Investigation of Probable Pollution from Automobile Exhaust Gases in Kampala City, Uganda

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Last but not least, I am thankful to the almighty God for granting me good health, strength and peace throughout the research period.
DEDICATION

This dissertation is dedicated to my dear parents Mr. Amon Rukiidi and Mrs. Rose Kazaana for their constant love and dedication to my education to ensure that I fulfill my life’s dreams.
**ACRONYMS AND ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GHG</td>
<td>Green House Gases</td>
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<tr>
<td>GWP</td>
<td>Global Warming Potential</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
</tr>
<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>I/M</td>
<td>Inspection and Monitoring Programme</td>
</tr>
<tr>
<td>LEAP</td>
<td>Long Range Energy Alternative Planning</td>
</tr>
<tr>
<td>IPCC</td>
<td>Inter Governmental Panel on Climate Change</td>
</tr>
<tr>
<td>NEMA</td>
<td>National Environment Management Authority</td>
</tr>
<tr>
<td>MEMD</td>
<td>Ministry of Energy and Mineral Development</td>
</tr>
<tr>
<td>MOWT</td>
<td>Ministry of Works and Transport</td>
</tr>
<tr>
<td>MWE</td>
<td>Ministry of Water and Environment</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation of Economic Co-operation and Development</td>
</tr>
<tr>
<td>PM</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>SEI</td>
<td>Swedish Environmental Institute</td>
</tr>
<tr>
<td>TED</td>
<td>Technology Environmental Database</td>
</tr>
<tr>
<td>UBOS</td>
<td>Uganda Bureau of Standards</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Programme</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
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<tr>
<td>URA</td>
<td>Uganda Revenue Authority</td>
</tr>
<tr>
<td>UTODA</td>
<td>Uganda Taxi Operators and Drivers Association</td>
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<tr>
<td>WHO</td>
<td>World Health Organisation</td>
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ABSTRACT

It is estimated that transport sources in developing countries contribute about 4% of the global fossil carbon dioxide versus 18% by industrialized countries. The cost of urban air pollution is estimated to be 2% of GDP in developed countries and more than 5% in developing countries. With an annual vehicle registration growth of over 30% in 2008 and a population growth rate of 6%, the number of automobiles in Kampala city of Uganda is expected to continue growing exponentially. Most of the vehicles used are imported into the country when quite old with worn out engines and low energy efficiencies. As a result, such vehicles profusely emit exhaust gases which may be harmful to both human health and the environment. Controlling pollution from the transport sector is vital to improving the quality of air and protecting public health. The objective of this dissertation was to determine the level of pollution from automobile exhaust gases in Kampala City and its impacts on human health and the environment. The study involved the analysis of tail pipe emissions using a gas analyser. It covered mini buses, motorcycles and personal vehicles which constitute 92% of the Kampala vehicle parc. It was established that the main types of exhaust gases from the automobiles were CO₂, NOx, CO, NO and HC. The findings estimated the highest level of NOx tail pipe emissions at 0.15 mg/m³, HC emissions at 2.59 mg/m³, CO at 110 mg/m³ and 286.6 mg/m³ for CO₂. The reported ambient air emissions were estimated at 0.18 ppm, 14000 ppm and 1.3 ppm corresponding to NO₂, CO₂ and CO, respectively. The study further investigated the impact of four mitigation methods on emission levels using the LEAP model. The impact of increasing penetration of city buses, introduction of tail pipe emission standards and hybrid cars and improvement of vehicle fuel economy were investigated. It was found that if left unabated, the emissions will continue to grow with the increasing number of motor vehicles. Implementation of the proposed mitigation methods resulted in a reduction in the GWP reduced by 52%, 51%, 17% and 8.5%, respectively. It is recommended that a comprehensive motor vehicle pollution control program be designed to implement the proposed NEMA vehicle emission standards. Establishment of an integrated transport system promoting the growth in number of city buses should be made a priority to reduce on emission levels and enable the decongestion of Kampala city.

Key Words: Greenhouse effect, climate change, mitigation, GWP, vehicle emissions standard, LEAP model, simulations.
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CHAPTER ONE

1. INTRODUCTION

1.1 Background

In the last century, the level of carbon dioxide in the atmosphere has increased by more than 30% as a result of human activities. The effects of climate change are becoming more pronounced and they include droughts, floods, heat waves and changes in the weather patterns. Global temperatures have increased by almost 0.8°C over the past 150 years. Without any global action, it is expected that temperatures will increase further by 1.8 – 4 ºC by 2100 (IPCC, 1996). It is anticipated that this rise will result in sea level increment of 15 to 95 centimeters. While the transportation sector is crucial to a nation’s economy and personal mobility, it is also a significant source of GHGs. Nearly 50% of global CO₂, HCs, and NOx emissions from fossil fuel combustion come from internal combustion engines (ICE). The contribution of the transport sector to total CO₂ emissions in developed nations is forecast to increase from 20% in 1997 to 30% in 2020 (Ken et al, 2004). The transport sector accounts for almost all the oil demand growth around the world (Ming et al, 2008). The world transportation oil demand has continuously risen with increasing GDP. World forecasts show that transport oil demand in developing nations will increase three times more than in developed nations. Increasing income will cause a tremendous increase in car ownership in developing countries, where the vehicle stock is expected to triple (IEA, 2006). Developing countries account for about 10% of the global automobile population and a little over 20% of the global transport energy consumption. In comparison, the United States alone consumes about 35% of the World’s transport energy (Shiva, 2006).

Road vehicles are among the main consumers of world energy and they dominate global oil utilization, consuming up to 80% of transport energy. The transport sector’s share of oil consumption has been increasing steadily at around 0.6% per year. Current policies are not sufficient to control road vehicle energy use. Even if governments implement all the measures that are currently being considered, projections by the IEA show that road vehicle energy use would still rise between now and 2030 at 1.4% per annum respectively (IEA 2007). In developing nations, it is envisaged that with rising income and the rapidly rising mobility that accompanies it, the increase in automobile emissions will be even greater than the developed nations. Steady growth in vehicular populations has put environmental stress on urban centers in various forms particularly causing poor air quality. There is growing evidence that links vehicle pollutants to human ill health. Motor vehicles are major emission sources for several air pollutants, including nitrogen oxides (NOₓ), carbon monoxide (CO), particulate matter (PM), and hydrocarbons (HCs) (WHO, 2005). These pollutants have significant adverse effects on human beings and the environment. Vehicle emissions cause both short and long term problems associated with health effects. For example, HCs and NOx are the precursors of ozone gas, which has effects ranging from short term consequences such as chest pain, decreased lung function, and increased susceptibility to respiratory infection, to possible long-term consequences, such as premature lung aging and chronic respiratory illnesses (WHO, 2005).

The most affected group is the urban inhabitants especially the traffic policemen who are exposed to the fumes for a long period of time. Steerenberg et al, 2001 compared children attending a school located near a busy way in Utrecht, Netherlands (mean black smoke levels; 53µg/m³) with children attending a school located in the middle of a green area (mean black smoke levels; 18µg/m³) in a suburban area. It was discovered that respiratory diseases were more pronounced in the urban than suburban children. The severity of the problem increases when traffic flow is interrupted and the delays and start-stops occur...
frequently. These phenomena are regularly observed at traffic intersections, junctions and at signalized roadways. Emission rates depend on the characteristics of traffic, vehicles and type of road intersections (Suresh et al, 2009). The age of a vehicle and maintenance levels also contribute to the emissions of all classes of vehicles. Further, the fuel quality has a direct effect on the vehicular exhaust emissions (Perry and Gee, 1995).

With an annual vehicle registration growth of over 30% in 2008 and a population growth of 4.5%, the number of automobiles continues to grow exponentially in Kampala City. It is estimated that there were over 450,000 vehicles on the road in 2008 (UBOS, 2009). The population in Kampala is steadily increasing resulting in signs of environmental stress characterized by poor air quality, excessive noise, traffic congestion, loss of green areas and degradation of historical buildings and monuments. Many stresses, especially from transport, are increasingly leading to deterioration in the quality of life and human health. The public at large does not understand the impact of exposure to high concentrations of outdoor pollution as they go about their day-to-day activities. The city taxi parks and their environs are congested with vehicles that emit great amounts of fumes whose imminent danger has not been analysed. A clear understanding of the looming dangers of increased vehicle numbers on the air quality needs to be established. Little research has been conducted on the role of automobile emissions on the air quality in Kampala city. This research aims at assessing the automobile exhaust gases in Kampala and the potential harm they can have on the population and environment.

1.2 Research Problem

The transport sector has an important role to play in the effort to avert the dangerous effects of climate change because it heavily depends on fossil fuels. Currently, most transport related emissions are concentrated in urban areas which account for the largest share of on-road transport energy consumption. An estimated one billion people in Africa are exposed to outdoor air emissions which exceeds maximum recommended levels world-wide (WHO, 2005). This research focused on the emissions from automobiles in Kampala city, Uganda. However, stationary units such as generators, construction equipment, refrigerant leakages, etc, also contribute significantly to the emissions levels. Many city premises operate generators as a backup to the insufficient electricity.

- With the increasing urban population and a creation of a large class of blue collar workers, there is an increasing demand for second hand vehicles in Kampala necessitating increased air pollution around the city. Most of the vehicles used in Kampala have very low energy efficiencies, mainly because they are imported into the country when quite old. The main considerations during importation are fiscal and not environmental.

- No proper assessment has been carried out to establish the level and impact of air pollution from the automobiles. Uganda does not have an air quality management system and the few existing data on air pollution has been obtained through measurements done on an ad hoc basis. The general public may be at risk of suffering from dangerous diseases in the long term but there is no researched evidence to prove this.

- Uganda, being a least developed country is very prone to the adverse effects of climate change because of its low capacity to adopt, lack of technology and institutional and financial capacities. Controlling pollution from the transport sector is vital to improving the quality of the air and protecting public health.
1.3 Research objectives

The overall objective of this research is to evaluate the level of pollution from automobile exhaust gases in Kampala city through monitoring and modeling of emissions. The research will also assess the impact of these emissions on human health and the environment.

The main objectives of the research include;

i. To Assess the current automobile exhaust gas emission levels and characterize the emissions from different automobile types

ii. To Study the effect of the different emission types and concentrations on public health and environment.

iii. Finally, propose appropriate mitigation methods in the transport sector to reduce on air pollution in the city.

1.4 Justification

Transportation comes with significant undesirable side effects, particularly in terms of air pollution in urban areas and emissions of greenhouse gases, which can impact global climate change. Evidence is also growing of transport’s negative impact on local populations, particularly on the poor in developing world cities (Meena, 2003). The health consequences of urban air pollution are high. Transport related air pollution increases the risk of death particularly from cardiopulmonary causes, allergic illness such as asthma, cancer, etc. The long term air pollution from cars in Austria, France and Switzerland triggered an extra 21,000 premature deaths per year from respiratory or heart diseases, more than the total number of annual traffic deaths in the three countries (WHO, 2005).

In Africa’s case, health risk assessment for air pollution in African cities is hampered by data gaps for both ambient air pollution and this study aims at filling such gaps. The study will be a starting point for the sensitization of the public and policy makers about the imminent dangers of air pollution in Kampala city using the key findings. Results from this study will be used by researchers, the public, city planners and local authorities to understand transport energy usage and emissions levels in the city. The study will further avail well researched data with critical analysis.

1.5 Scope and limitation of the study

In order to properly assess the contribution of automobile fuels to emissions, a full life cycle analysis is required. However in this study, the analysis focused on tail pipe emissions without much consideration of emissions that occur during fuel supply.

The emissions in automobiles are as a result of both combusted fuels and evaporative (fugitive) fuels. This study assesses the level of emissions from combustion only. The emissions assessed include Nitrogen Oxides (NOx), hydro carbons (HC), carbon dioxide (CO2) and carbon monoxide (CO). Particulate matter has a great impact on human health however this was not analysed in this study due to the limited gas types analysed by the instrument used.

The transport fleet in Kampala comprises of a range of vehicle types including private motor vehicles, public mini buses, buses, trucks, pickups, motor cycles and others. Private motor vehicles and mini buses are the most dominant. In assessing emissions, this study focused on the mini buses, private motor vehicles and motor cycles. The long-route buses which travel out of the city were not considered in this study, but are increasingly growing in number.
CHAPTER TWO

2.0 METHODOLOGY

The Methodology included 1) Review of literature, 2) Study design, 3) Equipment set up and measurement, 4) Data analysis and 4) Simulation using LEAP.

2.1 Literature review

Literature was obtained in three main ways that included reading documentation from different sources, conducting interviews with relevant officers and review of videos on climate change. The literature review involved reviewing information on the status of the automobile industry in Uganda and previous work done on vehicular emissions. Several gaps exist with no past work on vehicular emissions. Information was obtained from the Ministry of Works and Transport (MoWT), Uganda Revenue Authority (URA), Uganda Bureau of Statistics (UBOS) and National Environmental Management Authority (NEMA). Annual reports for the different organizations were reviewed. Several interviews were held with officers in the different organizations. Previous thesis reports were reviewed to compare findings by different researchers. The literature review involved understanding the role of transport emissions on the on-going climate change challenge, factors affecting emission levels, comparison of local and international emission standards, impact of vehicular emissions on human health and environment and vehicular emission mitigation measures.

