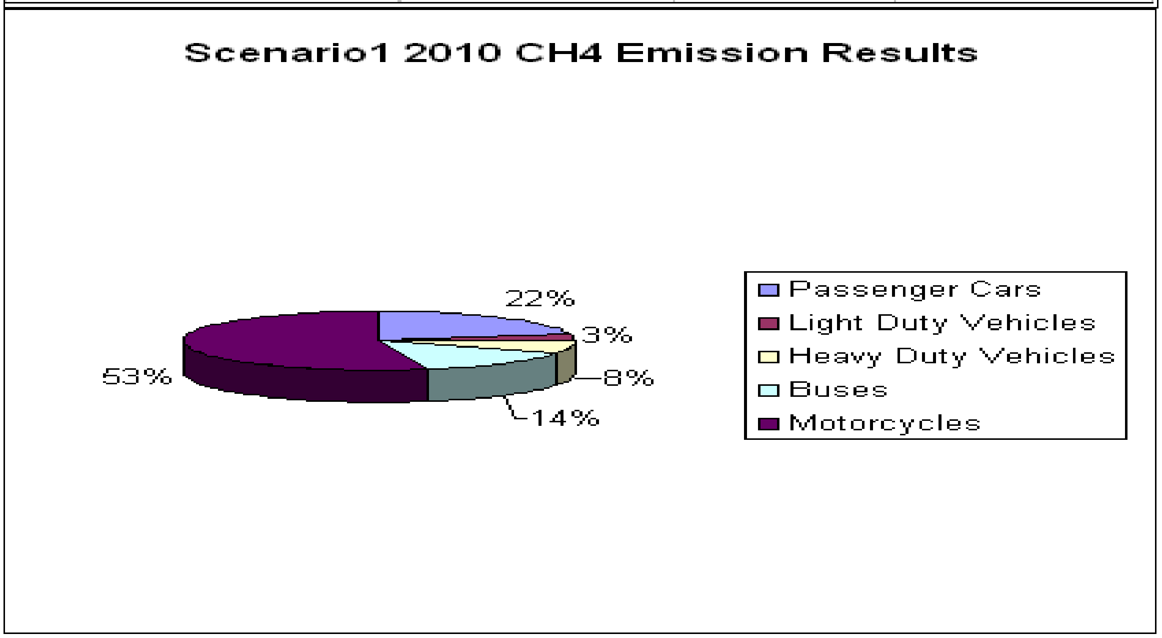
Appendix XLIII Scenario1 2010 N2O Emission Results

Scenario1 2010 N2O Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**337**	**0**	**337**
Gasoline 1.4 -2.0l	267	0	267
Diesel < 2.0l	70	0	70
LPG	0	0	0
Light Duty Vehicles	**43**	**0**	**43**
Gasoline <3.5t	35	0	35
Diesel <3.5t	7	0	7
Heavy Duty Vehicles	**38**	**0**	**38**
Diesel 7.5 -16t	21	0	21
Diesel 16 - 32t	15	0	15
Diesel >32t	2	0	2
Buses	**53**	**0**	**53**
Urban Buses	53	0	53
Motorcycles	**3**	**0**	**3**
4-stroke 250 - 750	3	0	3
Grand Total	**474**	**0**	**474**



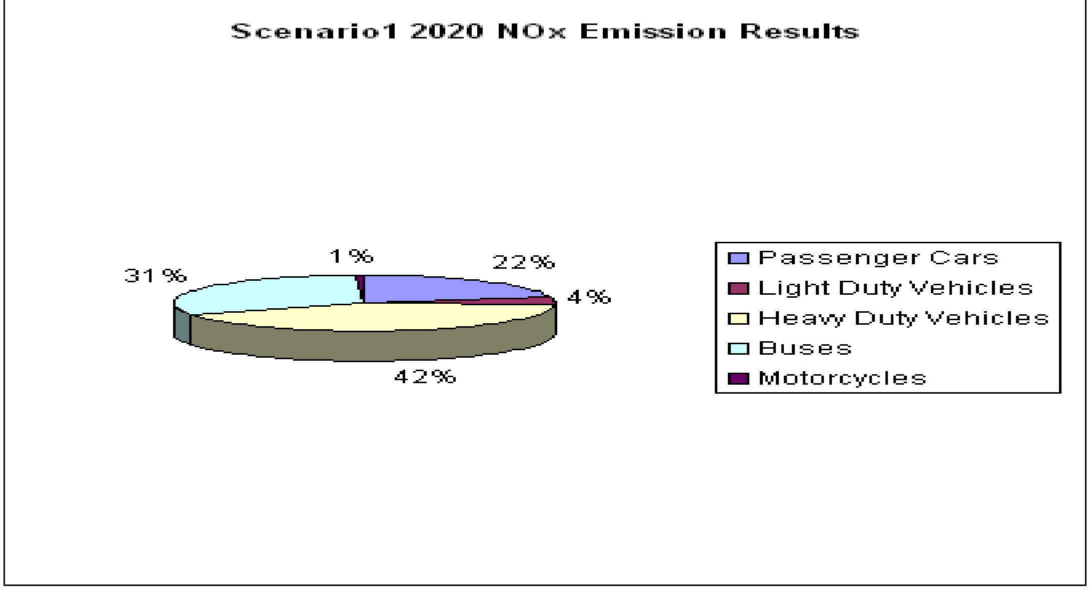
Appendix XLIV Scenario1 2010 CH4 Emission Results

Scenario1 2010 CH4 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**49**	**85**	**134**
Gasoline 1.4 -2.0l	34	85	119
Diesel < 2.0l	15	0	15
LPG	0	0	0
Light Duty Vehicles	**8**	**8**	**16**
Gasoline <3.5t	6	8	14
Diesel <3.5t	2	0	2
Heavy Duty Vehicles	**47**	**0**	**47**
Diesel 7.5 -16t	15	0	15
Diesel 16 - 32t	28	0	28
Diesel >32t	4	0	4
Buses	**87**	**0**	**87**
Urban Buses	87	0	87
Motorcycles	**331**	**0**	**331**
4-stroke 250 - 750	331	0	331
Grand Total	**522**	**93**	**615**



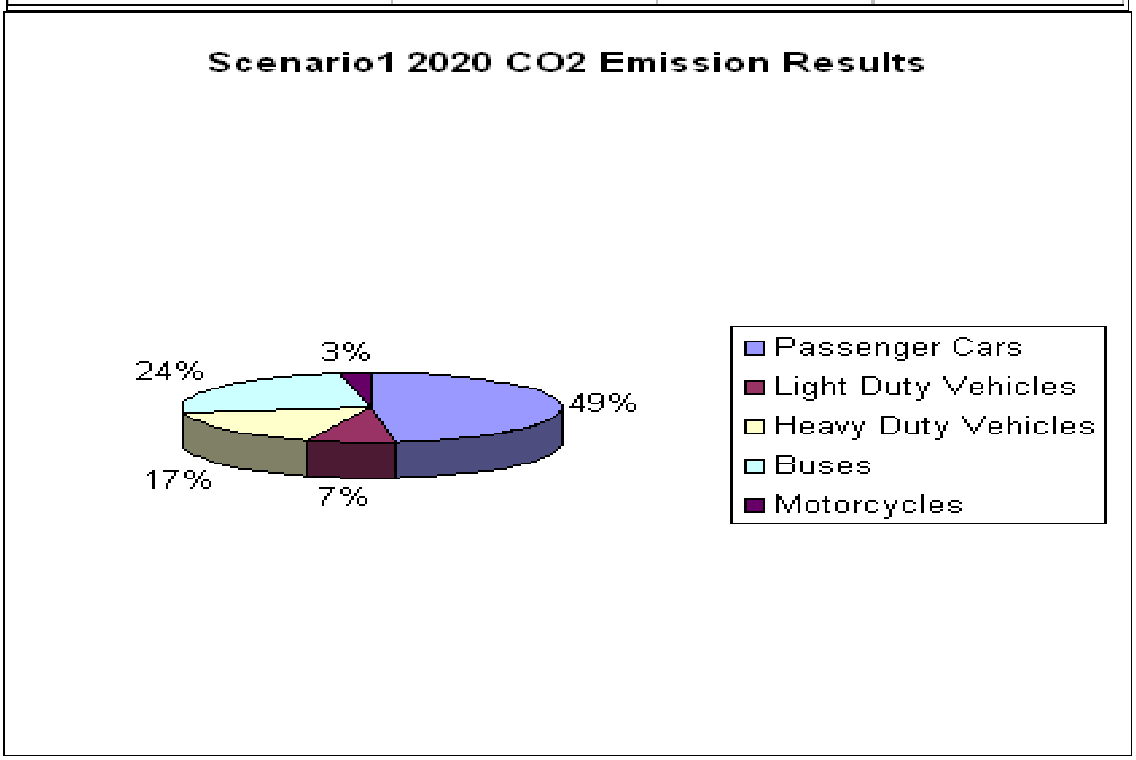
Appendix XLV Scenario1 2020 NOx Emission Results

