ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
School of Mechanical, Chemical and Materials Engineering

Investigation on Emission Caused by the Engines of Gasoline and Diesel Fueled vehicles: A case of Adama Town

A thesis submitted in partial fulfillment of the requirements for the award of Degree of

Master of Science

in

Automotive Engineering

By

Solomon Neway

Major Advisor: Dr. Suresh G. Associate Professor

Department Of Mechanical and Vehicle Engineering

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Adama

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Approved by

______________________________	__________	__________
Advisor	Signature	Date

CANDIDATE'S DECLARATION

I hereby declare that the study thesis work which is being presented in the paper entitled "**Investigation on Emission Cased by the Engines of Gasoline and Diesel Fueled Vehicles"** in partial fulfillment of the requirements for Graduate Independent Thesis of the degree of master of science in Automotive Engineering is an authentic record of my own work carried out from July 2015 to January 2015 under the supervision of Dr.Suresh G. Associate Professor, Department of Mechanical and Vehicle Engineering, Adama Science and Technology University, Adama, Ethiopia.

The matter embodied in this paper has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this paper have been duly acknowledged.

Name: Solomon Neway Signature: _________________

Place: Adama Science and Technology University, Adama

Date of Submission: January 03, 2016

This is it to certify that the above declaration made by candidate is correct to the best of my/ our Knowledge.

___________________ ____________________

D.r Suresh G. (Associate Professor) Date

(Advisor)

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DEDICATION

To my wife Shewabiru Haile Michael, our daughter Mebatsion Solomon and son Nahusenay Solomon

ACRONYMS AND ABBREVATIONS

ARAI	Automotive Research Association of India
CNG	Compressed Natural Gas
CARB	California Air Resources Board
ECS	Emission Control Systems
EGR	Exhaust Gas Re-circulation
EPA	Environmental Protection Authority
FID	Flame Ionization Detector
FTIR	Fourier Transformation Infrared
GHG	Green House Gases
GVWR	Growth Vehicle Weight Ratio
GWP	Global Warming Potential
HFC	Hydro Fluor Carbon
HiTAC	High Temperature Air Combustion
ICE	Internal Combustion Engine
IPCC	Intergovernmental Panel on Climate Change
IEA	International Energy Agency
I/M	Inspection and Monitoring Programme
LCD	Liquid Crystal Display
LNG	Liquid Natural Gas
LSD	Low Sulphur Diesel
NAS	National Academy of Sciences
NDIR	Non-Dispersive Infrared
NDUV	Non- Dispersive Ultra -Violate
NEMA	National Environmental Management Authority
NMVOC	Non- Methane Volatile Organic Compounds

PAH	Poly Aromatics Hydro carbon
PCV	Positive Crank Ventilation
PFC	Per- Flours- Carbon
PM	Particulate Matter
PSIP	Periodic Smoke Inspection Programme
PTI	Periodic Technical Inspection
RVG	Reactive Organic Gas
RVP	Reid- Vapor Pressure
SEI	Swedish Environmental Institute
SF6	Sulphur Hexafluoride
STP	Standard Temperature and Pressure
TED	Technology Environmental Database
TOG	Total Organic Gas
ULSD	Ultra- Low Sulphur Diesel
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate change
UNIDO	United Nations Industrial Development Organization
VOC	Volatile Organic Compound
WHO	World Health Organization

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ABSTRACT

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. 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. Adama is one of the old cities in Ethiopia and it is at a distance of 100 km from capital city of Addis Ababa, Ethiopia. Most of heavy duty truck vehicles in the country are across Adama because of it is corridor of import and export. The general objective of this study is to investigate emission caused by the engines of gasoline and diesel fueled vehicles in Adama. The measured vehicle emissions have been analyzed in detail. It found that emissions like CO, NO_x, HC, PM and CO_2 levels are higher than worldwide standards for human and environmental health. The findings indicate the level of pollution is high and will continue to grow if left unabated. Tailpipe emission findings estimated the highest level of NO_x emissions at 3.44 g/km, HC emissions at 6.53 g/km, CO at 13.9 g/km, $PM_{2.5}$ at 1.3 g/km and 35.96 g/km of CO_2. These amount of emission 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. Several mitigation methods can be applied to reduce the emission level such as reduce consumption of fossil fuels and increase efficiency in transport usage of energy. This study confirms that exhaust gases from vehicles pollute Adama's air, and that improperly maintained vehicles contribute significantly to this pollution. 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 should be made priority to enable the decongestion of Adama city.