2.2 Study design

The study design involved the identification of the study area, method of analysis, appropriate equipment and simulation packages.

2.2.1 Study area

Kampala is the capital city of Uganda occupying about 189 sq. Km of land and is located in the central part of the country. It is divided into five divisions that include; Central, Kawempe, Makindye, Nakawa and Rubaga. Kampala was originally built on seven hills namely; Kasubi, Mengo, Kibuli, Namirembe, Rubaga, Nsambya Hills and the little hill of Old Kampala. The population of Kampala has also expanded from one million in 2002 to about two million people in 2008 (UBOS, 2008). The city features a tropical wet and dry climate. Kampala was selected for this investigation given its high vehicle numbers causing heavy traffic congestion.

2.2.2 Method of investigation

The vehicle parc numbers were obtained from the Uganda Revenue Authority (URA) and the UBOS. A questionnaire which was aimed at determining the age of vehicles, mileage and peoples’ perceptions on the impact of vehicle emissions was prepared and administered to 50 automobile operators. The interviewee sample size was selected based on the availability and co-operation of automobile operators to respond to the study. The study focused on minibuses, personal vehicles and motor bikes which comprise about 80% of the vehicle parc. The Vehicles were randomly selected based on the age, type and model. The area of coverage for the study is shown in the Figure2-1. The encircled area represents the busiest places in terms of traffic in the city. Garages around Makerere University and Nakulabye town
were also covered during the study. Vehicles located in such places were easier to access compared to those in the taxi parks. The sample size tested comprised of 15 personal vehicles, 17 minibuses (taxis) and 20 motor cycles. The motorcycles comprised of both two and four stroke types.

Figure 2-1: Selected study area for within Kampala city.

2.3 Equipment set up and measurement

A gas analyser was used for the experimental work. The instrument weighed 1kg and could run for up to 4 hours on its internal re-chargeable battery. The gas analyser comprises of a 6-gas analyzer meter, an exhaust probe and a printer as shown in the Figure2-2. The meter is fitted with water, a filter and a protective rubber sleeve. The equipment measures the volume percentage of CO, CO₂, O₂, NO, HC and NOₓ in the exhaust gas. The CO, CO₂, O₂, NO and NOₓ emissions are measured in %s whereas HC is measured in ppm. The equipment records the oil temperature and the fuel/air ratio (Lambda). The instrument can be used for testing petrol, diesel, Compressed Natural Gas (CNG) and Liquid Natural Gas (LNG) exhaust gases.

Figure 2-2: The KANE gas analyser for automotive emissions and the printer set.
At the start of each experiment, the gas analyser was first purged and then a leak test carried out to ensure there was no air trapped that could affect the results. The filter was regularly checked to ensure that it was clean and not clogged with particles. When clogged, the gas analyser does not pass the leak test. The startup time before testing was about three minutes. When ready for use, the analyser probe was fitted into the exhaust pipe and clamped to keep it firmly held. The vehicle operator was required to run the engine in idle mode for five minutes and then measurements were done. The typical time for testing one vehicle was five minutes.

In the case of motorcycles, the operators were required to ride the motorbike through a distance of 1 km distance and then measurement of the emissions was done. The experimental work was subject to both controllable and uncontrollable factors. The controllable factors included the scheduling of the experiment in terms of time of day, the choice of vehicle and the location. The uncontrollable factors were operator behavior and the prevailing ambient conditions. Access to a vehicle, experiment timing and the actual site of experimentation depended on the vehicle operator’s willingness to participate in the test.

### 2.4 Data analysis

The emission data for CO and CO₂ was retrieved from the gas analyser in percentages. The data for HC, NOx and NO was in ppm. The data retrieved was entered into an MS Excel sheet for further processing. The data was standardized by converting it from % and ppm to mg/m³ using the formula below.

\[
1 \text{ ppm} = \frac{M_{\text{mg}}}{22.4} \quad \text{(2-1)}
\]

Where:
- 22.4 (in liters) is the molar volume at Standard Temperature and Pressure (STP)
- M is the molecular mass

Quality assurance was done for the collected data. The main aim was to create a database that contained valid data. The data was analysed to identify any errors that existed. Such errors were corrected where possible or invalid data eliminated if they could not be corrected. Where measurements were taken inaccurately, the experiment was repeated and better values taken or in other cases an average value derived. The performance of the instrument also had an effect on the kind of data. For example, a clean filter at the start of the experiment would yield better results than at the end of the day after carrying out several tests. Filters had to be changed from time to time to ensure accurate data collection.

### 2.5 Simulation using LEAP

The study utilized a transport model formulated using a computer software called LEAP. LEAP is an energy-environment planning system developed by Stockholm Environment Institute (SEI), Boston. The LEAP Software was downloaded at the Institute’s website at www.energycommunity.org. The model is based on an end-use driven scenario analysis. It also has a Technology and Environmental Database (TED) to estimate environmental emissions. A base scenario under the current account was developed assuming a contribution of the present trends. The Business-As-Usual (BAU) scenario is referred to as a base case in the comparative assessment. Other policy scenarios, with alternative assumptions about future development were developed as alternative scenarios. The LEAP framework is disaggregated in a hierarchical tree structure of four levels: sector, sub-sector, end-use, and device. The energy intensity values along with the type of fuel used in each device are required in order to estimate the energy
requirements at sector, sub-sector and end-use level. The emission factors of different pollutants in the TED module are linked to the device level to appraise the environmental emission from the energy utilization during the planning horizon. The model was used to examine different policies for reducing fuel use and pollution emissions from automobiles.

2.5.1 Model development

2.5.1.1 Current Account

Under this account an inventory of fuel use and the selected emissions is made. The study period used was 25 years taking 2005 as the base year and projecting to 2030. The analysis was done using the top down method. All data on vehicle stock and sales was entered under the current account. The LEAP framework was run under three different scenarios taking 2005 as the base year. Existing data on the vehicle parc in Uganda was used. There were 255,000 vehicles on the road in the base year (2005) excluding agricultural tractors and buses. The LEAP framework is disaggregated into a hierarchical tree structure as illustrated in Figure 2.3.

Figure 2.3: Framework of the LEAP model for transportation analysis

Level –1 Automobile stock

Input data into this level comprised of the automobile stock and sales data by vehicle type. The main types considered for this study were minibuses, personal vehicles, motor bikes and pick up vans. The model excludes the analysis of trucks, buses and agricultural tractors because of the limited data that was available on this vehicle parc in Uganda. The analysed automobiles comprise of 92% of the automobile composition giving a good representation of the existing types of vehicles. For the base year 2005, the motorbikes constituted the highest percentage of about 39% as shown in Figure 2.4 and continue to grow at a rate of 15.8%. The growth rates for the minibuses, cars, pickups and four wheel drives is at 12.6%, 7.4% and 6% respectively (UBOS, 2009). It was assumed that the vehicles in Kampala constitute 80% of all the vehicles in the country. The analysis does not take into consideration the mobility of vehicles from Kampala to the rest of the country and vice versa.
Chapter Two: Methodology

Figure 2.4: Percent share of vehicle sales in the base year (Source: Statistical Abstract of Uganda, 2009)

Level 2 - Sub-sector

For each of the entered automobile types, input data on the type of engine was required. It was assumed that all the automobiles in the base year (2005) were using internal combustion engines and it is still the case today. For the base year, it was assumed that no alternative systems had been introduced into the market. In the OECD, the use of hybrid vehicles is growing.

Level 3 – Fuel type

The model required an indication of the percentage of vehicles using the existing fuel types. In Uganda vehicles are currently using diesel or gasoline. Under this level, data on the fuel economy and mileage of vehicles was required to necessitate the computation of energy requirements and level of emissions. Fuel economies of 9 liters/100km, 10 liters/100km, 6.5 liters/100km and 9 liters/100km were assumed for minibuses, personal vehicles, motor bikes and pickups respectively when using gasoline. Fuel economies of 11 liters/100km, 9 liters/100km and 11.5 liters/100km were assumed for minibuses, personal cars and pick up vans in the case of diesel. This data was established during the field analysis of different automobiles. Motor bikes use gasoline with no diesel consumption. The minibuses predominantly use diesel with about 30% using petrol. Averages mileages of 150,000 km, 100,000 km, 20,000 km and 10,000 km were used for minibuses, personal vehicles, motor bikes and pick up vans, respectively.

Level 4 – Environmental loading

The main gases analysed were CO₂, NOₓ, NO and CO. The choice of gases was done in alignment with the field analysis of the same. Typical emission factors for developing countries were used as supplied in the TED for Tier 1. Tier 1 emission factors were developed through simple methods of estimation based on fuel consumption and average emission factors. The emission factors for a gasoline driven mini bus are 68.56 kg/GJ, 0.6 kg/GJ, 8 kg/GJ and 0.001 kg/GJ for CO₂, NOₓ, CO and NO respectively. For a gasoline driven motor bike, emission factors of 78.56 kg/GJ, 2 kg/GJ, 25 kg/GJ and 0.01 kg/GJ for CO₂, NOₓ, CO and NO were used.
2.5.1.2 Life cycle profile development

A new life cycle profile of the existing car stocks was created based on the study survey findings. Figure 2-5 shows the age ranges of the vehicles on Ugandan roads. Most of the vehicles are between 6 and 15 years of age with a very small percentage of the parc new. LEAP required that all stock vintage profiles have zero vehicles of age zero years. This is because data entered for the base year stocks should not include the new vehicles sold in the base year. Similarly for the motor bikes, a life cycle profile was developed.

![Figure 2-5: Life cycle profile of vehicle parc](image)

### 2.5.2 Scenarios Development

Under the current account, four different scenarios were developed for assessment. The scenarios included a Business-as-Usual improved vehicle fuel economy, introduction of emission standards, introduction of hybrid vehicles and increased penetration of city buses.

#### 2.5.2.1 Business-as-Usual Scenario (BAU)

In the BAU scenario, the future trends of parameters were assumed to be increasing continuously based on the current trends. In this scenario, the present efficiency of any technologies and the pattern of energy utilization for different technologies are unchanged in future. Any planned and ongoing projects are not implemented in this scenario. It was assumed that vehicle growth will follow the prevailing growth rates at 12.6% for minibuses, 7.4% for personal vehicles, 15.8% for motor bikes and 6% for pickups and four wheel drives.
2.5.2.2 Fuel Economy Improvement (FEI) Scenario

The first policy considered is the introduction of more stringent fuel economy standards for conventional internal combustion engines for gasoline and diesel vehicles. The FEI scenario considers the replacement of conventional taxis and private cars with high efficiency cars. The efficiency of the automotive technologies in terms of fuel requirement per vehicle kilometer has been improving. An assumption was made on possible fuel economy standards. It was assumed that a new proposed standard requires new cars to increase their fuel economy by 10% in 2015 and by 20% in 2025 in relation to the base fuel economy values under the current account as shown in Figure 2-6. A 10% improvement in fuel economy will result in consumption of 0.12 km/m³ instead of 0.085 km/m³ for the base case. The 20% improvement in 2025 will result in a new fuel economy of 0.138 km/m³.

![Figure 2-6: Improvement of fuel economy scenario policy](image)

2.5.2.3 New tail pipe emission standards

The Government is considering the introduction of new tail pipe emissions. NEMA drafted air quality standards that are undergoing review. Unfortunately, the NEMA standards are for only a given period with no evolution. This scenario is meant to analyse the emissions reduction benefits of introducing the new standards proposed by NEMA. It was assumed that these standards will be effected in 2015. However, given the model period up to 2030, some new standards were to be adopted based on the EURO Emissions standards. It was assumed that Uganda will upgrade from the proposed NEMA standards that are an equivalent of EURO 1997 to EURO 2006 in 2025.
2.5.2.4 Hybrid – Electric Vehicles

Hybrid vehicles combine a small internal combustion engine with an electric motor and battery to reduce fuel consumption and tailpipe emissions. Energy lost during braking is captured and returned to the battery through a process called regenerative braking. Unlike electric vehicles, hybrids have the advantage that they do not need to be plugged into the electric supply. Hybrid engines operate more efficiently and produce less pollution than the conventional internal combustion engine. The market penetration of hybrid electric vehicles is on the increase in the developed countries. It is anticipated that hybrid electric vehicles will be introduced into the Ugandan market in the near future. In developing this scenario, it was assumed that hybrid electric vehicles will comprise 10% of the personal vehicles in 2020 and increase to 15% by 2025. Hybrid fuel economy is expected to improve as the technology matures. Hybrid gasoline cars currently have a fuel economy of 5.8 liters/100 km. However it was assumed that this will reach 4 liters/100 km in 2025.