Scenario1 2020 NOx Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**3368**	**448**	**3816**
Gasoline 1.4 -2.0l	510	448	958
Diesel < 2.0l	2858	1	2859
LPG	1	0	1
Light Duty Vehicles	**646**	**48**	**694**
Gasoline <3.5t	63	48	111
Diesel <3.5t	583	0	583
Heavy Duty Vehicles	**7528**	**0**	**7528**
Diesel 7.5 -16t	3407	0	3407
Diesel 16 - 32t	3425	0	3425
Diesel >32t	697	0	697
Buses	**5482**	**0**	**5482**
Urban Buses	5482	0	5482
Motorcycles	**149**	**0**	**149**
4-stroke 250 - 750	149	0	149
Grand Total	**17173**	**496**	**17669**



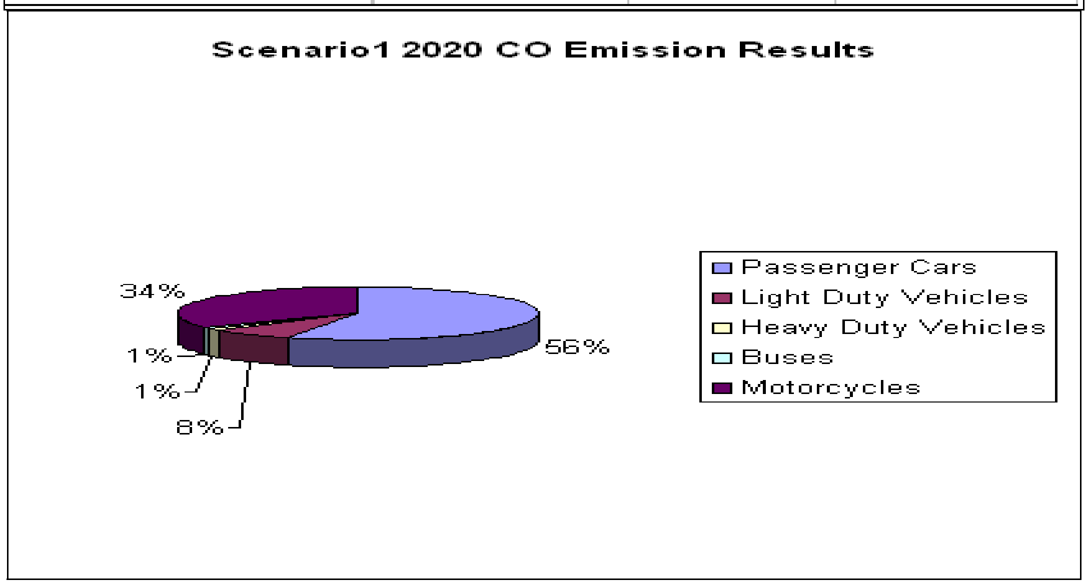
Appendix XLVI Scenario1 2020 CO2 Emission Results

Scenario1 2020 CO2 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**2802052**	**159933**	**2961985**
Gasoline 1.4 -2.0l	2042926	132505	2175431
Diesel < 2.0l	757618	27342	784960
LPG	1508	86	1594
Light Duty Vehicles	**436261**	**24944**	**461205**
Gasoline <3.5t	310951	21109	332060
Diesel <3.5t	125309	3835	129144
Heavy Duty Vehicles	**1051607**	**0**	**1051607**
Diesel 7.5 -16t	472486	0	472486
Diesel 16 - 32t	490592	0	490592
Diesel >32t	88529	0	88529
Buses	**1506594**	**0**	**1506594**
Urban Buses	1506594	0	1506594
Motorcycles	**169749**	**0**	**169749**
4-stroke 250 - 750	169749	0	169749
Grand Total	**5966263**	**184877**	**6151140**



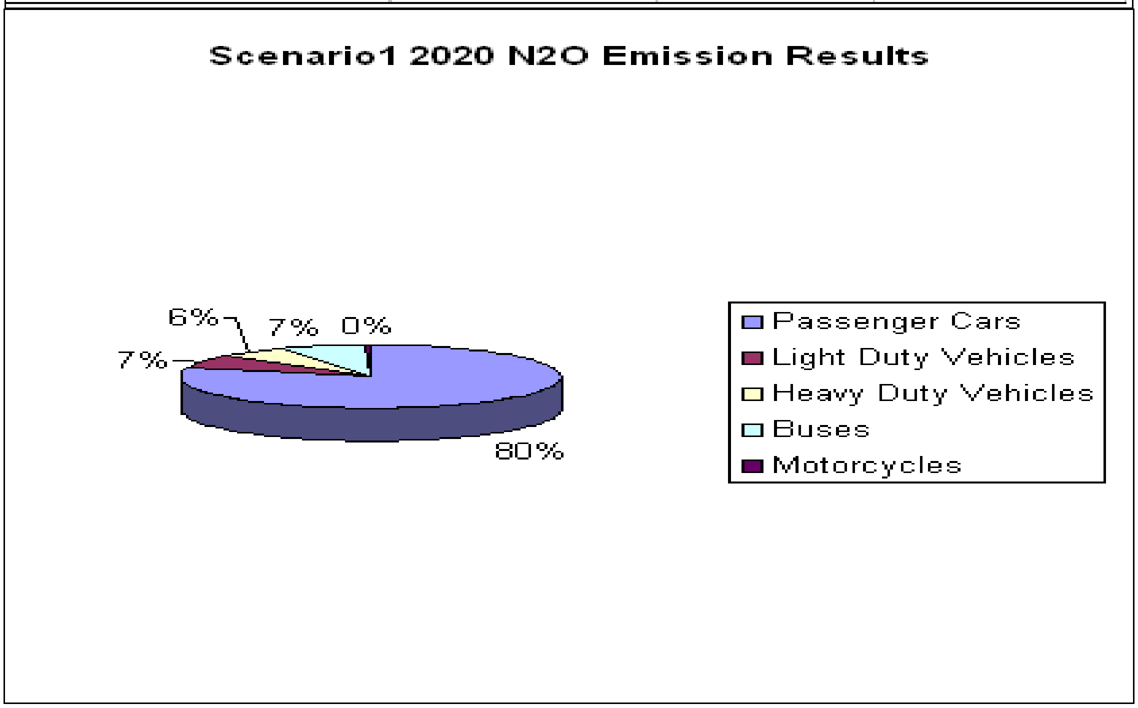
Appendix XLVII Scenario1 2020 CO Emission Results

Scenario1 2020 CO Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**63876**	**22620**	**86496**
Gasoline 1.4 -2.0l	61793	22492	84285
Diesel < 2.0l	2073	127	2200
LPG	11	1	12
Light Duty Vehicles	**9390**	**2375**	**11765**
Gasoline <3.5t	8945	2361	11306
Diesel <3.5t	446	14	460
Heavy Duty Vehicles	**2249**	**0**	**2249**
Diesel 7.5 -16t	1194	0	1194
Diesel 16 - 32t	929	0	929
Diesel >32t	126	0	126
Buses	**1329**	**0**	**1329**
Urban Buses	1329	0	1329
Motorcycles	**51709**	**0**	**51709**
4-stroke 250 - 750	51709	0	51709
Grand Total	**128553**	**24995**	**153548**



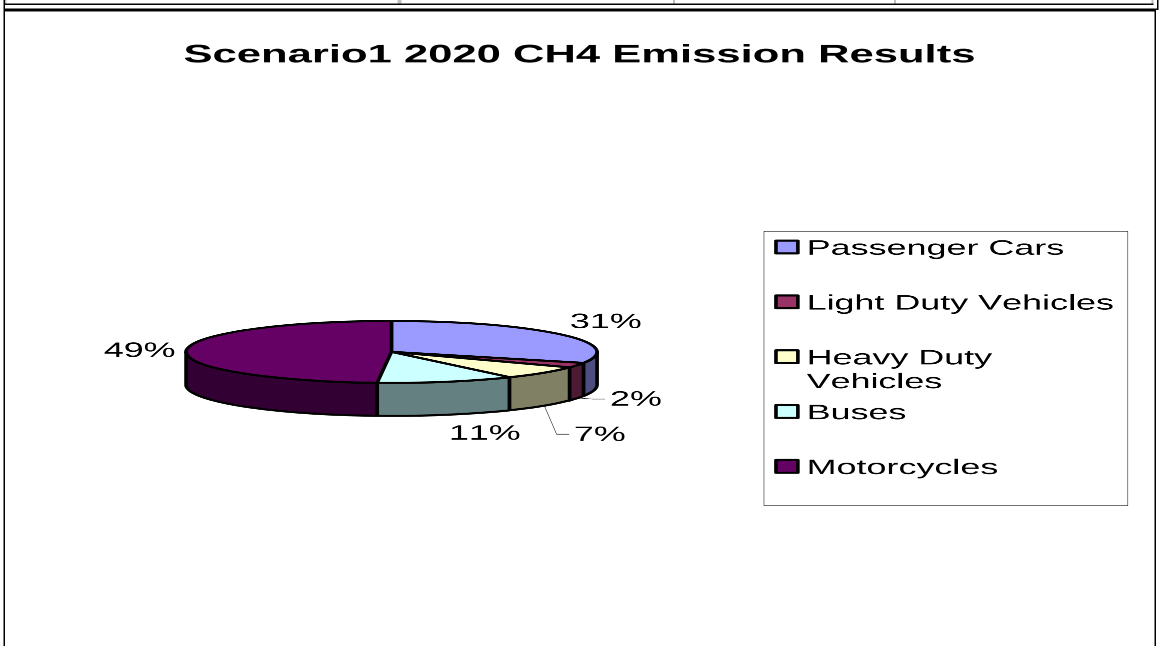
Appendix XLVIII Scenario1 2020 N2O Emission Results