Key Words: *Greenhouse effect, climate change, mitigation and vehicle emissions standard*

1. INTRODUCTION

1.1 Background of the study

Emissions of many air pollutants have been shown to have variety of negative effects on public health and the natural environment. Emissions that are principal pollutants of concern include: hydrocarbons, carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter, sulfur oxide (SO_x), volatile organic compounds (VOCs). Hydrocarbons are toxins. Hydrocarbons are a major contributor to smog, which can be a major problem in urban areas. Carbon monoxide poisoning is also a major killer. By 1964, most new cars sold in the U.S. were so equipped, and positive crank ventilation (PCV) quickly became standard equipment on all vehicles worldwide [1].

Air pollution and cars were first linked in the early 1950's by a California researcher who determined that traffic was to blame for the smoggy skies over Los Angeles. At the time, typical new cars were emitting nearly 13 grams per mile HC, 3.6 grams per mile NO_x, and 87 grams per mile CO [2].

Emission levels are dependent upon many parameter including vehicle-related factors such as model, size, fuel type, technology level and mileage, and operational factors such as speed, acceleration, gear selection, road gradient and ambient temperature [3]. The power to move a car comes from burning fuel in an engine. Pollution from cars comes from by-products of this combustion process (exhaust) and from evaporation of the fuel itself [1]. Similarly, Ford Motor Company Chemistry Department Research Staff has instrumented a 1992 Aero star van with Fourier transform infra-red instrumentation to measure approximately 20 species of emissions (e.g., CO, CO_2, methane, total HCs and so forth) at high time resolution while on the road [4]. Diesel engines while they have many advantages, they also have the disadvantage of emitting significant amounts of particulate matter (PM) and the oxides of nitrogen (NO_x) and lesser amounts of hydrocarbon (HC), carbon monoxide (CO) and toxic air pollutants [5].

In the last century, the level of CO_2 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 °C by 2100 [6]. 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 CO, HCs, and NO_x emissions from fossil fuel combustion come from internal combustion engines (ICE). The contribution of the transport sector to total CO_2 emissions in developed nations is forecast to increase from 20% in 1997 to 30% in 2020 [7]. The transport sector accounts for almost all the oil demand growth around the world. The world transportation oil demand has continuously risen with increasing Gross domestic product (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 [8]. 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 [3].

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 international energy agency (IEA) show that road vehicle energy use would still rise between now and 2030 at 1.4% per annum respectively [8]. 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 NO_X, CO, PM, and HCs [9]. 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 NO_x 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 [9].

The most affected group is the urban inhabitants especially the traffic policemen who are exposed to the fumes for a long period of time [10]. Steerenbeg et al, 2001 compared children attending a school located near a busy way in Utrecht, Netherlands (mean black smoke levels; 53 g/m^3) with children attending a school located in the middle of a green area (mean black smoke levels; 18 g/m^3) 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 [5]. 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 [11].

Adama is one of the old cities in the Oromia region and has city administration consisting of 14 urban and 4 rural kebeles. The city is located in Oromia National Regional State, East Shewa Zone at a distance of 100 km from Addis Ababa. Its astronomical location is 8º44’ North Latitude and 39º04’ East Longitude. Population projection values of 2014 at zonal and wereda levels by urban and rural resident based on figures from the central statistical agency, has an estimated total population of 190,385. Adama is exhibiting high social, economic, structural and change is found to be a fast growing city. Taking into account, Adama fast growth and to enable the transport sector to play its required role, the government has invested a huge resource to construct express way roads Addis to Adama so as to expand the road network. An effort has been made to improve the transport service provisions [12]. There is no integrated planning between agencies of the environmental protection and transport sector. The absence of coordination and symbiosis in implementing the laws and regulations pertinent to environment protection and transport sectors, as well as gaps in improving quality of fuel used in the transportation sector is also a main problem.