2.5.2.5 Increasing penetration of city buses

This scenario explores the possibility of increasing the penetration of city buses to replace the big number of very inefficient mini buses for public transport. Currently city buses are close to non-existent with a very small number in operation. It was assumed instead that the city buses will grow at a constant growth rate of 4% till 2030. This is a very conservative outlook given that it is likely to exceed the 4% once necessary policy is implemented. Growth in the number of city buses would affect the predicted growth rates for the minibuses and personal vehicles from 12.6% to 9% and from 7.4% to 6% respectively. Assuming that the bus transport system is efficient, some passengers who use personal vehicles will opt to use public means given the current parking space challenge in the city centre. Given that the buses carry more people per liter of fuel used, the emission levels will be greatly reduced.
CHAPTER THREE

3.0 LITERATURE REVIEW

3.1 Overview

Air pollution is defined as the contamination of air by discharge of harmful substances which can cause health problems including burning eyes and nose, itchy irritated throat and breathing problems. Air pollutants are classified in two main categories as either primary or secondary. Primary pollutants are emitted directly into the atmosphere by a stationary or mobile source. Secondary pollutants are formed in the atmosphere as a result of physical and chemical processes such as oxidation. The primary pollutants include CO, HC, VOCs, SOx, NOx, PM and compounds of lead. Secondary pollutants include nitrogen dioxide, photochemical oxidants e.g. Ozone, etc. The main sources of air pollutants are either natural or anthropogenic. Natural sources include forest fires, volcanoes, vegetative matter, etc. The anthropogenic sources include industrial processes, power generation, commercial and domestic fuel use, solid waste disposal, transport, etc. Automobiles are by far the predominant contributor to air pollution among the mobile sources.

Most vehicle emissions are a product of the engine combustion process. Most passenger cars and light-duty trucks use a gasoline fueled four-stroke, spark-ignited (SI) internal combustion engine. The main pollutants of concern in the case of SI engines are NOx, CO, HC, and organic toxics (i.e. benzene, acetaldehyde, formaldehyde, and 1,3-butadiene). Particulate Matter (PM), a very important pollutant in the case of compression-ignition engines, is produced in very small amounts in SI engines (Degobert, 1995). NOx and CO are formed during the combustion process and are emitted only from the tailpipe. Hydrocarbons and air toxics may originate both from the tailpipe in the form of unburned or partially burned fuel, as well as in the form of evaporative emissions from the fuel tank, fuel lines, and losses during the refueling process. Evaporative losses of HC are estimated to be about the same order of magnitude as the contribution from the exhaust (Sher, 1998; Degobert, 1995). evaporative losses are not assessed in this study.

3.2 Transport and Climate change

According to the IPCC guidelines, the direct greenhouse gases are Carbon dioxide, Methane, Hydro-Fluoro Carbons, Per-Fluoro-Carbons (PFCs), Sulphur Hexafluoride (SF6) and Nitrous oxides. The indirect greenhouse gases include Nitrogen Oxides (NOX), Carbon Monoxides (CO), Non-Methane Volatile Organic Compound (NMVOC), (HFCs) and Sulphur Dioxide (SO2). Some GHGs such as CO2 occur naturally and are emitted to the atmosphere through natural processes and human activities. Other GHGs (e.g., fluorinated gases) are created by human activities. Current vehicle fleets emit significant amounts of carbon monoxide (CO), nitrogen oxides (NOx), total organic gases (TOGs) or Reactive Organic Gases (ROGs more commonly known as volatile organic compounds, VOCs), particulate matter (PM10) and Carbon dioxide (CO2). The VOC and NOx are precursors to secondary ozone formation and aerosols and more importantly, particulate matter and ozone are the two critical pollutants of greatest concern causing human health deterioration and leading to a social cost (Guihua et al, 2009). The direct greenhouse gases have different effectiveness in radiative forcing. This can be determined by comparing their Global Warming Potential (GWP). GWP is a means of providing a simple measure of the relative radiative effects of the emissions of the various gases. The index is defined as the cumulative radiative forcing between the present and a future time horizon expressed relative to that of CO2. It is necessary to
define a time horizon because the gases have different lifetimes in the atmosphere. Methane and Nitrous Oxide have a greater GWP than carbon dioxide as shown in Table 3-1.

Table 3-1: Global Warming Potential defined on a 100-year horizon (IPCC, 1996).

<table>
<thead>
<tr>
<th>GHG</th>
<th>GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Dioxide</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>21</td>
</tr>
<tr>
<td>Nitrous Oxide</td>
<td>310</td>
</tr>
<tr>
<td>HFCs</td>
<td>140-11,700</td>
</tr>
<tr>
<td>PFCs</td>
<td>6,500 - 9,200</td>
</tr>
<tr>
<td>SF6</td>
<td>23,900</td>
</tr>
</tbody>
</table>

The main sectors contributing to emission levels include energy, Industrial processes, solvents, agriculture, land use change and forestry and waste. The power generation sector currently accounts for 24% of the CO₂ emission as shown in the Figure 3-1. Many forms of transportation create GHG (including CO₂) emissions, both direct and indirect. Transport is one of the major contributors to air pollution problems at the local, region and global levels contributing 14% of the global carbon dioxide emissions as shown in Figure 3-1. It relies on fossil fuel burning, primarily oil, and is now the fastest-growing source of greenhouse gas emissions, particularly in developing countries. Transportation accounts for 27% of total global energy consumption. Greenhouse-gas emissions (CO₂ and CFCs) from motor vehicles in developing countries contribute less than 3% to the global greenhouse effect, compared to a 9 to 12% contribution from motor vehicles in OECD countries and Eastern Europe (Asif, 1993).

There is a growing number of motorcycles being used for fast transportation in Kampala city contributing to 50% of the automobiles in Kampala city. An analysis of motor cycle emissions is of great importance given their growing numbers. Motor cycles are preferred to mini buses for public transport because of their mobility and convenience. Taiwan has the highest motorcycle density of 315 motorcycles/km² and one out of every Taiwanese has a motorcycle. According to the Taiwan Environmental Protection Administration (TEPA), motorcycles contribute 38% of the total CO, 64% of HC and 3% of NO emitted from automobiles (Lin C.W et al, 2008). This implies that motor cycles have a potential of producing high amounts of emissions if not checked.

According to the IPCC, the world’s temperature is expected to increase over the next hundred years by up to 5.8°C. This is much faster than anything experienced so far in human history. The goal of climate change policy should be to keep the global mean temperature rise to less than 2°C above pre-industrial
levels. At 2°C and above, damage to ecosystems and disruption to the climate system increases dramatically. We have very little time within which we can change our energy system to meet these targets. This means that global emissions will have to peak and start to decline by the end of the next decade at the latest. Given that personal mobility is a pre-requisite of economic and modern life, the question arises on how to meet the mobility needs of a contemporary lifestyle and yet reduce direct and indirect emissions of GHGs.

![Figure 3-2: Projected growth in CO₂ emission levels in the world (Source: Stern, 2006).](image)

From Figure 3-2, assuming a business as usual scenario, the largest source of transport emissions is the OECD North America producing 37% of the total emissions. This is confirmed by the world highest car ownership of 0.6 vehicles per person in North America (Stern, 2006). Africa has the lowest projected CO₂ emission growths followed closely by Asia. This is as a result of the low industrialization levels in these regions. However, the need to develop will see a twist in the future as the developing countries push for more industrialization to match the OECD.

### 3.3 The Kyoto Protocol

Recognising the threats on the climate worldwide, the signatories to the 1992 UN Framework Convention on Climate Change agreed on the Kyoto Protocol in 1997. The Protocol finally entered into force in early 2005 and its 165 member countries meet twice annually to negotiate further refinement and development of the agreement. Only one major industrialised nation, the United States, has not ratified Kyoto Protocol. The Protocol commits its signatories to reduce their greenhouse gas emissions by 5.2% from their 1990 level by the target period of 2008-2012. This has in turn resulted in the adoption of a series of regional and national emission reduction targets. In the European Union, for instance, the commitment is to achieve an overall reduction of 8%. In order to help reach this target, the EU agreed to increase its proportion of renewable energy from 6% to 12% by 2010. The Kyoto treaty does not require specific reductions in each sector (Difiglio et al, 2000).

At present the Kyoto countries are negotiating the second phase of the agreement, covering the period from 2013-2017. Greenpeace is calling for industrialised countries’ emissions to be reduced by 18% from 1990 levels for this second commitment period, and by 30% for the third period covering 2018-2022. Only with these cuts do we stand a reasonable chance of meeting the 2°C target. The Kyoto Protocol’s architecture relies fundamentally on legally binding emissions reduction obligations. To achieve these targets, carbon is turned into a commodity which can be traded. The aim is to encourage the most
economically efficient emissions reductions, in turn leveraging the necessary investment in clean technology from the private sector to drive a revolution in energy supply. Signatory countries agreed a negotiating ‘mandate’, known as the Bali Action Plan, in December 2007. The action plan commits all developed countries to take on quantified greenhouse gas emission reduction targets. The developing countries commit to nationally appropriate mitigation actions, implying that they are not required to meet any specific targets (UNFCCC, 2007). However, under the Bali Action Plan, no specific emission targets were set. It was expected that negotiations would be concluded in 2009 with a final agreement on the second Kyoto commitment period; however, this was not achieved at the UNFCCC conference that was held in Denmark, Copenhagen in 2009.

3.4 Impact of different emission types

Although automobiles contribute to the degradation of air quality, there is no simple means of measuring the precise impact. The impact will vary from city to city, depending upon such factors as vehicle density, the split between petrol and diesel vehicles, the type of vehicles on the road and their average age, the traffic management systems in place and atmospheric conditions. The pollutants from motor vehicles have significant adverse effects on human beings and the environment. Vehicle emissions cause near-term problems associated with health effects. For example, hydrocarbons and nitrogen oxides are the precursors of ozone, which have effects ranging from short term consequences such as chest pain, decreased lung function, and increased susceptibility to respiratory infection, to possible long-term consequences, such as premature lung aging and chronic respiratory illnesses (NRC, 2000; EPA 1993).

3.4.1 Carbon monoxide

Carbon monoxide (CO) is a tasteless, odorless, and colorless gas produced by the incomplete combustion of carbon-based fuels. Exposure to carbon monoxide interferes with absorption of oxygen from haemoglobin in the red blood cells (NRC, 2000). After a prolonged exposure, this impairs perception and thinking, slows reflexes, causes drowsiness and can cause unconsciousness and death. A combined exposure to CO and other pollutants, promotes morbidity in people with circulatory problems. It is associated with less worker productivity and general discomfort (EPA, 1993).

3.4.2 NOx

NOx is a generic term for mono-nitrogen oxides namely NO and NO\(_2\) which are produced during combustion at high temperatures. At ambient temperatures, oxygen and nitrogen do not react with each other. However, in an internal combustion engine, high temperatures lead to reaction between N\(_2\) and O\(_2\) to yield nitrogen oxides. NOx is categorized into three types that include; thermal NOx, fuel NOx and Prompt NOx (Bosch and Janssen 1988).

Thermal NOX is formed by the oxidation of N\(_2\) at high temperatures of about 1300K according to the following:

\[
N_2 + O_2 \rightarrow 2NO \quad \Delta H_{298} = 180.6 \text{kJ/mol} \quad \ldots (3-1)
\]

The thermal NOx emission from an engine can be controlled by lowering the combustion temperature such as operating the engine under excess air (fuel – lean) conditions. However, these approaches are not very effective though recent approaches based on High Temperature Air Combustion (HiTAC) are effective (Garin, 2001). The second category called fuel NOx is formed from the oxidation of nitrogen present in fuels. This is relatively independent of temperature at normal combustion temperatures. The third category, prompt NOx, is formed by the reaction of hydrocarbon fragments with atmospheric
nitrogen to yield products such as HCN and H$_2$CN. The products are subsequently oxidized to NO in the lean zone. NO can further react with oxygen to form NO$_2$ or N$_2$O (Sounak et al, 2009)

NO$_2$, along with volatile organic compounds, (VOCs), is a precursor of ground-level ozone and other photochemical pollutants (Silman, 1999). Exposure to NOx increases susceptibility to viral infections such as influenza and irritation in the lungs causing bronchitis and pneumonia. This results in sensitivity to dust and pollen in asthmatics. Most of these health effects are in combination with other pollutants.

### 3.4.2.1 Tropospheric Ozone

Ozone is one of the most widespread secondary pollutants and is the main component of urban smog. Ozone, a photochemical oxidant, results from the reaction of nitrogen oxides and hydrocarbons in the presence of sunlight. Exposure to elevated levels of ozone can cause eye irritation, cough and chest discomfort, headaches, upper respiratory illness, increased asthma attacks, and reduced pulmonary function. In young children, exposure to even low levels of ozone can have adverse effects. The WHO air quality standards for Europe recommend a 1-hour guideline in the range of 150-200 µg/m$^3$ (0.076-0.1 ppm). To lessen the potential for acute and chronic adverse effects and to provide an additional margin of protection, an 8-hour guideline for exposure to ozone of 100-120 µg/m$^3$ (0.05-0.06 ppm) is recommended [WHO 1987]. The proposed draft air Quality Standards of Uganda recommend a 1-hour guideline at 0.10ppm exposure to Ozone (NEMA, 2008).