Scenario1 2020 N2O Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**647**	**0**	**647**
Gasoline 1.4 -2.0l	512	0	512
Diesel < 2.0l	135	0	135
LPG	0	0	0
Light Duty Vehicles	**55**	**0**	**55**
Gasoline <3.5t	46	0	46
Diesel <3.5t	9	0	9
Heavy Duty Vehicles	**50**	**0**	**50**
Diesel 7.5 -16t	28	0	28
Diesel 16 - 32t	20	0	20
Diesel >32t	3	0	3
Buses	**60**	**0**	**60**
Urban Buses	60	0	60
Motorcycles	**4**	**0**	**4**
4-stroke 250 - 750	4	0	4
Grand Total	**816**	**0**	**816**



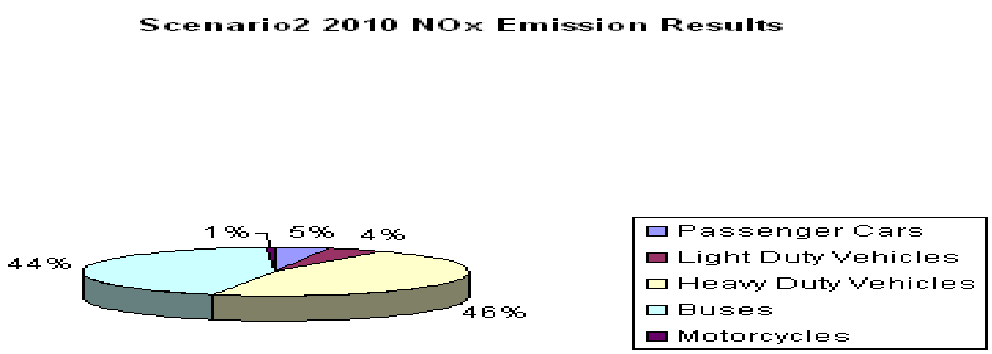
Appendix XLIX Scenario1 2020 CH4 Emission Results

Scenario1 2020 CH4 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**94**	**181**	**275**
Gasoline 1.4 -2.0l	66	181	247
Diesel < 2.0l	28	0	28
LPG	0	0	0
Light Duty Vehicles	**10**	**12**	**22**
Gasoline <3.5t	7	12	19
Diesel <3.5t	3	0	3
Heavy Duty Vehicles	**61**	**0**	**61**
Diesel 7.5 -16t	19	0	19
Diesel 16 - 32t	37	0	37
Diesel >32t	5	0	5
Buses	**98**	**0**	**98**
Urban Buses	98	0	98
Motorcycles	**435**	**0**	**435**
4-stroke 250 - 750	435	0	435
Grand Total	**698**	**193**	**891**



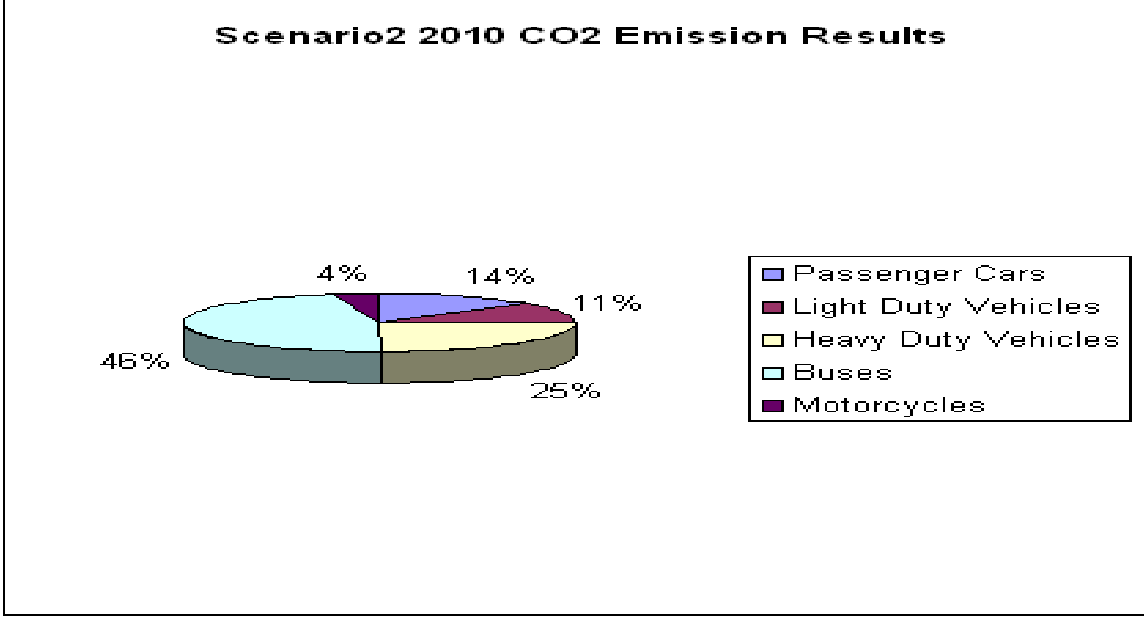
Appendix L Scenario2 2010 NOx Emission Results

Scenario2 2010 NOx Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**501**	**60**	**561**
Gasoline 1.4 -2.0l	76	60	136
Diesel < 2.0l	425	0	425
LPG	0	0	0
Light Duty Vehicles	**497**	**33**	**530**
Gasoline <3.5t	48	33	82
Diesel <3.5t	449	0	449
Heavy Duty Vehicles	**5793**	**0**	**5793**
Diesel 7.5 -16t	2621	0	2621
Diesel 16 - 32t	2635	0	2635
Diesel >32t	536	0	536
Buses	**5434**	**0**	**5434**
Urban Buses	5434	0	5434
Motorcycles	**113**	**0**	**113**
4-stroke 250 - 750	113	0	113
Grand Total	**12338**	**93**	**12431**



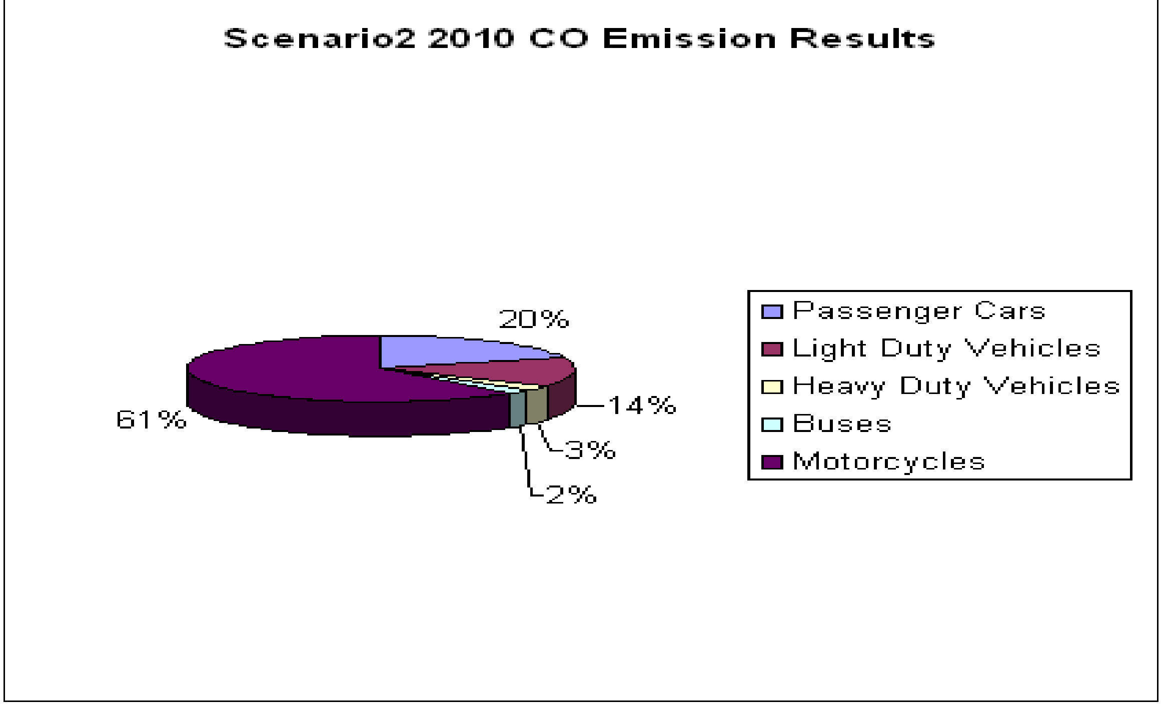
Appendix LI Scenario2 2010 CO2 Emission Results