The city widely suffers from high levels of traffic congestion leading to ambient air and noise pollution due to vehicular emissions. Air and noise pollution in particular has a negative effect on health, pollution from decrepit vehicles is also a major problem to the city.

Moreover, there also exist no proper provisions in the scope of new infrastructure development and maintenance. This is particularly true in projects relating to road construction and maintenance. The lack of such adequate environmental related provisions creates adverse effects on the environment. Degradation of the environment due to these factors reduces the quality of life of the people and it has become imperative to enforce more stringent environmental control on the projects. Though the use of renewable fuel (blended to gasoline) is gaining acceptance and is to be encouraged, the use of HC especially petrol and diesel fuels still remain the cause for environmental pollution in the Ethiopia city.

Most of heavy duty truck vehicles in the country run across Adama city because of it is a corridor of import and export. With increase in annual vehicle registration and a population growth of over the year, the number of trucks continues to grow exponentially in Adama City. The population in Adama is steadily increasing resulting in signs of environmental stress characterized by poor air quality, excessive noise, traffic congestion and loss of green areas. Many stresses, especially from transport, are increasingly leading to deterioration in the quality of life and human health. The city taxi parking area and its surroundings are congested with vehicles that emit great amounts of fumes whose imminent danger has not been analyzed. A clear understanding of the looming dangers of increased vehicle numbers on the air quality needs to be established [13].

1.2 Statement of problem

Currently, most transport related emissions are concentrated in urban areas which account for the largest share of on-road transport energy consumption. This research focused on the emissions from vehicle in Adama city, Ethiopia. However, stationary units such as generators, construction equipment, refrigerant leakages, etc, also contribute significantly to the emissions levels.

- ✓ Most of the vehicles used in Adama 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.
- ✓ Ethiopia does not have an air quality management system and the few existing data on air pollution has been obtained through measurements done on an adhoc basis.
- ✓ Ethiopia, being a developing country it is not in a position to take these pollution adverse effects or the climate change because of lack of technology and institutional as well as financial capacities. Controlling pollution from the transport sector is vital factor to be taken seriously to improve the public health.

1.3 Objectives of the study

1.3.1 General objective

The general objective of this study is to investigate emission caused by the engines of gasoline and diesel fueled vehicles in Adama.

1.3.2 The specific objectives of the study

The specific objectives are as follows:

i. To gather the data related to gasoline and diesel light vehicles in Adama City.
ii. To measure the exhaust emissions like HC, CO, CO_2 and NO_x from gasoline vehicles.
iii. To measure particulate matter from diesel vehicles.
iv. Finally, to propose appropriate mitigation methods in the transport sector to reduce air pollution in the City.

1.4 Significance of the study

This research looks into different methods systematically to measure and derive vehicle emissions factors. The results of the review provide guidance to researchers and practitioners in assessing appropriate methods to derive vehicle emission factors under their specific resource and skill constraints. This work produces a comprehensive set of on road direct vehicle emission data for the test vehicles. This data set is very useful in constructing or modifying emission models. This is also helps in drawing the relationships between direct emission and vehicles characteristics. These observations are also very useful for the government in formulating policy and measures to control vehicle emissions.

1.5 Scope of the study

In order to properly investigate the contribution of vehicle fuel to emission, a detail analysis is required for each fuel types. However, in this study the analysis was focused on tail pipe emission from gasoline and diesel vehicles without much consideration of emissions that occur during fuel supply.

Emissions in a vehicle are a result of both combusted and evaporating fuels. These studies were assessing the level of emission from combustion only. The assessment were includes CO_2, CO, HC, NO_X and PM. However, during assessment HC, CO were measured from gasoline fueled vehicles based on California BAR-90 standard, NO_x was measured from gasoline fueled vehicles based on Indian ARAI, 2011 standard at free acceleration, CO_2 was conducted from Gasoline fueled vehicles with reference to IPCC, 2007 standard on idle/2500rpm and PM was measured from diesel fueled vehicles based on California CARB-1990 at full acceleration.