### 3.4.3 Poly Aromatic Hydrocarbons (PAHs)

PAHs are a group of organic chemical compounds that contain two or more aromatic benzene rings fused together. More than 500 PAHs have been detected in the air: the lighter PAHs are found in the gas phase, while PAHs with five or more rings, such as benzo[a]pyrene, are usually adsorbed onto fine PM. In the past, the major urban source of PAHs in Europe was the domestic burning of coal. Today, vehicle emissions are the dominant source in most urban areas, though wood combustion may be important in some areas, such as Scandinavia and Eastern Europe. In general, roadside PAH concentrations are higher than urban background concentrations, which in turn are higher than rural concentrations. Some PAHs are carcinogenic, and benzo[a]pyrene is often used as a marker of the carcinogenic potency of ambient total PAHs. The particulate fraction of PAHs is usually of greatest concern, since it contains the majority of the carcinogenic compounds and can be transported over long distances. Though routine measurement of PAHs has been scarce in the past, PAH concentrations appear to be an order of magnitude lower in urban areas today than they were when coal burning was commonplace (EC, 2000).

### 3.4.4 Particulate Matter (PM)

PM in ambient air comes partly from natural sources, such as wind-borne soil, sea spray and emissions of biogenic, organic compounds. Anthropogenic sources include not only fossil-fuel combustion, but also mining, agriculture and industry. PM emissions from road traffic come from exhaust pipes, tyre wear, brake linings and resuspension of road dust. PM is emitted directly (primary emissions) or formed in the atmosphere by conversion of gaseous precursors that is, nitrogen oxides, sulfur dioxide, VOCs and ammonia into secondary particles. PM may be transported in the atmosphere over hundreds to thousands of kilometers, depending on the particle size.

PM ranges in size from a few nanometers to tens of micrometers. Particles smaller than 1 µm have a number concentrations in the range of 100 –100 000 per cm$^3$, while those exceeding 1 µm have concentrations less than 10 per cm$^3$. Coarse particles (PM 2.5–10) settle more quickly after formation or emission than do fine particles (PM 2.5). The highest concentrations of coarse particles are generally found in street canyons (Palmgren et al., 2003). Particles larger than 10 µm are less likely to enter the
human respiratory tract, and are not considered harmful to health. The ultra-fine particles dominate the number concentration of particles in ambient air, but hardly contribute to the mass. At polluted sites, particles consist mainly of carbonaceous material – that is, elemental carbon and organic compounds.

There is limited data on emissions or concentrations of PM as a result of energy usage in the transport sector. However, particulate matter (PM) has received increased attention because it includes metals, organic compounds, and carbons some of which are toxic. Previous studies concluded that PM2.5 (aerodynamic diameter 62.5 µm) and PM10 (aerodynamic diameter 610 µm) are associated with a range of adverse health effects, including increased illness, hospitalization, and higher mortality rates (Hsun-Li, et al, 2008). The WHO limits on concentration for PM10 and PM2.5 are 150µg/m³ and 65µg/m³, respectively. Table 3-2 summarizes the different impacts of different emissions types on human health.

<table>
<thead>
<tr>
<th>Health Outcome</th>
<th>Pollutant</th>
<th>Evidence</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality</td>
<td>Black Smoke</td>
<td>None</td>
<td>No experimental studies</td>
</tr>
<tr>
<td></td>
<td>Ozone</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>PM 2.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory diseases</td>
<td>Black smoke</td>
<td>Strong</td>
<td>Strong experimental evidence for inflammatory effects</td>
</tr>
<tr>
<td></td>
<td>Ozone</td>
<td>Strong</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nitrogen dioxide</td>
<td>Strong</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VOCs</td>
<td>strong</td>
<td></td>
</tr>
<tr>
<td>Cardiovascular diseases</td>
<td>Black smoke</td>
<td>Some</td>
<td>Some experimental evidence for cardiovascular effects</td>
</tr>
<tr>
<td>Reproductive outcome</td>
<td>NO₂</td>
<td>Some</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>CO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>SO₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total Suspended Particles</td>
<td>Some</td>
<td></td>
</tr>
</tbody>
</table>

The pollutants of greatest concern at present, because of their impact on human health, are PM, ground-level ozone and nitrogen dioxide. The transport sector is an important contributor of all three. This results in a complex mixture that includes PM and gaseous pollutants such as nitrogen oxides (nitric oxide and nitrogen dioxide), carbon monoxide and VOCs, all of which pose risks to health. There is growing evidence that the health effects of combined pollutants are greater as compared to individual pollutants.

### 3.4.5 Health effects - Case studies

Vehicle emissions contribute to adverse health effects in humans; in addition these emissions are harmful to terrestrial and aquatic ecosystems, and contribute to crop damage and other welfare losses. However, most of the studies conducted have analysed the effects of the pollution mix generated by a variety of sources, which include traffic, communal and industrial combustion, and long-range transport of air pollution. Identifying the effects related specifically to the pollution created by transport is a challenge.

A study on mortality of professional drivers in London showed excess deaths from stomach cancer, lung cancer, bronchitis, asthma and emphysema among lorry drivers (Balarajan et al, 1998). This pattern was however not confirmed among taxi drivers. Hansen, 1993 conducted a study on Danish lorry drivers who were followed for a ten-year period and it was noted that there was an increased mortality from lung cancer indicating that exposure to diesel exhaust may have contributed to the observed increased risk of lung cancer.
A study was conducted in Rome where the mortality pattern of taxi drivers exposed to vehicle exhaust was analysed (Borgia et al, 1994). An increase in lung cancer was observed. However, owing to statistical uncertainty, the results did not clearly indicate the association between the risk of lung cancer and exposure to vehicle exhaust among the taxi drivers. Lagorio et al, 1994 compared the mortality in a cohort of petrol station attendants with that in the regional population. The data analysis indicated some increased risks in oesophageal cancer and brain cancer. This was applicable to both the attendants of small stations with a small work force and those working at large petrol stations with high number of sales of petrol per full time employee.

A cohort study of Roman traffic police officers showed mortality from cardiovascular diseases that were higher than expected, though that from respiratory conditions was lower than expected. There was no statistically significant excess mortality from lung and other types of cancer found (Forastiere et al, 1994).

Janssen et al, 2003 reported on 24 schools located within 400m of busy motorways in the Netherlands. The study included 2503 school children aged 7 – 12 years. PM 2.5, soot and nitrogen dioxide were measured in the schools for a year. Non-allergic symptoms such as bronchitis were increased near motorways with high traffic counts of lorries not cars.

Jakobsson et al, 1997 studied the increased risk of lung cancer among urban and rural taxi drivers. He observed that urban drivers have a higher risk of lung cancer when compared with their colleagues from rural areas in Sweden.

A wide range of studies indicate an increased risk of various types of cancer and respiratory diseases in people exposed to higher levels of transport related air pollution. Such effects were measured or modeled mainly in subgroups that are susceptible or have higher levels of exposure than average.

### 3.5 Factors affecting the emission levels

Internal combustion engines and conventional fuels are the leading contributors to transport related pollution. Road-traffic emissions come from a number of sources. They include exhaust pipe emissions and contributions from friction processes and resuspended road dust. Emission levels depend on three major factors that are categorized as traffic characteristics, road characteristics, engine design characteristics and fuel quality.

#### 3.5.1 Engine Design Parameters

Motor vehicle fuel is used to overcome engine and driveline losses, standby and idling, accessories such as air conditioning, overcoming aerodynamic drag, inertia and tyre rolling resistance. The vehicle characteristics that affect the level of emission include type, size, age of a vehicle and condition of its engine. The age of a vehicle and poor maintenance contributes to the higher emission in all classes of vehicle. Further the quality of fuel has a direct effect on the exhaust emissions (Suresh et al, 2000). There are two major types of internal combustion engines that include the diesel engine and the spark ignition petrol engine often called the Otto engine. The petrol engine uses a spark plug to ignite the fuel, while combustion in a diesel engine is started by auto-ignition, due to the heat created during compression. Certain engine design parameters are capable of inducing significant changes in emissions. Most notable among these are air/fuel ratio and mixture preparation, ignition timing, and combustion chamber design and compression ratio.
3.5.1.1 Air/Fuel Ratio and Mixture Preparation

The air/fuel ratio has a significant effect on all three major pollutants (CO, HC and NOx) from gasoline engines. In fact, CO emissions are almost totally dependent on air/fuel ratio whereas HC and NOx emissions rates can be strongly influenced depending on other engine design parameters (Robin et al, 2006).

For diesel vehicles, HC emissions have a dependence on the equivalence ratio that is defined as actual fuel versus air ratio normalized with respect to the stoichiometric fuel versus air ratio.

\[
\phi = \frac{\left(\frac{m_f}{m_a}\right)_{\text{actual}}}{\left(\frac{m_f}{m_a}\right)_{\text{stoichiometric}}} 
\]

Where \( \phi \) = equivalence ratio
\( F \) = index of fuel
\( a \) = index for air
\( m \) = mass

CO emissions can be dramatically reduced by increasing air/fuel ratio to the lean side of stoichiometric. HC emissions can also be reduced significantly with increasing air/fuel ratio, until flame speed becomes so slow that pockets of unburned fuel are exhausted before full combustion occurs. Conversely, NOx emissions increase as air/fuel mixtures are enleaned up to the point of maximum or peak thermal efficiency; beyond this point, further enleanment can result in lower NOx emission rates.

3.5.1.2 Ignition Timing

Ignition timing is the second most important engine control variable affecting the emission of HC and NOx from engines. When timing is optimized for fuel economy and performance, HC and NOx emissions are also relatively high. As ignition timing is delayed, peak combustion temperatures tend to be reduced thereby lowering NOx and peak thermal efficiency. By allowing combustion to continue after the exhaust port is opened (thereby resulting in higher exhaust temperatures), oxidation of unburned hydrocarbons is greater and overall hydrocarbon emissions are reduced.

3.5.1.3 Compression Ratio and Combustion Chambers

According to the fundamental laws of thermodynamics, increase in compression ratio leads to improved thermal efficiency and concurrently increased specific power and reduced specific fuel consumption. In actual applications, increase in compression ratio tends to be limited by available fuel octane quality. Compression ratios can be linked to combustion chamber shapes and in combination these parameters can have a significant impact on emissions. Higher surface to volume ratios will increase the available quench zone and lead to higher hydrocarbon emissions; conversely, more compact shapes such as the hemispherical or bent roof chambers reduce heat loss, thus increasing maximum temperatures. This tends to increase the formation of NOx while reducing HC.

Further, combustion chamber material and size and spark plug location can influence emissions. In general, because of its higher thermal conductivity, aluminum engine heads lead to lower combustion temperatures and therefore to lower NOx rates, but at the expense of increased HC emissions. Since the length of the flame path has a strong influence on engine detonation and therefore fuel octane...
requirement, larger combustion chambers which can lower HC emission tend to be used only with lower compression ratios (IEA, 2007).

### 3.5.2 Vehicle Non – Engine Components

#### 3.5.2.1 Tyres

Pneumatic tyres offer a number of advantages related to the highly compliant nature of rubber, such as generating the forces responsible for traction and providing cushioning for comfort. However, the main disadvantage is that energy is expended as the pneumatic tyre repeatedly deforms and recovers during its rotation under the weight of the vehicle. Energy is dissipated when a tyre is deformed due to rubber hysteretic losses behaviour. This phenomenon is called rolling resistance (RR). About 20% of a motor vehicle’s fuel is estimated to be used to overcome rolling resistance of tyres. Globally, tyres are responsible for an estimated 300 Mtoe energy consumption and 800 Mt CO\(_2\) emissions (IEA, 2007). Additional fuel is required when tyres are under-inflated. A study by the IEA revealed that in the EU tyres in service were under-inflated by 0.2 to 0.4 bars on average for passenger cars and 0.5 bars for trucks. This under inflation in turn corresponded to an increase in energy consumption and CO\(_2\) emissions of roughly 1 to 2.5% for passenger cars, and 1% for trucks. Under–inflated tyres have since time immemorial been regarded more of a safety issue than an energy efficiency issue.

#### 3.5.2.2 Cooling technology

Mobile air conditioning systems are responsible for as much as 15% of the fuel used by modern cars. This increases depending on the specific driving conditions, for example, during heavy congestion. Air conditioning is estimated to contribute 5-10% of passenger car oil use. The cooling process requires active systems, basically heat pumps including a refrigerant alternatively evaporated and condensed. The pump itself is usually activated through a belt driven by the engine. In the near future because of the surging car ownership rates, developing countries will have huge fuel consumption and GHG emissions related to cooling their cars.

#### 3.5.2.3 Lighting

Light applications of road vehicles account for 3.2% of all road vehicle energy use. Because of the very poor yield of the engines and alternators, the energy use by vehicle lighting accounts for a surprisingly high share of global oil demand; 1.4%. This is an equivalent of 48 Mtoe per year and leads to the emissions of over 1230 MtCO\(_2\) per year. The energy use for vehicle lighting is rising due to three sorts of upward pressures. First, the global vehicle fleet is set to grow by 70% to 2030 from 1044 million vehicles in 2005. Second, the number and power of lights per vehicle is increasing. Thirdly, many countries are introducing legislation requiring headlamps to be on during the day time in response to safety data which has shown that a significant proportion of head-on collisions can be avoided by making vehicles more visible in day time.