Scenario2 2010 CO2 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**416470**	**21307**	**437777**
Gasoline 1.4 -2.0l	303641	17653	321294
Diesel < 2.0l	112605	3643	116248
LPG	224	11	235
Light Duty Vehicles	**335694**	**17205**	**352899**
Gasoline <3.5t	239270	14559	253829
Diesel <3.5t	96424	2645	99069
Heavy Duty Vehicles	**809199**	**0**	**809199**
Diesel 7.5 -16t	363570	0	363570
Diesel 16 - 32t	377503	0	377503
Diesel >32t	68126	0	68126
Buses	**1493591**	**0**	**1493591**
Urban Buses	1493591	0	1493591
Motorcycles	**128896**	**0**	**128896**
4-stroke 250 - 750	128896	0	128896
Grand Total	**3183850**	**38512**	**3222362**



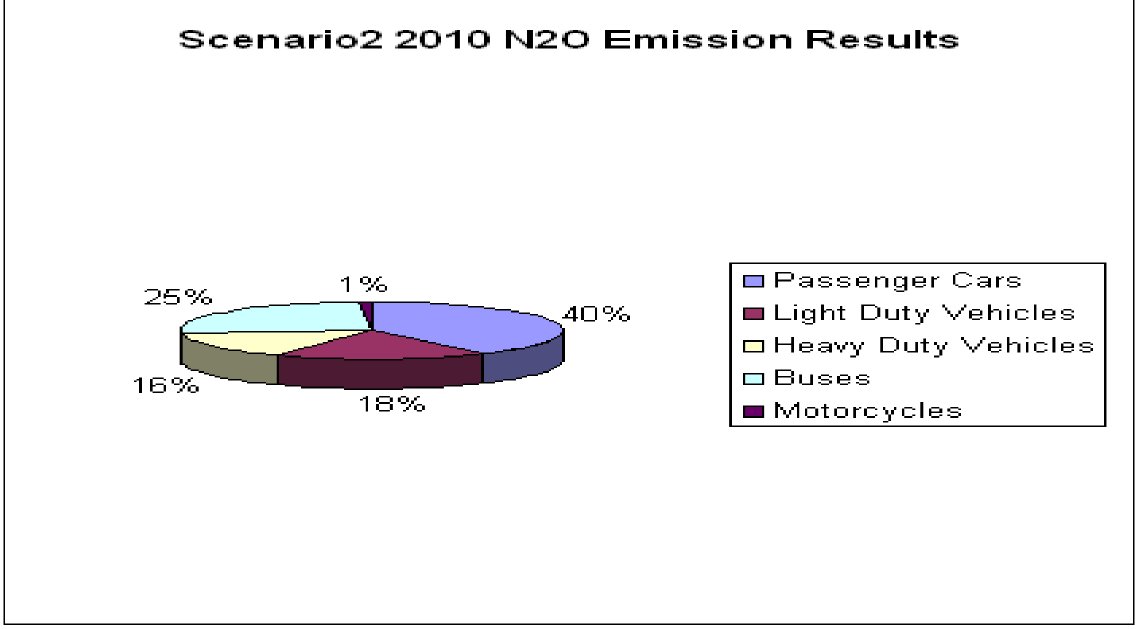
Appendix LII Scenario2 2010 CO Emission Results

Scenario2 2010 CO Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**9494**	**3014**	**12508**
Gasoline 1.4 -2.0l	9184	2996	12180
Diesel < 2.0l	308	17	325
LPG	2	0	2
Light Duty Vehicles	**7225**	**1638**	**8863**
Gasoline <3.5t	6883	1628	8511
Diesel <3.5t	343	10	353
Heavy Duty Vehicles	**1731**	**0**	**1731**
Diesel 7.5 -16t	919	0	919
Diesel 16 - 32t	714	0	714
Diesel >32t	97	0	97
Buses	**1317**	**0**	**1317**
Urban Buses	1317	0	1317
Motorcycles	**39265**	**0**	**39265**
4-stroke 250 - 750	39265	0	39265
Grand Total	**59032**	**4652**	**63684**



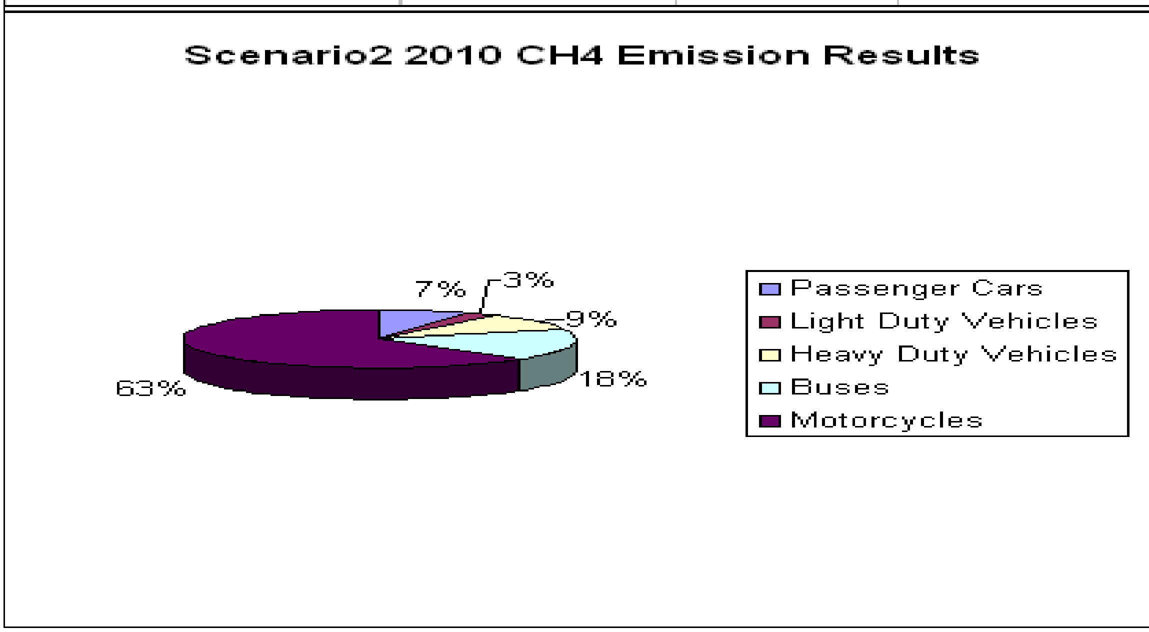
Appendix LIII Scenario2 2010 N2O Emission Results

Scenario2 2010 N2O Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**96**	**0**	**96**
Gasoline 1.4 -2.0l	76	0	76
Diesel < 2.0l	20	0	20
LPG	0	0	0
Light Duty Vehicles	**43**	**0**	**43**
Gasoline <3.5t	35	0	35
Diesel <3.5t	7	0	7
Heavy Duty Vehicles	**38**	**0**	**38**
Diesel 7.5 -16t	21	0	21
Diesel 16 - 32t	15	0	15
Diesel >32t	2	0	2
Buses	**60**	**0**	**60**
Urban Buses	60	0	60
Motorcycles	**3**	**0**	**3**
4-stroke 250 - 750	3	0	3
Grand Total	**240**	**0**	**240**



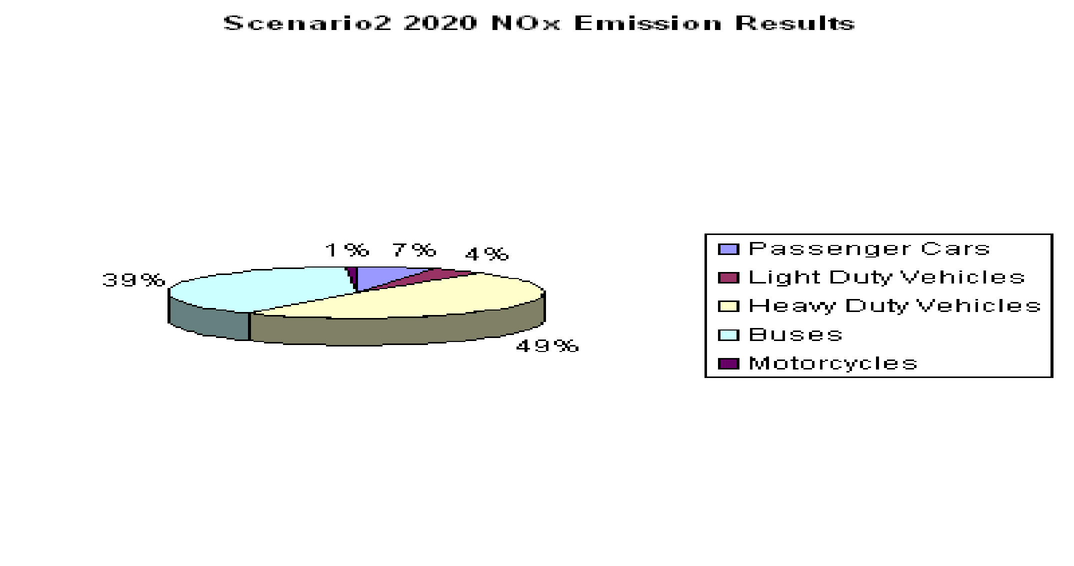
Appendix LIV Scenario2 2010 CH4 Emission Results