The transport fleet in Adama comprises of a range of vehicles type including public buses, public mini buses, trucks, pickups, private motor vehicles, tricycles, motor cycles and others. Private motor vehicles, mini buses, public buses and tricycles are the most dominant. In conducting this research, it is considered only both gasoline/diesel fueled mini buses (taxi) and three wheelers due to constraint. The long- route light -duty mini buses were not considered in this study, which are increasingly growing in number.

1.6 Limitation of the study

Only particulate matter emission from diesel vehicles was measured, but other pollutants from diesel vehicles were not measured due to non-availability of exhaust gas analyzer. It was very tough task to convince the drivers to stop and get their vehicles tested. Shortage of time and insufficient fund also limited the work.

1.7 Organization of the study

This thesis is organized in to six chapters. The first chapter deals with the introduction and background of the study. The second chapter focuses on the literature review. Third chapter includes Method and Materials, Fourth chapter deals with methods in determination of vehicles emission and contribution to urban air, fifth Chapter includes Results and discussion of the findings of the research. Finally, Conclusion and recommendation are given in the last chapter,

2. LITERATURE REVIEW

2.1 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, SO_x, NO_x, 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 [14].

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 NO_x, 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 [15] [14]. NO_x and CO is formed during the combustion process and is 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 [15].

2.2 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 NO_x, CO, Non-Methane Volatile Organic Compound (NMVOC), (HFCs) and Sulphur Dioxide (SO_2, Some GHGs such as CO_2 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 CO, NO_x, total organic gases (TOGs) or Reactive Organic Gases (ROGs) more commonly known as volatile organic compounds, VOCs), PM_{10} and CO_2. The VOC and NO_x 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 [5]. The direct greenhouse gases have different effectiveness in radioactive forcing. This can be determined by comparing their Global Warming Potential (GWP). GWP is a means of providing a simple measure of the relative radioactive effects of the emissions of the various gases. The index is defined as the cumulative radioactive forcing between the present and a future time horizon expressed relative to that of CO_2. It is necessary to define a time horizon because the gases have different life times in the atmosphere. Methane and Nitrous Oxide have a greater GWP than carbon dioxide as shown in Table 1 [6].

Table 1: Global Warming Potential defined on a 100-year horizon.

GHG	GWP
Carbon Dioxide	1
Methane	21
Nitrous Oxide	310
HFCs	140-11,70
PFCs	6,500-9200
SF6	23,900

The main sectors contributing to emission levels include energy, Energy supply, industry, Forestry, agriculture, Transport, residential and commercial building and waste and waste water. The Energy supply sector currently accounts for 26% of the CO_2 emission as shown in the Figure 1. Many forms of transportation create GHG (including CO_2) emissions, both direct and indirect. Transport is one of the major contributors to air pollution problems at the local, region and global levels contributing 13% of the global carbon dioxide emissions. 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 (CO_2 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 [16].