#### 3.5.3 Traffic characteristics

Traffic characteristics such as flow, queue length and delay-events arise depending on the configuration of the road, whether it is a junction, intersection or any other design. The influencing factors on vehicle emissions include engine ignition timing, air–fuel ratio, compression ratio, combustion chamber geometry, and more importantly, whether the vehicle is idling, accelerating or decelerating. (Chow et al, 2006). The emission rate therefore depends on the stop-and-go traffic pattern. Chow et al, 2006 observed that over a day, the concentration levels of most air pollutants generally followed a diurnal pattern of traffic. It was found that higher levels of NO\(_2\) occurred during rush hours when the traffic and human activity is high. Frey et al, 2002 observed that average emissions during acceleration are typically five times greater than during idling for hydrocarbons and CO\(_2\), and ten times greater for NO and CO.
3.5.4 Road Characteristics

A study conducted by Rosqvist (2007) on traffic emissions in residential areas showed that fuel consumptions and exhaust emissions are highly dependent on street design and structure of the street. Pierson et al (1996) found that emissions of CO and NOx were twice as high driving uphill whereas Kean et al, 2003 found that increase in NOx emissions with vehicle speed was not much as compared to CO emissions. This shows that driving is dependent on the terrain and make of road, whether wide or narrow, resulting in accelerations, decelerations and idling.

3.5.5 Fuel Quality

The quality of fuel used in vehicle engines will affect the composition of the emissions released. The fuel used has several properties that affect the level of vehicular emissions when used. The major ones are the sulphur and oxygenate content.

3.5.5.1 Sulphur

Sulphur in diesel fuel contributes to formation of particulate matter (PM) in the engine. Sulphur is directly linked to the formation of primary particulates and contributes significantly to the formation of secondary particulates. Reductions down to 500 ppm have a direct effect on the PM emissions. International norm is for diesel fuel containing 500 ppm to be referred to as Low Sulphur Diesel (LSD) while fuel containing 50 ppm sulphur or lower is referred to as Ultra Low Sulphur Diesel (ULSD). Sulphur free diesel generally refers to levels below 10 ppm. The fuel specifications in East Africa require a sulfur content of 0.05% for gasoline which is very high (EAC, 2000). The AFRI-2 standards being adopted by most African states require fuel specifications of 3500 ppm sulphur in diesel and 500 ppm in gasoline. Studies show that reduction of sulphur content from 3000 ppm to 500 ppm would reduce PM emissions by 10 – 15% directly. However, as PM is made up of a variety of compounds other than sulphur, reducing sulphur to zero would not necessarily reduce PM to zero. Sulphur also affects the performance of vehicle emissions control equipment and therefore has indirect effects on emissions of CO, hydrocarbons and NOx. Sulphur content in fuel affects the performance of catalysts when a vehicle is fitted with a catalytic converter.

3.5.5.2 Oxygenates

These are organic compounds containing carbon, oxygen and hydrogen. They are added in petrol as a blending component and to increase octane number. Their use in petrol effectively increases the available oxygen for combustion which has the effect of reducing CO formation and HC emissions. However, their presence can result in increased VOC emissions.

3.5.6 Factors affecting Motorcycle emissions

Lin et al, 2008 observed that engine type, size and age significantly affect the HC emissions. Larger size engines emit smaller amounts of HCs whereas older motorcycles emitted greater amounts. In addition, two stroke engine machines produced significantly higher HC emission levels than the four stroke. The two stroke engines produce considerable hydrocarbon and particulate emissions because of air fuel mixture short – circuiting and two stroke lubricating oil (Biona et al, 2007). Emissions of CO and HC are highest when a motor cycle is in an idling state.

3.6 Quantification of emissions

Quantification of emissions can be done by either a “top–down” or “bottom-up” approach to generate an emissions inventory. The top-down approach describes the total polluting activity throughout a selected area of interest, such as the national petrol sales for calculation of road transport emissions. This is related to the magnitude of the associated air pollution source by means of an emission factor that can be obtained by laboratory measurement of a representative sample of engines or vehicles under simulated conditions.
Chapter Three: Literature Review

typical operating conditions (Colvile et al, 2000). An emission factor is the amount of pollutant produced per unit activity. For highway vehicles, emission factors are typically expressed in grams of pollutant emitted per vehicle-Km of travel, grams of pollutant emitted per gram of fuel consumed, or grams of pollutant emitted per unit time (NRC, 2000). Thus, the activity data required for emission inventory development would typically be an estimate of total vehicle Km traveled, total fuel consumed, or time spent for emissions process, respectively.

The bottom-up approach is different in that it starts with geographically resolved data for example traffic flow on an individual length of road. For some sources emissions data are determined directly by measurement of each individual source. Total emissions for a geographical area of interest can then be obtained by summing all the individual contributions. Top-down and bottom-up methods give different total emissions as each is subject to different sources of error. A bottom up emissions inventory inherently suffers from requiring very large amounts of data, such that there is a tendency to make several assumptions and approximations. There are several challenges in estimating transport emissions. Different types of sources of a given pollutant might have very different source-receptor relationships. This is unimportant for well-mixed pollutants such as CO₂, for which the total global concentration is of interest. Also, there is a possibility that the local air quality has a contribution of sources outside the area of inventory and this could be significant (Carruthers et al, 1999).

3.7 Uganda’s automobile industry

3.7.1 Petroleum product consumption

With no indigenous production of petroleum products, Uganda is reliant on imports from other countries, primarily from the Arabian Gulf and Mediterranean regions, and Singapore. Because of Uganda’s land locked location, such products are usually supplied via Mombasa in Kenya and Dar es Salaam in Tanzania. At present the oil marketing companies in Uganda transport a large proportion of the clean white products via the Kenyan Petroleum Company (KPC) pipeline. Figure 3-3 below shows the split between the petroleum products in Uganda from 2004 to 2008. However, while the pipeline is the most cost effective way of transporting petroleum products, the capacity is limited.

Diesel and petrol are among the highly consumed products implying that the transport industry consumes most of the petroleum products in the country. All the petrol and 80% of the diesel are used in the transport sector. In 2009, petrol which is solely consumed by vehicles accounted for 26% of petroleum product sales, while diesel which is largely consumed by both vehicles and other users accounted for 60% (MEMD, 2009). The consumption level of petroleum products continues to grow with the growing numbers of motor vehicles.
3.7.2 Automobile population growth

Uganda’s economic performance has continued to improve over the years by an average growth rate of 5.6 percent for the past decade. As a result, the number of vehicles on Uganda’s roads has rapidly increased since 2000, accompanied by an increase in demand for petroleum products. The growing number of vehicles is a key determinant of the level of automobile emissions. Figure 3-4 shows the current and projected number of vehicles on Ugandan roads stretching from 2000 to 2010. A significant growth was achieved between 2006 and 2008.

Figure 3-4: Motor vehicle numbers in Uganda from 2004 to 2008. (Source: Uganda Bureau of Statistics statistical abstracts 2009).
The number of vehicles continued to rise and is projected to continue growing at an average growth rate of about 9%. The estimated total number of vehicles was 469,251 in 2008 with motor cycles constituting about 50% as shown in Figure 3-5.

Figure 3-5: Distribution of vehicle by type in Uganda. (Source: UBOS Statistical Abstract 2009)

Table 3-3 shows the newly registered vehicles and number of vehicles estimated on the road. The data shows that newly registered vehicles increased by 31.0 percent in 2008 and the number of vehicles on the road increased by 22.9% in the same period.


<table>
<thead>
<tr>
<th>Category</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newly registered</td>
<td>35,538</td>
<td>51,107</td>
<td>59,617</td>
<td>77,305</td>
<td>101,240</td>
</tr>
<tr>
<td>Percentage increase</td>
<td>44</td>
<td>17</td>
<td>30</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Estimated number of vehicles</td>
<td>247,045</td>
<td>278,594</td>
<td>382,773</td>
<td>382,773</td>
<td>470,448</td>
</tr>
<tr>
<td>Percentage increase</td>
<td>13</td>
<td>13</td>
<td>21</td>
<td>23</td>
<td></td>
</tr>
</tbody>
</table>

The continued increase in the number of vehicles on Uganda’s roads is a result of improved economic performance and improvement in people’s welfare, which push up the demand for cars among other goods. This increase in demand for vehicles puts pressure on the supply logistics for petroleum products just like other demand pushing factors. Traffic congestion is pronounced in Kampala City where it has been estimated that 10% of all vehicle kilometers are undertaken in conditions of severe congestion with average speeds of 15 km/h. The total incremental consumption of fuel arising out of this congestion was estimated to be equivalent to 5.5 million US dollars per annum. The initial handling capacity for all the roads in Kampala has been exceeded.

Figure 3-6 illustrates a typical day in Kampala at the Wandegeya junction in Kampala city. The presence of the motor cycles used for fast transport is making an already congested city worse. The narrow roads contribute greatly to the congestion.
3.7.3 Emission Legislation

Vehicle importation in Uganda is based on fiscal policy with no environmental considerations. However, due to the growing concern on greenhouse gases and climate change associated to vehicle emissions, The Uganda Revenue Authority (URA) and the National Environmental Management Authority (NEMA) are under obligation to introduce emissions standards to regulate vehicle importation.

Table 3-4 shows the comparison between World Bank ambient air quality guidelines (2005) and the draft ambient air quality standards for Uganda. The World Bank guidelines are based on World Health Organisation (WHO) Air Quality Standards. It is observed that the WHO standards are more stringent compared to the proposed Uganda regulations.

Table 3 – 4: Ambient air quality emission standards for Uganda and WHO. (Source: NEMA, 2007 and WHO, 2005)

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Time of average</th>
<th>Draft Ugandan Ambient Air quality standards (ppm)</th>
<th>WHO ambient Air Quality standards (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur dioxide (SO₂)</td>
<td>Annual</td>
<td>0.15</td>
<td>0.0076</td>
</tr>
<tr>
<td></td>
<td>24 hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 hour</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 mins</td>
<td></td>
<td>0.19</td>
</tr>
<tr>
<td>Nitrogen dioxide (NO₂)</td>
<td>Annual</td>
<td>0.1</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td>1 hour</td>
<td></td>
<td>0.111</td>
</tr>
<tr>
<td>Particulate Matter (PM10)</td>
<td>Annual</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24 hour</td>
<td>300</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>1 hour</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Carbon Monoxide</td>
<td>8 hour</td>
<td>9</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1 hour</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Hydro carbons</td>
<td>24 hours</td>
<td>5</td>
<td>-</td>
</tr>
</tbody>
</table>

NEMA has also developed draft emission standards for automobiles. The proposed emission standards for vehicles are as shown in Table 3-5. The standards were developed for heavy duty diesel powered vehicles, diesel passenger cars, petrol passenger cars and petrol gasoline light trucks.
Table 3-5: Draft emission standards for automobiles (Source: National Environmental Management Authority (NEMA, 2007)

<table>
<thead>
<tr>
<th>Vehicle category</th>
<th>Standard Applicable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NOx</td>
</tr>
<tr>
<td>Heavy duty diesel powered (g/kWh)</td>
<td>7.0</td>
</tr>
<tr>
<td>Diesel Passenger cars (g/km)</td>
<td>1.25</td>
</tr>
<tr>
<td>Petrol/gasoline passenger cars (g/km)</td>
<td>0.08</td>
</tr>
<tr>
<td>Diesel light duty trucks (g/km)</td>
<td>0.38</td>
</tr>
<tr>
<td>Petrol gasoline light trucks (g/km)</td>
<td>0.6</td>
</tr>
</tbody>
</table>

- Heavy vehicles include good vehicles and buses (exceeding 3.5 metric tons) and trains
- Light duty vehicles include cars, vans and light trucks (less than 3.5 metric tons)

From Table 3-6, it is observed that draft motor vehicle emissions of Uganda lie within different ranges of Euro emission standards for different emissions shown in Table 3-6. The NOx emissions from petrol passenger cars lie within the 2006 Euro Standards whereas the diesel NOx emissions lie close to the 1997 Euro emissions standards. The CO emission standard for Uganda is in close range with the Euro standards of 1993.

Table 3-6: European Emission standards for cars as function of year when each standard came into force.

<table>
<thead>
<tr>
<th>EU Passenger Car Emission limits (g/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petrol Engines</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1991</td>
</tr>
<tr>
<td>1993</td>
</tr>
<tr>
<td>1996</td>
</tr>
<tr>
<td>1997</td>
</tr>
<tr>
<td>2001</td>
</tr>
<tr>
<td>2006</td>
</tr>
<tr>
<td>Diesel Engines</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>1991</td>
</tr>
<tr>
<td>1993</td>
</tr>
<tr>
<td>1996</td>
</tr>
<tr>
<td>1997</td>
</tr>
<tr>
<td>2001</td>
</tr>
<tr>
<td>2006</td>
</tr>
</tbody>
</table>

3.7.4 Emissions levels in Uganda

Uganda’s emission data is still lacking and does not provide the trend in emissions over a period of time. No detailed research has been done to quantify existing emission levels. However, during the preparation of Uganda’s First Communication to the UNFCCC, estimates of emissions from different sources were made using standard emission factors. This section presents some of the key findings that were submitted to the UNFCCC. The key GHG emitted in Uganda is CO2 with emissions per unit of GDP of 0.06 ktCO2 per million (UNDP, 2007). The estimated CO2 emissions from petroleum products (transport and
energy) is 708.61 Gg of CO₂ emitted from a total carbon content of 195.07 Gg as of 2002. Emissions from thermal generators for CO₂, CH₄, CO, N₂O and NOₓ respectively were 73.3, 0.01, 0.51, 0.0019 and 1.01 Gg in 2002. Agricultural activities are the biggest contributor to all the other GHG emissions including methane, Nitrous oxide, Carbon monoxide, and Nitrogen oxides (MWE2001).