Scenario2 2010 CH4 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**14**	**24**	**38**
Gasoline 1.4 -2.0l	10	24	34
Diesel < 2.0l	4	0	4
LPG	0	0	0
Light Duty Vehicles	**8**	**8**	**16**
Gasoline <3.5t	6	8	14
Diesel <3.5t	2	0	2
Heavy Duty Vehicles	**47**	**0**	**47**
Diesel 7.5 -16t	15	0	15
Diesel 16 - 32t	28	0	28
Diesel >32t	4	0	4
Buses	**97**	**0**	**97**
Urban Buses	97	0	97
Motorcycles	**331**	**0**	**331**
4-stroke 250 - 750	331	0	331
Grand Total	**497**	**32**	**529**



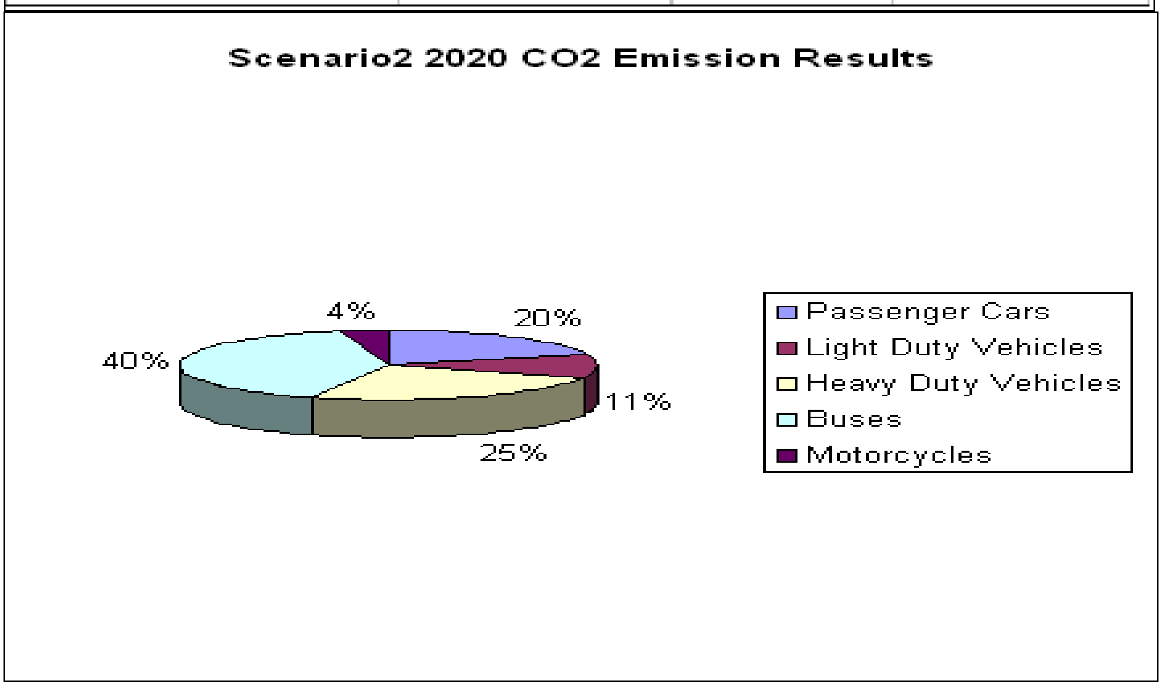
Appendix LV Scenario2 2020 NOx Emission Results

Scenario2 2020 NOx Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**961**	**128**	**1.089**
Gasoline 1.4 -2.0l	145	128	273
Diesel < 2.0l	816	0	816
LPG	0	0	0
Light Duty Vehicles	**646**	**48**	**694**
Gasoline <3.5t	63	48	111
Diesel <3.5t	583	0	583
Heavy Duty Vehicles	**7.528**	**0**	**7.528**
Diesel 7.5 -16t	3.407	0	3.407
Diesel 16 - 32t	3.425	0	3.425
Diesel >32t	697	0	697
Buses	**6.159**	**0**	**6.159**
Urban Buses	6.159	0	6.159
Motorcycles	**149**	**0**	**149**
4-stroke 250 - 750	149	0	149
Grand Total	**15.443**	**176**	**15.619**



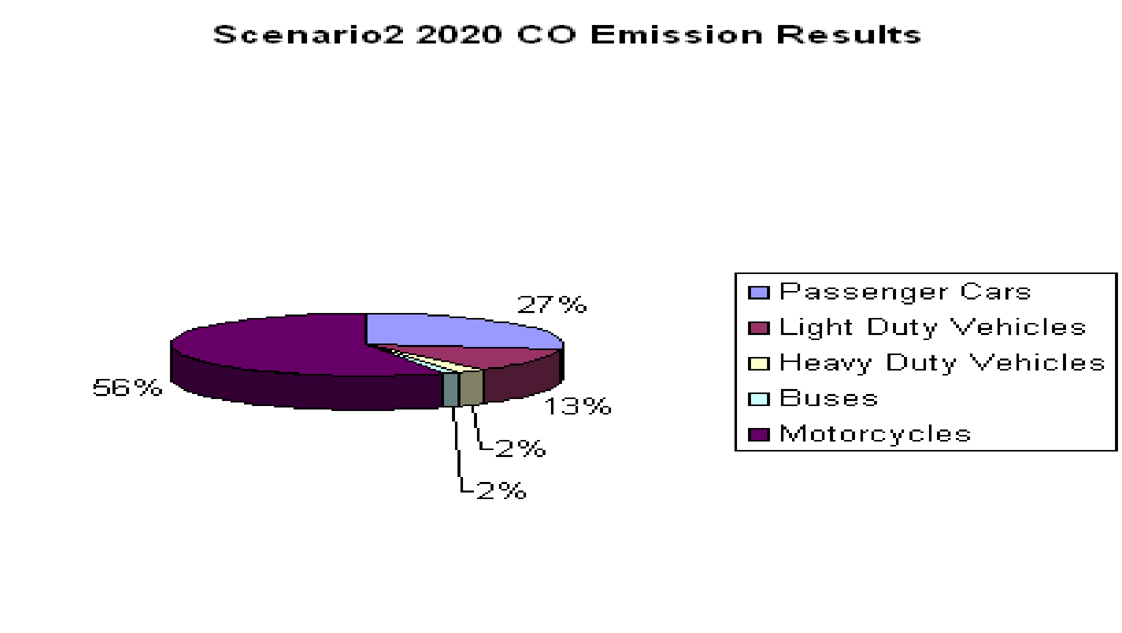
Appendix LVI Scenario2 2020 CO2 Emission Results

Scenario2 2020 CO2 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**799.725**	**45.646**	**845.371**
Gasoline 1.4 -2.0l	583.065	37.818	620.883
Diesel < 2.0l	216.229	7.804	224.033
LPG	430	24	454
Light Duty Vehicles	**436.261**	**24.944**	**461.205**
Gasoline <3.5t	310.951	21.109	332.060
Diesel <3.5t	125.309	3.835	129.144
Heavy Duty Vehicles	**1.051.607**	**0**	**1.051.607**
Diesel 7.5 -16t	472.486	0	472.486
Diesel 16 - 32t	490.592	0	490.592
Diesel >32t	88.529	0	88.529
Buses	**1.692.608**	**0**	**1.692.608**
Urban Buses	1.692.608	0	1.692.608
Motorcycles	**169.749**	**0**	**169.749**
4-stroke 250 - 750	169.749	0	169.749
Grand Total	**4.149.950**	**70.590**	**4.220.540**



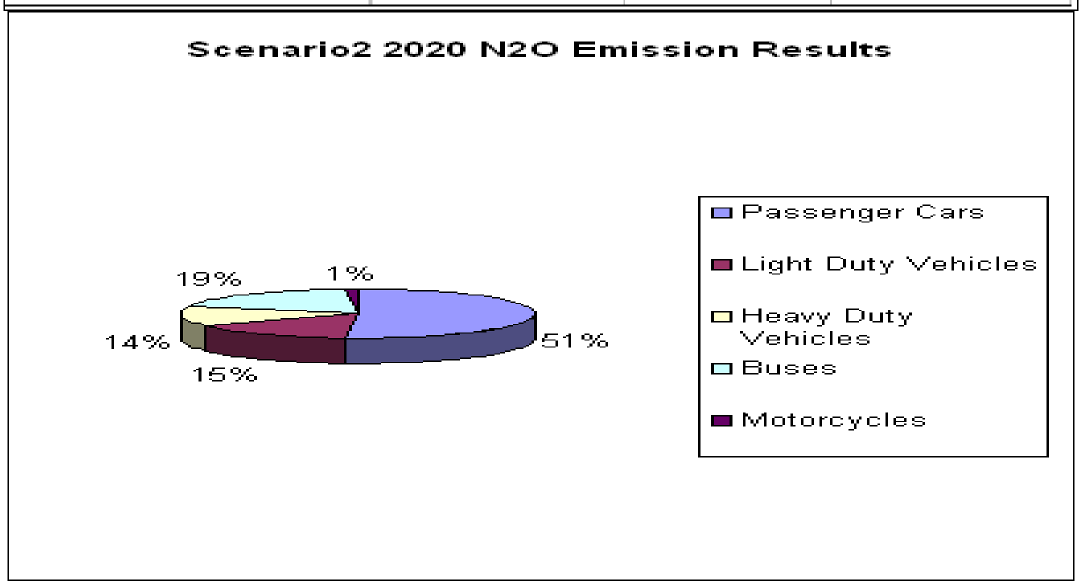
Appendix LVII Scenario2 2020 CO Emission Results

Scenario2 2020 CO Emission Results			
Sector	Hot [t]	Cold[t]	Total [t]
Passenger Cars	**18.231**	**6.456**	**24.687**
Gasoline 1.4 -2.0l	17.636	6.419	24.055
Diesel < 2.0l	592	36	628
LPG	3	0	3
Light Duty Vehicles	**9.390**	**2.375**	**11.765**
Gasoline <3.5t	8.945	2.361	11.306
Diesel <3.5t	446	14	460
Heavy Duty Vehicles	**2.249**	**0**	**2.249**
Diesel 7.5 -16t	1.194	0	1.194
Diesel 16 - 32t	929	0	929
Diesel >32t	126	0	126
Buses	**1.493**	**0**	**1.493**
Urban Buses	1.493	0	1.493
Motorcycles	**51.709**	**0**	**51.709**
4-stroke 250 - 750	51.709	0	51.709
Grand Total	**83.072**	**8.831**	**91.903**



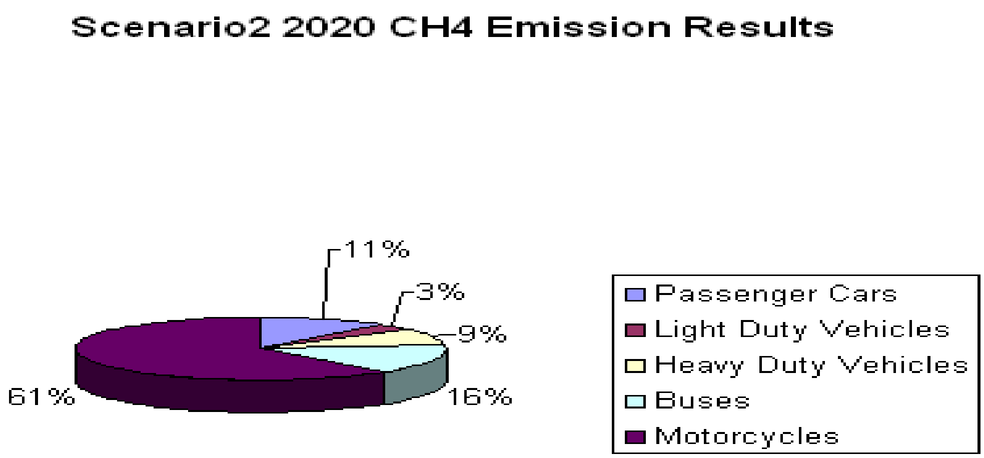
Appendix LVIII Scenario2 2020 N2O Emission Results

Scenario2 2020 N2O Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**185**	**0**	**185**
Gasoline 1.4 -2.0l	146	0	146
Diesel < 2.0l	38	0	38
LPG	0	0	0
Light Duty Vehicles	**55**	**0**	**55**
Gasoline <3.5t	46	0	46
Diesel <3.5t	9	0	9
Heavy Duty Vehicles	**50**	**0**	**50**
Diesel 7.5 -16t	28	0	28
Diesel 16 - 32t	20	0	20
Diesel >32t	3	0	3
Buses	**68**	**0**	**68**
Urban Buses	68	0	68
Motorcycles	**4**	**0**	**4**
4-stroke 250 - 750	4	0	4
Grand Total	**362**	**0**	**362**



Appendix LIX Scenario2 2020 CH4 Emission Results

Scenario2 2020 CH4 Emission Results			
Sector	**Hot [t]**	**Cold[t]**	**Total [t]**
Passenger Cars	**27**	**52**	**79**
Gasoline 1.4 -2.0l	19	52	71
Diesel < 2.0l	8	0	8
LPG	0	0	0
Light Duty Vehicles	**10**	**12**	**22**
Gasoline <3.5t	7	12	19
Diesel <3.5t	3	0	3
Heavy Duty Vehicles	**61**	**0**	**61**
Diesel 7.5 -16t	19	0	19
Diesel 16 - 32t	37	0	37
Diesel >32t	5	0	5
Buses	**110**	**0**	**110**
Urban Buses	110	0	110
Motorcycles	**435**	**0**	**435**
4-stroke 250 - 750	435	0	435
Grand Total	**643**	**64**	**707**



References

- AATSE (Australian Academy of Technological Science and Engineering), 1995. *Engine and Environment,* http://www.phm.gov.au/australia_innovates/?behaviour=view_article&Section_id=1020&article_id=10041 (27-02-2006).

- Aragao, J.J., A. Brasileiro and R. Marar, 1998. The Brazilian Bus Industry and the New Legislation on Public Procurement Procedures. International Conference CODATU VIII. Cape town, South Africa.

- Ahlvik, P., S. Eggleston, N. Gorissen, D. Hassel, L. Ntziachristos, R. Rijkeboer, Z. Samaras, and K.H. Zierock, 1997. COPERT II Computer Programme to calculate Emissions from Road Transport, Methodology and Emission Factors. Technical Report No. 6 European Environment Agency.

- American Stirling Company, 2002. Stirling Engine Reference Guide and Catalog. http://www.stirlingengine.com/catalogs/catalog1.pdf (07-03-2006).

- Andre, M., U. Hammarstrom and I. Reynaud, 1998. Driving Statistics for the Assessment of Air Pollutant Emissions from Road Transport. p.186, INRETS Report, LEN9730, Bron, France.

- APEIS Asia-Pacific Environmental Innovation Strategies, 2006. Research on Innovative and Strategic Policy Options (RISPO). Strategic Policy Options. http://www.iges.or.jp/APEIS/RISPO/spo/pdf/sp4205.pdf (12-06-2007).

- Armstrong-Wright, A., 1986. Urban Transport Systems: Guidelines for Examining Options. World Bank Technical Paper Urban Series No. 52. Washington, D.C.

- Asia Development Bank (ADB), 2003. Policy Guidelines for Reducing Vehicle Emission in Asia. Publication Stock No.110202 ADB Philippines.

- Barkov, V., and M. Zamakhayev, 1967. Highway Engineering. MIR Publishers, Moscow.

- Bel, S., C. Kouridis, and I. Ntziachristos, 2005. COPERT 4 Beta Version Software Description. LAT, Aristotle University Thessaloniki, Greece.
- Bishop G.A., J.R. Starkey, A. Ihlenfeldt, W.J. Williams, and D.H. Stedman, 1989. IR Long-Path Photometry: A Remote Sensing Tool for Automovile Emissions. Analytical Chemistry 61, No. 10:671-7.

- Black-Arbelaez, T., L. Nondek, I. Mintyer, D. Moorcroft and P. Kalas, 2000. The World Bank/Donor Supported Program of National CDM/JI Strategy Studies. Washington D.C./Lyon.

- Bloomberg, 2007. Foreign Exchange Rate, http://www.bloomberg.com/index_eu.html (19-10-2007)

- Buschmann, G., H. Clemens, M. Hoetger and B. Mayr, 2001. The Steam Engine-Status of Development and Market Potential. http://en.iav.de/IAV_Internet/proof_news/handouts_en/techpub/Steam.pdf (06-03-2006).

- BUWAL, 1994. Ergänzungsmessungen zum Projekt, Luftschadstoffenmissionen des straßenverkehrs in der Schweiz 1990-2010, Arbeitsunterlage 17, Bundesamt für Umwelt, Wald und Landshaft, Berlin.

- Canning, D., and E. Bennathan; 2000. The Social Rate of Return on Infrastructure Investments. Policy Research Working Paper 2390. World Bank Washington, D.C.