### 3.8 Mitigation Measures for Vehicular Emissions

#### 3.8.1 Energy Efficient technologies

New technology with improved engine design, alternative and hybrid motor technology and advances in component design have the potential to significantly reduce energy intensity in vehicle fleets and hence a reduction in pollution. However, adopting new technology especially in the early stages of its deployment in the market involves a higher cost to potential consumers.

##### 3.8.1.1 Catalytic Converters

New vehicles fitted with catalytic converters treat the exhaust gas before it leaves the vehicle, removing 90% of the pollutants. This is the main method of pollution control in petrol engines. Harmful emissions such as nitrogen oxides (NOₓ) unburnt hydrocarbons (HC) and carbon oxides are converted into less toxic emissions, thereby reducing the risk of exposure to high concentrations. Even though less toxic emissions are created, they can still have long term implications - for example by converting carbon monoxide (CO) to carbon dioxide (CO₂) which is known to contribute towards global warming. Vehicles fitted with fuel injectors and engine management systems allow catalytic converters to operate optimally. In general, all of these devices are sensitive to fuel specifications, in particular requiring low sulphur content.

##### 3.8.1.2 Retrofits

Older cars having little or no pollution controls can be retrofitted. Retrofitting is the installation of pollution control devices after the vehicle is in use rather than during vehicle manufacture. Retrofit programs can be mandatory or voluntary with both positive and negative inducements. In 1997, an emission upgrade program began in the County of San Diego. The program consisted of retrofitting a catalytic converter and a closed-looped air/fuel ratio control system on vehicles originally equipped with oxidation catalysts and open loop engine controls. After 30,000 miles, the average emission reduction from six durability vehicles was 70% for HC, 68% for CO, and 50% for NOₓ. Real world experience indicates that retrofit programs can be very successful, especially if they are focused on specific vehicle categories. A combination of tax incentives coupled with restrictions on the use of non-retrofitted vehicles has worked well in stimulating successful retrofit programs.

#### 3.8.2 Improved fuel quality

The effects of fuel quality changes in isolation of changes to vehicles are relatively small compared to reductions achievable from changes to engine technology. The real benefits of fuel quality changes are achieved when they are used to enable new vehicle technologies. Any vehicle emission strategy needs to consider the environmental performance of the vehicle fleet in the long term. Any changes to fuel specifications need to also take into account the shorter term impact of vehicle driveability. Fuel specifications should be established in order to achieve a specific objective, bearing in mind that different local conditions can significantly impact the outcome of a particular specification change. An example is the variation in vehicle parc technology, emission level, age and condition.

For air quality, if a fuel is fit-for-purpose, then both performance and enabling specification can be used to reduce vehicle emissions and improve air quality. Performance specifications can have an immediate impact since the entire fleet can benefit from the specifications. The impact of enabling specifications on
the other hand can take longer to exhibit since it is dependent on new vehicle technologies that are introduced. Typically, the overall reductions in emissions attainable from fuel performance specifications, although significant in their own right, are much less than that achievable through improved vehicle technology especially when coming off a low technology base such as applied to Uganda’s current vehicle parc.

In order to improve on the fuel quality, the following methods are applied for diesel and gasoline.

For gasoline:
- Phasing out lead to reduce lead emissions and enable new car technology with catalytic converters. Uganda phased out leaded gasoline in 2007 and all fuel stations sell unleaded fuel.
- Reducing benzene to reduce air toxics and carcinogenic emissions
- Reducing volatility to reduce evaporative emissions
- Reducing sulfur to improve catalytic converter efficiency and reduce PM

For Diesel:
- Sulfur reduction is the primary focus with regard to diesel due to PM, NOx and SOx emissions.
- Total aromatics, PAH, final boiling point and cetane number are parameters, which influence particle formation and therefore are often tightened

### 3.8.3 Alternative fuels

Alternative fuels include methanol (made from natural gas, coal or biomass), ethanol (made from grain or sugar); vegetable oils; compressed natural gas (CNG) mainly composed of methane, liquefied petroleum gas (LPG) composed of propane and butane; electricity; hydrogen; synthetic liquid fuels derived from hydrogenation of coal; and various fuel blends. A forecast into the future indicates that between 2050 and 2085 the use of oil in cars will be phased out completely and replaced mainly by electric vehicles. The electricity will come from renewable energy sources. It is also forecasted that by 2080, about 90% of primary energy demand will be covered by renewable energy sources; in 2090 the renewable share will reach 98.2% (Energy Revolution 2009).

The leading alternative fuel under consideration with proven success in several countries like Brazil is biodiesel. Biodiesel is produced by reacting vegetable or animal fats with methanol or ethanol to produce a lower-viscosity fuel that is similar in physical characteristics to diesel, and which can be used neat or blended with petroleum diesel in a diesel engine. Engines running on biodiesel instead of petroleum diesel tend to have lower black smoke and CO emissions, but higher NOx and possibly higher emissions of particulate matter. The reduction in smoke emissions is believed to be due to better combustion of the short chain hydrocarbons found in biodiesel, as well as the effects of the oxygen content. The higher NOx emissions from biodiesel-powered engines are partly due to the higher cetane number of biodiesel, which causes a shorter ignition delay and higher peak cylinder pressure. Other advantages of biodiesel include high cetane number, very low sulfur content, and the fact that it is a renewable resource.

The main disadvantages of using biofuels include high cost ($1.50 to $3.50 per gallon before taxes), reduced energy density (resulting in lower engine power output), and low flash point, which may make it hazardous to handle. The heating value for biodiesel is less than that for diesel. More fuel must be burned to provide the same work output as diesel fuel. The effects of biodiesel on engine performance and emissions over a long time in actual service are not well documented. Alternative fuels do not necessarily have full-fuel-cycle carbon emissions (including emissions from both vehicle use and upstream processes to extract, convert, and deliver fuel to vehicles) that are significantly different than gasoline (e.g. grain ethanol has full-fuel cycle emissions that are very similar to gasoline) (Difiglio et al, 2000). Efficient use of transport systems will still be the main way of limiting fuel use. Public transport systems will continue to
be far more energy efficient than individual vehicles. However, we assume that cars will still be needed, especially in rural areas. The introduction of cleaner fuels with matching vehicle technology will accelerate the development of cleaner air quality, but this will still take time to achieve with the current low vehicle turnover in Uganda.

### 3.8.4 Tail pipe emissions standards

Emission standards prescribe limits for the regulated exhaust gases as well as the test conditions and test procedures under which these limits apply. The first control on emissions was introduced in the USA and Japan in the 1960s in response to concerns about the impact of increased vehicle use on urban air quality. Regulated emissions apply to tail pipe emissions focusing on regulations for spark ignition vehicles using petrol and compression ignition vehicles using diesel. The main emissions regulated are hydro carbons, carbon monoxide, NOx and particulates. Particulates are mainly produced by the compression ignition vehicles using diesel.

They are intended to simulate a range of, and reflect the transient nature of actual vehicle operating conditions. Uganda is still in the process of establishing vehicle emission standards. South Africa elected to follow the European Vehicle emissions legislations but in a somewhat lagged fashion. The challenge of the developing countries lies in enforcing emission legislation given the existing old vehicle fleet that cannot be replaced in a few months or years.

### 3.8.5 Inspection and Maintenance (I/M) program

For countries with only minimal, if any, controls on vehicles, a simple I/M programme can be a good pollution control starting point as even vehicles with no pollution controls can benefit from improved maintenance. A simple idle check on CO and HC missions from gasoline vehicles or visible smoke check on diesel vehicles can be used to identify the highest polluters and those vehicles which would most benefit from remedial maintenance. Hong Kong, whose air quality problem is primarily excess particulate, trained a small group of smoke inspectors who then patrolled the streets, identifying vehicles with excess smoke and requiring them to be repaired or pay a fine. Such a programme requires minimal capital investment and resources. As vehicle technology advances, more sophisticated test procedures may be necessary, including loaded mode tests that use a dynamometer to simulate the work that an engine must perform in actual driving.

In 1992, a demonstration of centralized emissions I/M capability was carried out in British Columbia. It was the first I/M program to measure hydrocarbons (HC), carbon monoxide (CO) and the oxides of nitrogen (NOx) using the acceleration simulation mode (ASM) test, which is a loaded mode test simulating vehicle acceleration. The inspection also included an idle test and an anti-tampering check to further ensure that high emitting vehicles were identified and repaired. Overall, about 88% of the repairs were effective in reducing emissions. Based on audit results, overall emissions were reduced by approximately 20% for HC, 24% for CO and 2.7% for NOx. In addition to the emissions reductions, the audit program found that fuel economy for the failed vehicles improved by approximately 5.5% for an estimated annual savings of $72 per year per vehicle. Overall, this data confirms that I/M programs, when properly performed in a centralized facility using a loaded mode test, can achieve a substantial reduction in emissions. These reductions are accompanied by substantial fuel savings. Real world experience indicates that high quality I/M programs can reduce CO and HC exhaust emissions by approximately 20 to 30% (Weyn et al, 1994).

Although improvement in vehicle technology plays a significant role in reducing traffic emissions at the source, air pollution will remain a challenge because of increasing demand for transportation (WBSCD, 2001). This is however contrasted by evidence in Beijing China, that indicates that the annual rate of
increase of the car population alone is about 19.1% causing heavy traffic congestion, but annual concentrations of pollution has not increased at the same rate. On the contrary in some areas reductions in pollution concentration have been attributed to the introduction of Euro Norms and better designed new vehicles (Hao et al, 2006). Anderson et al, 1996 states that increase in the overall vehicle-kilometers traveled (VKT) over the past two decades has outweighed any gains in emission reductions achieved through advances in car technologies. This is attributed to the changing spatial arrangement of interacting activities that increase the need for travel for passengers (Kanaroglou et al, 1999).

### 3.8.6 Introduction of electric bicycles and motorcycles

There has been an increased growth in the use of electric bicycles around the world especially in Asia and Europe in the last five years. Electric bicycles are considered to be cheap to run and convenient to use (I.D de Vries et al, 2006). Cost effective electric bicycles offer a very attractive solution to Uganda’s transport problems and at the same time will drastically reduce the pollution levels.

<table>
<thead>
<tr>
<th>Emission per 100 km traveled</th>
<th>CO$_2$ (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small motor car</td>
<td>20</td>
</tr>
<tr>
<td>Motor bike</td>
<td>7.5</td>
</tr>
<tr>
<td>Electric bike</td>
<td>1.03</td>
</tr>
</tbody>
</table>

Table 3-7 shows CO$_2$ emitted from an electric bike being approximately 20 times less than a motor car and 7.5 times less than a motor bike. Given the predicted growth in the number of motorcycles in Uganda which will result in increased emissions, the introduction of electric bikes/cycles will reduce the expected levels of emissions. However, the introduction of electric bikes will be affected by the following:

- **Culture** – Ugandans do not have a big culture of cycling. This is partially due to the long distances people have to travel. The city plans should consider having well demarcated cycle paths to encourage the public to adopt cycling to work.

- **Safety** – Kampala city has high traffic congestion and presents risks of accidents to cyclists. As earlier mentioned, safety levels can be improved by designing the city roads with more cycle paths.
CHAPTER FOUR

4.0 RESULTS

4.1 Vehicle parc age and mileage

The field survey revealed that most of the personal vehicles and mini buses for public transport are imported into the county as second hand overhauled vehicles. Out of the 50 vehicle owners interviewed, 37 indicated they had purchased their vehicles from bonded warehouses and from other existing owners. 90% of the vehicles lie between 8–15 years indicating that the Ugandan vehicle parc is quite old. The vehicle owners indicated that at purchase time, some of the vehicle mileages were altered to reflect lower mileage indicating that there is a high level of uncertainty in the recorded vehicle mileage data. The vehicle mileage for minibuses ranged between 40,898 km and 390,965km with an average of 20,404 km and standard deviation of 92,705km.

The vehicle mileage for the personal vehicles ranged between 5,668 km and 212,017 km with an average of 108,349 km and standard deviation of 63,307.56km. The results show that on average minibuses cover longer distances compared to personal vehicles. This is because minibuses are used within the city centre for public transportation necessitating them to drive more compared to personal vehicles.

A typical motor bike in Kampala city has a mileage of 24,503 km. The lowest and highest mileages recorded were 8,523 km and 78,384 km with a standard deviation of 17,210.42 km. The motor bikes are categorized as either two or four stroke. All motor bikes are imported into the country as brand new with zero mileage. However, some of the buyers purchased their motor bikes second hand from owners within the city. The results show that motor bikes have lower mileages as compared to the personal vehicles and mini buses. Motor bikes are used as a quick form of transport to move between short distances. They do no operate long routes out of the city and hence the low mileage values.

4.2 Automobile emissions

The analysis of the emissions from different vehicles showed that CO\textsubscript{2}, NO\textsubscript{x}, CO, HC and NO are released during combustion of fossil fuels. The results obtained are a combination of all the vehicle types considered in the analysis. They cover vehicles with different engine types and sizes. This because of the difficulty involved in accessing vehicles for the experiments. The analysis was done on tail pipe emissions.