- Climate Corporation, 2007. Price of Certificate of Emissions on the European Market. http://www.bloomberg.com/index_eu.html (19-10-2007).

- CONCAWE, 1990. The Effect of Temperature and Fuel Volatility on Vehicle Evaporative Emissions. CONCAWE Report no. 90/51, Brussels

- Crackneil, J.A., 2000. World Bank Urban Transport Strategy Review Background Paper: Experience in Urban Traffic Management and Demand Management in Developing Countries. Washington D.C., http://wbln0018.worldbank.org/transport/utsr.nsf/5d346125687632dc8525684d006437be/518ac9c22a28917485256988 0050b9ad/$FILE/Final_UK_DMTM.pdf (02-01-2007).

- DieselNet, 2006. Emission Test Cycles. http://www.dieselnet.com/standards/cycles/#iso (16-06-2006)

- Dowling, M., 1992. The Impact of Oil Formulation on Emissions from Diesel Engines. SAE Paper 922 198, SAE International, Warren dale, Pennsylvania.

- Dutt, A. K., Y. Xie, F.J. Costa, and Z. Yang. 1994. The Asian City: Processes of Development, Characteristics and Planning: City Forms of China and India in Global Perspective. Boston, Kluwer Academic Publishers.

- DVLA (Driver Vehicle and Licensing Authority), 2006. Vehicles Registered in Ghana. DVLA Accra-Ghana.

- Eggleston, S., D. Gaudioso, N. Gorissen, R. Joumard, R.C. Rijkeboer, Z. Samaras and K.H. Zierock, 1993. CORINAIR Working Group on Emissions Factors for Calculating 1990 Emissions from Road Traffic. Volume 1: Methodology and Emission Factors. Final Report, Document of the European Commission ISBN 92-826-5571-X.

- Eggleston, S., N. Gorissen, R. Joumard, R.C. Rijkeboer, Z. Samaras and K.H. Zierock, 1989. CORINAIR Working Group on Emissions Factors for Calculating 1990 Emissions from Road Traffic. Volume 1: Methodology and Emission Factors. Final Report, Contract No. 88/6611/0067, EUR 12260 EN.

- Energy Information Administration (EIA), 2007, West African Gas Pipeline Project, **http://www.eia.doe.gov/emeu/cabs/wagp.html** (19-10-2007).

- Eriksson, O., 2003, Sensitivity Analysis Methods for Road Traffic Emissions. http://www.mai.liu.se/~oleri/lic/kappa.pdf (18-04-2006).

- European Conference of Ministers of Transport (ECMT), 1999. Improving thte Environmental Performance of Vehicles, Fleet Renewal and Scrappage Schemes. Report of the ECMT committee of Deputies. Paris

- European Union Official Journal L242, 1991. Council Directive 91/441/EEC of 26 June Amending Directive 70/220/EEC on the Approximation of Laws of the Member States relating to Measures to be Taken Against Air Pollution by Emissions from Motor Vehicles P0001-0106. http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31991L0441:EN:HTML (07-05-2007).

- Eyckmans, J. and H. Tulkens, 2005. Optimal and Stable International Climate Agreements. ACCO Leuven-Belgium.

- Faiz, A., C.S. Weaver and M.P. Walsh, 1996. Air Pollution from Motor Vehicles: Standards and Technologies for Controlling Emissions. The International Bank for reconstruction and Development/The World Bank, Washington. D.C.

- Fjellstrom, K., 2003a. Transit Reform in Bangkok, SMART Urban Tranport Vol. 2 Number 3: 6-9.

- Fouracre, P.R., A. Astrop, and D. Maunder, 1999. The Accessibility for the Urban Poor. TRL Project Report 153799. Transport Research Laboratory, Crowthorne, United Kingdom.

- Frey, H.C. and D.A. Eichenberger, 1997. Remote Sensing of Mobile Air Source Pollutant Emissions, Report No. FHWY/NC/97-005, North Carolina State University.

- Frey, H.C. and K. Kim, 2005. Operational Evaluation of Emissions and Fuel use of B20 versus Diesel Fueled Dump Trucks. Report Nº FHWA/NC/2005-07 US Department of Transport.

- Ghana Ministry of Transport, 2007. Environmental and Social Management Framework, For the Transportation Sector Development Program (Road Sector). Center for Environment and Health Research and Training, January, 2007

- Ghana Statistical Service, 2007. General Information on Ghana, http://www.ghanaweb.com/GhanaHomePage/general/ (12-05-2007)

- Government of Ghana Country Report, 2003. Ghana's Climate Change Technology Needs and Needs Assessment Report http://www.epa.gov.gh/iACTT/Ghana%20CCTNAR.pdf (29-06-05).

- Government of Ghana, 2001. 9th Session of the United Nations Commission on Sustainable Development http://www.un.org/esa/agenda21/natlinfo/countr/ghana/eco.htm#trans (01-07-05).

- Gwilliam, K., 2002. Cities on the Move, A World Bank Urban Transport Strategy Review ISBN 0-8213-5148-6, Washington D.C.

- Harms, K., 2001, Perspective in Automotive Control, Third International Federation of Automatic Control Workshop, Advances in Automotive Control. Karlruhe, Germany.

- Hickman, A.J., D. Hassel, R. Joumard, Z. Samaras and S. Sorenson, 1999. Methodology for Calculating Transport Emissions and Energy Consumption, Deliverable 22 of the MEET project, TRL Report No. PR/SE/491/98, p.362, Crowthorn, UK.

- Hook, W., 2002. Preserving and Expanding the Role of Non-motorised Transport. A Source Book for Policy-makers in Developing Cities. Eschborn Deutsche Gesellschaft für Technishe Zusammenarbeit (GTZ) GmbH.

- Institute for Transportation and Development Policy (ITDP), 2003a. Bus Rapid Transit Spreads to Africa and Asia. Sustainable Transport Autumn 2003, 4-11.

- International Energy Agency (IEA), 2002. Bus Systems for the Future, Achieving Sustainable Transport Worldwide. Paris, IEA Publications.

- International Energy Agency (IEA), 2005. Fact Sheet, Carbon dioxide From Fuel Combustion. http://www.iea.org/textbase/papers/2005/co2_fact.pdf (18-03-2006).

- Inter governmental Panel on Climate Change (IPCC), 1996. Climate Change 1995: The Science of Climate Change. Cambridge University Press, Cambridge UK.

- Jimenez, J.L., M.D. Koplow, D.D. Nelson, M.S. Zahniser, and S.E. Scmidt, 1999. Characterization of on-Road Vehicle NO emissions by a TILDAS Remote Sensor. Journal of the Air &Waste Management Association 49:463-70.

- Jost, P., D. Hassel, and F.J. Weber, 1992. Emission and Fuel Consumption Modeling based on Continuous Measurements. Deliverable No. 7 of the DRIVE project V1053, TÜV- Rheinland, Köln.

- Joumard, R. (editor), 1999, Methods for Estimation of Atmospheric Emissions from Transport: European Scientist Network and Scientific state-of-the-art. http://www.inrets.fr/infos/cost319/index.html (17-01-2007).

- Joumard, R., P. Jost, J. Hickman, and D. Hassel, 1995. Hot Passenger Car Emissions as a Function of Instantaneous Speed and Acceleration. The Science of Total Environment 169.

- Kanyoke, E. L., 2004. Pollutant Emissions Measured, Rising Transport Pollution in the Accra-Tema Metropolitan Area, Ghana. Lund University, Sweden.

- Keller, M., R. Evequoz, and J. Heldstab, 1995. Luftschadstoffemissionen des Straßenverkehrs 1950-2010, BUWAL Schriftenreihe Umwelt Nr. 255, BUWAL-Bern.

- Kelly, N. A. and P.J. Groblicki, 1993. Real World Emissions from a Modern Production Vehicle Driven in Los Angeles. Journal Air Waste Management Association 1993,43(10): 1351-1357.

- Knecht, W., 1991. Reduction of Heavy Duty Diesel Emissions and Application of Particulate Traps and Oxidation Catalysts: *The Diesel Engine Energy Stake and Environment Constraints,* TÜV Brussels, Rheinland/OPET.

- Kouridis, C., L. Ntziachristos, and Z. Samaras, 2000. Computer Programme to calculate Emissions from Road Transport, User manual version 2.1 European Environment Agency.

- Kylander, M.E., S. Rauch, G.M. Morrison and K. Andam, 2003. Impact of Automobile Emissions on the Levels of Platinum and Lead In Accra, Ghana. Journal of Environmental Monitoring 2003, 5, 91-95. The Royal Society of Chemistry.

- Lenaers, G., 1994. A Dedicated System for on the Road Exhaust Emissions Measurements on Vehicles 3rd International Symposium on Transport and Air Pollution, Poster Proceedings. Institut National deRecherche sur les Tranports et leur Sẻcuritẻ, Arcueil- France.

- Liu, D.Q., A.L. Zhang and Z.X . Wu, 1999. Urban Transport Development. Chinese Population, Resources and Environment 9(4): 38-41

- Maclean, H.L and L.B. Lave, 2002. Evaluating Automobile fuel, propulsion System Technologies Progress in Energy and Combustion Science. Pergamon, Pittsburgh, PA 15213-3890 USA.
- Mahmod, M.M. and B. van Avarem., 2008. A Simulation Framework for Modelling the Impacts of an Integrated Road-Vehicle System on Local Air Quality. Centre for Transport Studies, University of Twente, The Netherlands.

- Malcom, C., T. Younglove, J. Tietjen, M. Barth, N. Davies and J. Lent, 2002. Understanding Real-World Vehicle Activity Patterns and Vehicle Fleet Distribution in the SOCAB. 12th CRC On-Road Vehicle Emissions Workshop.

University of California, College of Engineering, Center for Environmental Research and Technology (CE-CERT). San Diego CA.

- Mckibbin, W., 2005. Sensible Climate Policy, Lowy Institute for international Policy Sydney-Austrialia

- National Climate change Process (Canada), 1998. Foundation Paper on Climate Change (Transportation Sector). http://www.tc.gc.ca/programs/environment/climatechange/english/climatechange progreports/trans_found.pdf (24-02-2006).

- Ntziachristos, L., Z. Samaras, S. Eggleston, N. Gorisen, D. Hassel, A.J. Hickman, R. Joumard, R.C. Rijkeboer, L.White and K.H. Zierock, 2000. Computer Programme to Calculate Emission From Road Transport, Technical Report No. 49. European Environment Agency.

- Ntziachristos, L. and Z. Samaras, 1999.Amendment of COPERT II for the compilation of the ACEA Forecasts in the Framework of Auto Oil II Program, Final Report to the ACEA, Thessaloniki, Greece.

- Pedersen, O., 2001. The Freight Transport and Logistical System of Ghana. Centre for Development Research, Copenhagen, Denmark.

- Pidgeon, W.M., and N. Dobie, 1991. The IM240 Transient I/M Dynamometer Driving Schedule and the Composite I/M Test Procedure USEPA, NTIS No. PB 92-104405

- Pischinger, R. and J. Haghofer, 1984. Eine Methode zur Berechnung des Kraftstoffverbrauches und der Schadstoffemissionen von Kraftfahrzeugen aus dem Geschwindigkeitsverlauf, XX Fisita Congress, SAE 845114.

- Popp, P.J., G.A. Bishop, D.H and Stedman, 1997. High-Speed Ultraviolet Spectrophotometer Capable of Real Time NO and Aromatic Hydrocarbon Detection in Vehicle Exhaust. Paper presented at the Seventh CRC on-Road Vehicle Emissions Workshop, San Diego, CA.

- Roth, G. 1996. Roads in a Market Economy. Alershot, Avebury.

- Rouphail, N.M., H.C. Frey, A. Unal and R. Dalton, 2000. Integration of Real time emissions and Traffic Management Systems, National Research Council Washington, D.C.

- RWTÜV, 1993., Verdampfungs und Verdunstungsemissionen. RWTÜV Arbeitsunterlage 13, im Auftrag des BUWAL, Essen, Germany.

- Samaras, Z., R. Coffey, N. Kyriakis, G. Koufodimos, D. Hassel and R. Joumard, 1998. Methodologies for Estimating Air Pollutant Emissions from Transport. Laboratory of Applied Thermodynamics Report N$^{\underline{0}}$ 9829. Aristotle University Thessaloniki, School of Engineering, Greece.

- Schipper, L and C. Marrie-Lilliu, 1999. Transportation and CO_2 Emissions, Flexing the Link: A Path for the Development, World Bank, Washington, D.C.

- Schwaab, J.A., S. Thielman, 2001. Economic Instruments for Sustainable Road Transport, (GTZ) GmbH Germany.

- Sorenson, S.C. and J. Schramm, 1992. Individual and Public Transportation Emissions and Energy Consumption Models. Tech. Univ. Denmark Report RE 91-5. Lingby- Denmark.

- Sturm P.J., P. Boulter, P. deHaan, R. Joumard, S. Hausberger, J. Hickman, M. Keller, W. Niederle, L. Ntziachristos, C. Reiter, Z. Samaras, G. Schinagl, T.

Schweizer and R. Pischinger, 1998. Instantaneous Emission Data and Their use in Estimating Passenger Car Emissions. VKM-THD Report, Vol.74 Verlag der Techn. Univ. Graz. Austria.

- The Auto Channel, 2006. New Car Review: 2004 Madza RX8. http://www.theautochannel.com/news/2004/06/18/199826.html (03-03-2006).

- The Chugoku Shimhun, 1998. Monument to Technology, Struck by Hardships. http://www.chugoku-np.co.jp/MAZDA/tokusyu/e980122.html (02-03-2006).

- Tryzno, P. 2004. Applicability of Telecommunications and Road Charges on Traffic Congestion in Accra. TRITA-LWR Master Thesis LWR-EX-04-11 Department of Land and Water Resources, KTH Sweden.

- Union of Concerned Scientist, 2005. Clean Vehicles: Greenhouse Gas Reductions and Off the Shelf Technology. http://www.ucsusa.org/clean_vehicles/cars_pickups_suvs/technologies-to-reduce-vehicle-greenhouse-gases.html (24-02-2006).

- United Nations Economic and Social Commission for Asia and Pacific/UN ESCAP, 2001. Sustainable Transport Pricing and Changes – Principles and Issues, UN.

- United Nations Framework Convention on Climate Change (UNFCCC), 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change. http://unfccc.int/resource/docs/convkp/kpeng.pdf 24-10-2007

- United Nations Framework Convention on Climate Change (UNFCC), 2004. The First Ten Years. ISBN 92-9219-010-5, Halesworth United Kingdom.

- Urban Transport Planning and Traffic Management (UTP&TM) Report, 2005. The QUESTOR project. Ghana Ministry of Transport.

- USEPA, 1991. Supplement A to Compilation of Air Pollutant Emission Factors (AP-42) Volume II Mobile Sources. USEPA, Ann Arbor, USA

- USEPA, 1992. Procedure for Emission Inventory Preparation Volume IV: Mobile Sources. http://www.epa.gov/otaq/invntory/r92009.pdf (17-03-2006).

- USEPA, 1994. Fact Sheet, Office of Mobile Source, EPA 400-F-92-007 http://www.epa.gov/otaq/consumer/05-autos.pdf (23-07-2005).

- USEPA, 1995. EPA I/M Briefing Book: Everything You Ever Wanted to Know About Inspection and Maintenance, Report No. EPA-AA-EPSD-IM-94-1226. USEPA Office of Air and Radiation Washington, D.C.

- USEPA, 2006. Mobile Source Emissions: Past, Present and Future, Definitions http://www.epa.gov/otaq/invntory/overview/definitions.htm (16-01-2007).

- Visnic, B., 2000. Developers Say Steam is Clean Power of the Future. WARD'S AutoWorld. http://waw.wardsauto.com/ar/auto_developers_say_steam/index.htm (06-03-2006).

- Weaver, C.S., and L.M. Chan, 1995. "Company Archives" Multiple Sources: Engines, Fuel and Emission Engineering, Inc. Sacramento, California.

- Wenzel, T., B.C. Singer and R. Slott, R., 2000. Some Issues in the Statistical Analysis of Vehicle Emissions. Journal of Transportation and Statistics, September, 2000 Edition.

- Wikipedia Encyclopedia, 2006. Stirling Engines.

http://en.wikipedia.org/wiki/Stirling_engine (07-03-2006).

- Wikipedia Encyclopedia, 2007. Alcohol fuels, http://en.wikipedia.org/wiki/Alcohol_fuel (01-11-2007**)**

- World Commission on Environment and Development (WCED), 1987. Our Common Future, Oxford University Press.

- World Development Indicators(WDI) Datebase, 2007 http://devdata.worldbank.org/external/CPProfile.asp?CCODE=gha&PTYPE=CP

- World Resource Institute WRI, 2003. Earth Trends Country Profile, Climate and Atmosphere Profile. http://earthtrends.wri.org/pdf_library/country_profiles/cli_cou_288.pdf (17-03-2006)

- Wright, L. and K. Fjellstrom, 2003. Mass Transit Option, Sustainable Transport: A Source Book for Policy Makers in Developing Cities. Eschborn, GTZ

- Zhang, X and X. Hu, 2003. Enabling Sustainable Urban Road Transport in China: A Policy and Institutional Perspective. Research Center for Contemporary Management, Institute of Energy, Environment and Economy, Tsinghua University.

- Zhang, Y., D.H. Stedman, G.A. Bishop, S.P. Beaton, P.L. Guenther and I.F. McVey, I.F., 1996. Enhancement of Remote Sensing for Mobile Source Nitric Oxide. Journal of the Air & Waste Management Association 46:25-9.

- Zhao, F., M-C, Lai and D.L. Harrington,2002, *Automotive Spark-Ignited Direct-Injection Gasoline.* Pergamon Pr Publishers, U.S