4.2.1 Carbon dioxide emissions

From Figure 4-1, it is observed that the maximum amount of CO\textsubscript{2} emitted from the different automobiles is 286.8 mg/m\textsuperscript{3}, 245.5 mg/m\textsuperscript{3} and 141.4 mg/m\textsuperscript{3} from minibuses, motor bikes and personal cars, respectively. The general trend in emission levels shows that minibuses emit more CO\textsubscript{2} compared to both the personal vehicles and motor bikes. The motor bikes emit more CO\textsubscript{2} compared to the personal vehicles. This is supported by the findings from the survey where car owners were asked how often they carried out maintenance work on their vehicles. Majority of the minibus operators showed reluctance in having a regular maintenance schedule with some doing it after 3–4 weeks. However, the survey showed that vehicles owned by individuals or organizations were well maintained with a weekly maintenance schedule. The mini bus operators viewed the maintenance program as costly and hence the reluctance to have vehicles regularly maintained. Poor maintenance results in poor engine performance.
The level of emission from the motor bikes is higher as compared to the personal cars. This is because the motor bikes, which are used for public transportation, carry one passenger at a time on average and for short distances. This involves frequent acceleration and idling resulting in high emission levels. This implies that the number of motor cycle which is increasing tremendously poses a big health and environmental threat. High emissions levels for the different automobile types were also observed in very old vehicles that had not undergone any major overhaul.

### 4.2.2 NOx emissions

Figure 4-2 shows the NOx emissions for the different automobiles. The highest level of NOx observed was from the motor bikes and minibuses at 0.15 mg/m³ and 0.13 mg/m³. The personal vehicles emitted less NOx compared to the minibuses and motor bikes with the highest amounts at 0.06 mg/m³. The amounts of NOx emitted is less in amount compared to the CO₂ released for all the automobile types. NOx is produced during combustion at high temperatures. At ambient temperatures, oxygen and nitrogen do not react with each other. However, in internal combustion engine, high temperatures lead to reactions between nitrogen and oxygen to yield nitrogen oxides.
4.2.3 HC emissions

Figure 4-3 shows the level of HC emissions from the three automobiles types. The level of HC emissions observed is highest in the motor bikes at 2.59 mg/m$^3$ followed by minibuses at 0.72 mg/m$^3$ and personal vehicles at 0.2 mg/m$^3$. However, the high amounts observed in the motor bikes correspond to those with the highest mileage and very old. During the study the very old motor bikes were also found to belong to the two stroke motor cycle category which emit significant amounts of HC compared to the four stroke type. HCs result from incomplete combustion in the engine due to reduction in the level of oxygen and may represent the number of particles being emitted. The low emission levels in the personal vehicles is attributed to the high maintenance standards and less travel as observed during the study.

![Graph showing HC emissions for different automobiles]

**Figure 4-3: HC emissions for the different automobiles**

4.2.4 NO emissions

The amount of NO emitted is low compared to the NO$_x$ and CO levels. The highest observed amounts were 0.19 mg/m$^3$, 0.15 mg/m$^3$ and 0.06 mg/m$^3$ for minibuses, motorbikes and personal vehicles. In all automobile types, there were some that never emitted any NO. This may be attributed to the fact that most of the NO reacts to form NO$_x$. 
Chapter Four

Results

4.2.5 CO emissions

Emission of carbon monoxide is an indicator of incomplete combustion in the engine. Figure 4-5 shows the level of carbon monoxide emitted by the three automobile types. The minibuses emitted more carbon monoxide than the personal vehicles and motor bikes. The emission amounts were 110 mg/m³ for the minibuses, 83 mg/m³ for the motor bikes and 16.9 mg/m³ for the personal vehicles.

![Figure 4-5: Automobile CO emissions](image_url)
4.3 Simulation Results

4.3.1 Vehicle demand projections

Results from the LEAP model reveal that if the current growth rates for the different automobiles are maintained, there will be 2,400,000 million vehicles in Kampala by 2030 as shown in Figure 4-6. This gives an estimated increase in volume of vehicles from the base year of about 400%.

![Figure 4-6: Automobile projections in Uganda from 2005 to 2030](image)

The total automobile demand chart above does not give a breakdown of the specific automobiles. However, Figure 4-7 shows the projected sales data for the different automobiles types. It is observed that motor bike usage will continue to grow under the BAU scenario based on the current growth rates of 12.6%. The number of motor bikes sold in 2030 will be 750,000. Minibuses and motor bikes are the cheapest and commonest modes of public transport and given the growing population in the city, it is expected that their demand will increase. The pickup vans and four wheel drives will still have the least share in the vehicle parc.

![Figure 4-7: Automobile sales](image)
4.3.2 Energy Demand

The main fuels used in the transport sector within Kampala are diesel and gasoline. Figure 4-8 shows an increase in demand for both diesel and gasoline. This is supported by the increase in the number of automobiles shown in figure 4-7. The use of diesel grows faster compared to gasoline up to 2021 with consumption at 1.17 and 1.16 MTOE for the two fuel types, respectively. However, from 2022 onwards, gasoline consumption overtakes diesel reaching a maximum of 3.88 and 2.98 MTOE in 2030, respectively. This is attributed to the rapid growth in the motor bikes which mainly used gasoline compared to the other automobile types. However, the transport sector in Kampala is currently diesel driven. The total energy demand for both transport fuels in 2030 is 6.9 MTOE for the business-as-usual scenario.

![Figure 4-8: Projected Energy demand for the transport sector](image)

Improvements in vehicle fuel economy results in a reduction in the amount of projected energy demand. Despite the increase in vehicle stock, improvement in fuel economy results in a lower energy demand compared to the BAU scenario. The analysis assumed new fuel economy standards requiring a reduction of 10% in 2015 and 20% in 2025. At 10%, a slight reduction in amounts of energy demand is noted. Stricter legislation in 2025 results in a noticeable reduction in energy demand by 235.8 thousand TOE as shown in Figure 4-9.
Figure 4-9: Projected Energy demand – Improved fuel economy

There is no impact on the energy demand resulting from the establishment of new tail pipe emissions as shown in Figure 4-10. The introduction of hybrid cars results in a slight reduction of 10 million Gigajoules in 2030. Overall, the improved fuel economy scenario has the greatest impact on energy demand reduction of about 70 million gigajoules in 2030.

Figure 4-10: Impact of the scenarios on the projected energy demand
4.3.3 Impact of different scenarios on the emission trends

This section reviews the impact of the three scenarios on emissions. An estimate of the emission reduction as a result of the scenarios is reported.

4.3.3.1 Carbon dioxide emissions

From Figure 4-11, it is observed that all the alternative scenarios to the BAU will give a reduction in the level of carbon dioxide emissions. The greatest reduction is due to the introduction of hybrid electric vehicles followed by the implementation of fuel economy standards. A 10% reduction in the vehicle fuel economy in 2015 has a negligible impact on the carbon dioxide emissions. A 20% reduction in 2025 in the fuel economy causes a noticeable reduction in the levels of carbon dioxide. If no measures are implemented in the planning horizon, the carbon dioxide emission levels will be approximately 2800 million kgCO₂ equivalent compared to 1100 million kgCO₂ equivalent.

Introduction of hybrid electric vehicles will realize a reduction of 480 million kg CO₂ equivalent in 2030 as shown in Figure 4-12. A reduction of 250 million kg CO₂ equivalent is achieved when new standards for improved fuel economy are introduced. Tail pipe emission standards results in an emission reduction of 125 million kg CO₂ equivalent.
4.3.4 Carbon monoxide emissions

The level of CO reaches 280 thousand tonnes CO$_2$ equivalent in the year 2030 for the BAU scenario as shown in Figure 4-13. The greatest reduction in CO is achieved by increasing the penetration of hybrid cars giving a reduction of 45 thousand tonnes CO$_2$ equivalent in 2030. Establishment of standards in order to improve the vehicle fuel economy resulted in CO emission reduction by 30 thousand tonnes CO$_2$ equivalent. Introduction of tail pipe emission standards gives a reduction in CO emissions of 35 tonnes CO$_2$ equivalent in 2030.
4.3.5 Nitrogen Oxides (NOx)

If no emission reduction strategy is applied, the amount of NOx emissions will be 24.5 million kilograms CO₂ equivalent for the BAU scenario as shown in Figure 4-14. Introduction of Hybrid vehicles will cause a great reduction giving 20 million kilograms CO₂ equivalent in 2030. Tail pipe emission standards and improvement of fuel economy strategy will result in a slight reduction giving emissions of up to 22 million kilograms CO₂ equivalent by 2030.

Figure 4-14. NOx emissions for the different strategies.

A 10% improvement in fuel economy in 2015 has no effect on the emission of NOx as this continues to increase as illustrated in Figure 4-15. The impact of the strategy for improvement of fuel economy is noticed after 2020 when a 20% improvement is applied.

Figure 4-15: Impact of different scenarios compared to BAU
4.3.6 Global Warming Potential

Figure 4-16 shows the impact of the analysed three scenarios on the GWP. It is observed that the introduction of tail pipe emission standards will have the greatest impact on reducing the GWP by 51% to 11.5 million kg CO₂ equivalent in 2030 compared to 23.5 million kg CO₂ equivalent for the BAU scenario. Introduction of hybrid electric vehicles will have the second greatest impact with a reduction of 17% to 19.5 million kg CO₂ equivalent. Improvement of fuel economy strategy will give an 8.5% reduction to a GWP of 21.5 million kg CO₂ equivalent.

![Environment: Global Warming Potential](image)

Figure 4–16: Impact of different scenarios on the GWP

4.3.7 Introduction of city buses

The introduction of city buses policy scenario gives a very big reduction in the overall energy demand. Figure 4-17 shows that an introduction of city buses results in reduced consumption of fuel by 73 million GJ in 2030. This option is gives a higher reduction in fuel consumption compared to the improved fuel economy case.

![Demand: Energy Demand Final Units](image)

Figure 4-17: Energy demand reduction resulting from the introduction of city buses
The results in Figure 4-18 show that introduction of city buses will have a remarkable impact on reducing the GWP resulting with a reduction of 21.8 million kg CO₂ equivalent by 2030. This scenario option competes favourably with the introduction of tail pipe emissions.

![Figure 4-18: Impact of introducing city buses on GWP](image)

### 4.3.8 Emission impact on public health

An investigation was carried out on the public’s perception on the role of vehicles in causing emissions and their impacts on public health. Of the 30 drivers and 10 vehicle mechanics who responded to the interview, 95% indicated that they were not aware of the impacts their driving has on the environment and public health in terms of emissions released. They showed a laissez-faire attitude and indicated that all they are worried about was their ability to meet their family needs for the day. However, when asked whether they had experienced any form of discomfort resulting from driving in highly polluted environments, they were quick to mention that they usually experience headaches and chest problems at the end of a typical working day. Three of the drivers reported having undergone some chest congestion treatment but did not link this driving in polluted environments. They also implied that they were non-smokers and had been driving for over 10 years.
CHAPTER FIVE

5.0 DISCUSSION

5.1 Automobile population growth and Energy demand

The findings show that the number of automobiles in Kampala will continue to grow to about 3 million automobiles in 2030. This projection is supported by the increasing population in Kampala at an urbanization rate of 9.28%. The vehicle parc in Kampala is relatively old with 90% of the vehicles being 8–15 years old. A tremendous growth in the motor cycle industry is observed and this is due to the growing need for fast transport by passengers in Kampala. This is catalysed by the ever present traffic congestion that the motor cycles can maneuver through with less limitation compared to other vehicle types. The observed growth in personal vehicles results from the ever growing number of blue collar workers that opt for private means of transport instead of the inefficient public means by minibuses. Improvement in the city transport system has the potential of reducing on the growth of both the 14 seater minibuses and personal vehicles. The provision of public transport modes of significant quantity and quality to provide an integrated service is crucial to the success of breaking the link between increased transport demand and the rise of private transport.

The growing number of motor vehicles results in increased fuel consumption estimated at 3 million TOE in 2030 which leads to increased emission levels. An integrated public transport system would result in great reduction in the amount of energy consumed and hence a reduction in emissions too. A study by Sheldon et al (2009) revealed that ride sharing can reduce on the number of non-commercial passenger vehicles in the city and as a result the fuel consumed. Sheldon et al established that adding one additional passenger for every 100 vehicles would reduce annual fuel consumption by 0.80 - 0.82 billion gallons of gasoline per year. And if one passenger were added in every 10 vehicles, the potential savings would be 7.54 – 7.74 billion gallons per year.

5.2 Emissions types and their impacts

The analysis showed that the main emissions from the transport sector are carbon dioxide, carbon monoxide, hydro carbons and nitrogen oxides. Motor cycles gave off the highest level of hydro carbon emission of about 2.59 mg/m³. A study conducted in Manila by Biona et al, 2007 assessed the energy usage and emissions from motor cycles. It was found that motor cycles produced 9.5, 9.7, 40.5 and 0.07 g/km of HC, CO, CO₂ and NOx, respectively. The amount of HC produced by the motor cycles was greater than that from gasoline private cars and diesel powered taxis and buses on a per passenger – km basis but significantly low in NOx. The two stroke motor cycles emit more compared to the four stroke because of the air fuel mixture short-circuiting and two stroke lubricating oil.

The highest NOx emissions were observed in motor cycles with lowest amounts from personal vehicles. Motor cycles emitted NOx emissions estimated at 0.15 mg/m³ compared to minibuses and personal vehicles at 0.13 mg/m³ and 0.06 mg/m³, respectively. Carbon dioxide emissions were greatest in the minibuses amounting to 286.8 mg/m³ as compared to 245.5 mg/m³ and 141.4 mg/m³ in motor cycles and personal vehicles, respectively. The findings show that minibuses are not well serviced with a poor maintenance record whereas personal vehicles are well maintained resulting in good engine functioning. This is further supported by the level of CO from minibuses that was 110 mg/m³ compared to 16.9 mg/m³ from the personal vehicles. The highest emissions obtained were from CO₂, CO, HC, NOx and NO, respectively.
Although the ambient air quality was not monitored in this study due to lack of equipment, it is observed that the level of tail pipe emissions obtained are a good indicator of the existing ambient air emission concentrations. NEMA carried out a base line survey in 2008 at the Wandegeya traffic junction and estimated the ambient air quality using safety air badges and Chromatography. The emissions were estimated as NO\textsubscript{2} – 0.18 ppm (0.37 mg/m\textsuperscript{3}), CO\textsubscript{2} – 14000ppm (27500 mg/m\textsuperscript{3}) and CO – 1.3 ppm (1.625 mg/m\textsuperscript{3}). The NOx emissions exceed the annual draft air quality standard of 0.1 ppm and the World Bank standard of 40µg/m\textsuperscript{3}. Exposure to excess NO\textsubscript{2} affect the respiratory system with acute exposures causing inflammatory and permeability responses, decreased lung function, and increases airway reactivity. The CO\textsubscript{2}emission levels observed at the Wandegeya traffic junction were in excess although there is no clear standard for CO\textsubscript{2} emission levels. One of the study areas was the Old Taxi Park that is located in a valley and this implies that the concentration levels must be high and daily exposures pose a health risk to the taxi operators and passengers. This is because of the reduction in air movement preventing the dilution of the emissions and is worsened by the highly raised buildings surrounding the park. More work on the impacts of emissions on public health is required in order to understand and quantify the level of danger.

Vehicle operators were asked whether they were informed on the impact of the vehicle emissions on their health. Out of the 40 surveyed, 95% indicated that this was not their concern. They said that their main worry was how to obtain money to fend for their families. The impact of emissions on their health was viewed as a long term outcome that is superseded by the need to take care of today’s needs. 20 operators indicated that at the end of a typical work day, they report headaches and chest congestion. However this needs to be examined further to obtain conclusive results.

5.3 Mitigation methods

There are several possible mitigation methods that can be applied to reduce on the emission level as earlier discussed in the literature review. However, for analysis purposes three mitigation methods were assessed using the LEAP Model. They include; introduction of tail pipe emission standards, improvement in the fuel economy and introduction of hybrid electric vehicles. This does not in any way undermine the role played by other mitigation methods like land use planning, carpooling schemes, alternative fuels and emission trading, among others.

5.3.1 Introduction of Hybrid Electric Vehicles

The LEAP Model indicated that all the three mitigation methods will have a reduction effect on the amounts of emissions from the transport system. Introduction of hybrid electric vehicles will reduce the GWP to19.5 million kg CO\textsubscript{2} equivalent compared to 23.5 million kg CO\textsubscript{2} equivalent in the BAU scenario. The hybrid alternative presents a vehicle with a very low fuel consumption resulting in a great reduction in emissions. However, the analysis did not consider the economic implications of the alternative scenarios. A study by John et al, 2020 on energy impacts of hybrids revealed that the use of Plug–in Hybrid Vehicles (PHEV) could halve gasoline use relative to conventional vehicles. This would have a negative effect on the Hybrid scenario greatly given the current high cost of purchasing a hybrid vehicle compared to the conventional internal combustion engine vehicle. However, hybrid should be competitively priced when all the costs over the life of the vehicle are included. This is because any cost premium is likely to be offset by fuel savings.

5.3.2 Introduction of tail pipe emission standards

The results indicate that the introduction of tail pipe emission standards will reduce on the overall amounts of emissions from the transport sector in Kampala. It was observed that introduction of tail pipe emission standards would have the greatest impact on reducing the GWP to 11.5 million kg CO\textsubscript{2} equivalent in 2030 compared to 23.5 million kg CO\textsubscript{2} equivalent in the BAU scenario. The lack of tail pipe
emission standards in the country has resulted into an unregulated industry. In order to achieve desired emission standards new vehicles have to be fitted with emission control devices such as catalytic converters or particulate traps or requiring such devices to be retrofitted to existing vehicles. An introduction of tail pipe emission standards in Tokyo in 2003 resulted in a tremendous decrease in emissions as reported by Daniel et al, 2008 in a study that assessed the air quality impacts of Tokyo’s diesel emission regulations. A 30% and 20% reduction in NOx and CO emissions respectively was realized. South Africa introduced emission standards for new passenger car models with effect from 2006. As from 2008 all new vehicles sold needed to comply with EURO 2 vehicle emission standards.

Vehicle owners should be encouraged to carry out maintenance on any installed emission control devices as required by the manufacturer, and the service industry regulated to perform this maintenance properly. There is need for an Inspection and Monitoring Programme (I/M) that would enable the implementation of new emission standards. The IM programme usually consists of a periodic emissions test of in-use vehicles, and is intended to detect and bring about the repair of in-use vehicles with excessive emission levels. For countries with only minimal, if any, controls on vehicles, a simple I/M programme can be a good pollution control starting point as even vehicles with no pollution controls can benefit from improved maintenance. A simple idle check on CO and HC missions from gasoline vehicles or visible smoke check on diesel vehicles can be used to identify the highest polluters and those vehicles which would most benefit from remedial maintenance.

5.3.3 Improved fuel economy standards

Improvement of fuel economy strategy will give a GWP of 21.5 million Kg CO₂ equivalent. Although improvement in fuel economy had the least impact on emissions directly, it resulted into a great reduction in the amount of energy consumed for transportation. Improved fuel economy is achieved through improvement of the vehicle technologies and maintenance. More efficient automobiles fitted with catalytic converters should replace the current second hand vehicles being imported. This will result into expensive cars which most of the population will find hard to get. A tradeoff between a poor environment and health and efficient cars will have to be made. The age range of the Kampala vehicle fleet lies between 6 and 15 years, which presents old vehicles with poor fuel economies resulting in increased consumption of diesel and gasoline.

5.3.4 Increased penetration of city buses

Introduction of city buses as a substitution for some of the minibuses used for public transportation and personal vehicles will result in a great reduction in the level of emissions. This scenario gave a reduction of 22.8 million CO₂ equivalent in the GWP compared to the business as usual scenario. The results showed that this policy option will have a similar impact as the introduction of tail pipe emissions. Simoes et al, 2000 compared the environmental impact of urban buses with standard vehicles and found that while the fuel consumption of standard vehicles is typically 5 times than of the average buses, on a passenger – kilometer basis, the vehicle passenger consumes 2 to 4 times more. This explains the reduction in emissions despite the higher fuel consumption rates of the buses. Simon et al, 2000 established that a passenger standard vehicle has CO emission rates ten times higher than those for an urban bus, but shows the opposite in relation with NOx. The research findings show that public buses will out score the minibuses and personal vehicles in reducing the emission levels and as a result the health and environmental impact.
CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

The main aim of this research was to determine the level of pollution from automobile exhaust gases and impacts on human health in Kampala. The analysis of emissions was done on personal vehicles, motor cycles and motor bikes which constitute 80% of the automobile population in Kampala city. It was discovered that the main types of exhaust gases from the Kampala automobiles are CO$_2$, NO$_x$, CO, NO and HC. The analysis did not include the measurement of particulate matter (PM).

6.1 Conclusions

The findings indicate the level of pollution is high and will continue to grow if left unabated. Tail pipe emission findings estimated the highest level of NO$_x$ emissions at 0.13 mg/m$^3$, HC emissions at 2.59 mg/m$^3$, CO at 110 mg/m$^3$ and 286.6 mg/m$^3$ of CO$_2$. These amounts exceed the proposed draft NEMA ambient air quality emission data and the World Bank ambient air quality guidelines. This implies that persons exposed to these emissions on a daily basis are likely to develop health complications over time as the concentration levels increase. The potential diseases include lung cancer, bronchitis, cardio vascular diseases and neurobehavioral effects.

The reduction in transport emissions can be achieved in two main ways that include reduced consumption of fossil fuels and increased efficiency in transport energy use. Several mitigation methods can be applied to cause a reduction in the emission level. They include;

- Introduction of more efficient automobiles with improved fuel economy.
- Introduction of tail pipe emission standards,
- Designing an integrated transport system with big buses and trains,
- Use of alternative fuels such as biofuels
- Traffic management
- Encouraging alternative modes of transport such as walking and cycling,
- Better land use planning to include expansive roads to avoid congestion
- Car pooling to allow more occupants per vehicle

The LEAP model focused on four scenarios i.e. improvement in fuel economy, introduction of hybrid vehicles, introduction of tail pipe emission standards and increased penetration of city buses. All the above had a positive reduction effect on the level of emission. It was observed that the introduction of tail pipe emission standards and introduction of city buses will have the greatest impact on reducing the emission levels. Introduction of tail pipe emission reduces the GWP by 51% whereas increased penetration of city buses reduced it by 52%. Introduction of hybrid electric vehicles will have the second greatest impact with a reduction of 17% on the GWP. Improvement of fuel economy strategy will give a reduction in GWP by 8.5%. This analysis did not include the cost implications of implementing the proposed policy alternatives.

6.2 Recommendations

Several mitigation methods that can be considered for implementation at policy level to ensure a sustainable transport sector in Kampala have been reviewed. Some mitigation methods are easier to
implement compared to others. The key recommendations below cover practical and easy to implement mitigation methods.

- If emission reduction is to be achieved in Kampala city, it is recommended that a comprehensive motor vehicle pollution control program be designed to implement the proposed NEMA vehicle emission standards. This program will assist in the implementation of the set vehicle emission standards through an inspection and monitoring program.
- Establishment of an integrated transport system should be made priority to enable the decongestion of Kampala city. This would include introduction of buses that would carry more passengers at a time compared to the 14-seater minibuses.
- The country should introduce a limit on the type of vehicles that are imported. Currently, there are no standards, whatsoever, on the vehicle importation.

6.3 Further work

This research has attempted to fill in some of the gaps as concerns emission studies in Kampala city. The biggest achievement has been the characterization and quantification of automobile emissions in Kampala city. However, there are several areas that were not addressed and they are discussed below.

- The analysis did not examine the economic implications of implementing the different mitigation methods. This would probably change the whole outlook in terms of cost effectiveness of the proposed methods.
- A sensitivity analysis for the different scenarios is required to understand the impact of variations in the parameters used such as the automobile growth rates.
- There is need for extra research work to assess the health impact of motor vehicle emissions on peoples’ health. This would involve a program that monitors peoples’ health over time when exposed to different concentration levels.
- This work can be further expanded to cover the whole country and include all vehicle types. However, this would not alter the findings much given that 80% of the vehicles are located in Kampala City.
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## APPENDICES

### Appendix I: Table showing detailed data from the vehicle gas analysis experiments

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<th>D.O.M (km)</th>
<th>Fuel Type</th>
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<th>O₂ (mg/m³)</th>
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## Appendices

### Appendix 2: Results of detailed analysis from motor cycles.

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Appendices

Appendix 3: The life cycle profile for motor cycles as used in the LEAP model

Appendix 4: GWP resulting from the growth in minibuses
Appendix 5: GWP resulting from growth in personal vehicles

Environment: Global Warming Potential - Personal vehicles
Fuel: All Fuels, GHGs: All GHGs

Appendix 6: GWP resulting from the growth in motor cycles

Environment: Global Warming Potential - Motor bikes
Fuel: All Fuels, GHGs: All GHGs
Appendices

Appendix 7: Questionnaire for Motorists

Dear Respondent,

Your response to the following short questions about your vehicle will be highly appreciated. Please tick besides the appropriate answer or fill in the space where necessary.

1. How did you purchase your car?
   a). Brand new car
   b). Used car from the bond
   c). Already registered

2. How long have you had your car?
   a). 1 – 2 years
   b). 3– 4 years
   c). 5- 8 years

3. What is your vehicle mileage?

4. How often do you take your car for servicing?
   a). Rarely
   b). Sometimes
   c). Often

5. What fuel type do you use often?
   a). Gas Oil (Diesel)
   b). Petrol

6. How much do you spend on fuel
   a) Per day? .................................................................
   or
   b) Per week? .............................................................
   or
   c) Per Month? ...........................................................

7. Do you know about the impact of emissions on humans?
   a). Yes
   b). No

8. Are you willing to participate in any measures aimed at reducing vehicle emissions in Kampala city?
   a). Yes
   b). No

"A healthy population and a healthy environment are a social good and an economic good. We cannot think of a healthy population without a healthy environment and ecosystems."

Klaus Töpfer, Executive Director, UNEP