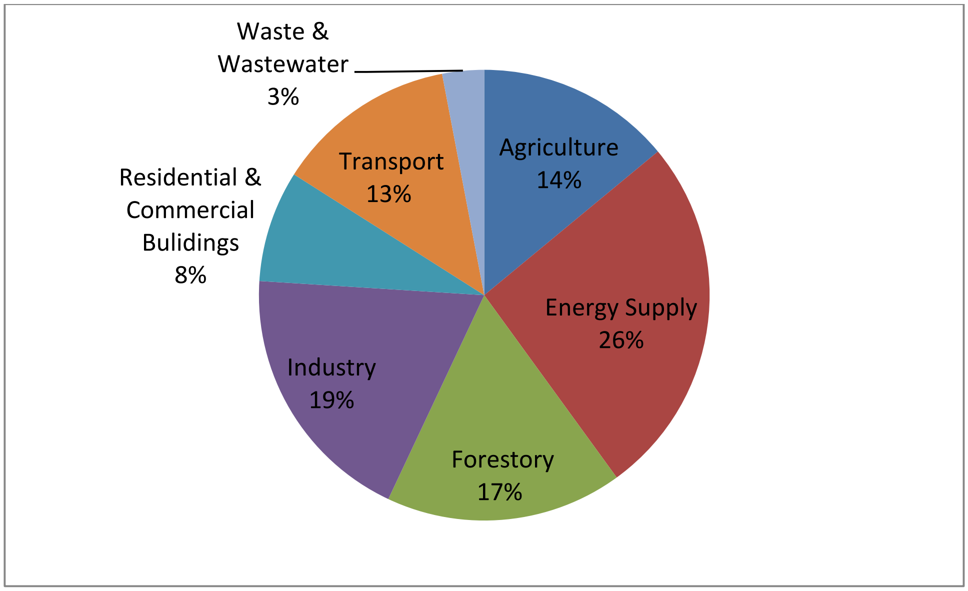


Figure 1: Global share of CO2 emission by sector

2.3 The Kyoto Protocol

Recognizing 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 industrialized 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 [17].

At present the Kyoto countries are negotiating the second phase of the agreement, covering the period from 2013-2017. Greenpeace is calling for industrialized 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 counties commit to nationally appropriate mitigation actions, implying that they are not required to meet any specific targets. 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 UNFCC conference that was held in Denmark, Copenhagen in 2009 [17].

2.4 The Combustion Process

Most vehicle fuels (gasoline, diesel, natural gas, ethanol, etc.) are mixtures of hydrocarbons, compounds that contain hydrogen and carbon atoms. In a "perfect" engine, oxygen in the air would convert all of the hydrogen in fuel to water and all of the carbon in the fuel to carbon dioxide (carbon mixed with oxygen). Nitrogen in the air would remain unaffected. In reality, the combustion process is not "perfect," and automotive engines emit several types of pollutants:

a. "Perfect" Combustion Process:

> FUEL (hydrocarbons) + AIR (oxygen and nitrogen) = Carbon dioxide (CO_2) + Water (H_2O) + Nitrogen

b. Typical Real-World Engine Combustion Process:

> FUEL (Hydrocarbons) + AIR (Oxygen and Nitrogen) = Unburned or Partially Burned Hydrocarbons (VOCs) + Nitrogen Oxides (NO_x) + Carbon Monoxide (CO) + Carbon Dioxide (CO_2) + Water (H_2O)

2.5 Sources of Emissions in Vehicles

The power to move a car comes from burning fuel in an engine. Pollution from cars comes from by-products of this combustion process (exhaust) and from evaporation of the fuel itself.

2.5.1 Exhaust Pollutants

- **Hydrocarbons (HC):** Hydrocarbon emissions result when fuel molecules in the engine do not burn or burn only partially.
- **Nitrogen oxides (NO_x):** Under the high pressure and high temperature conditions in an engine, nitrogen and oxygen atoms in the air we breathe react to form various nitrogen oxides, collectively known as NOx.
- **Carbon monoxide (CO):** Carbon monoxide is a product of incomplete combustion and occurs when carbon in the fuel is partially oxidized rather than fully oxidized to carbon dioxide.
- **Carbon dioxide (CO_2):** Carbon dioxide does not directly impair human health, but it is considered a "greenhouse gas". In other words, as it accumulates in the atmosphere, it is believed to trap the earth's heat and contribute to the potential for climate change.

2.5.2 Evaporative Emissions and Control

Gasoline is a relatively volatile fuel. Even at normal temperatures, significant gasoline evaporation occurs if gasoline is stored in a vented tank. The most common measure of gasoline volatility is the Reid vapor pressure (RVP), which is the vapor pressure measured under standard conditions at an air-to-liquid ratio of 4:1 and a temperature of 37.8ºC. Gasoline volatility is normally adjusted to compensate for variations in ambient temperature. When temperatures are below freezing 0ºC, gasoline is usually adjusted to an RVP of about 90 kPa (13 psi) to increase fuel vaporization. This level of volatility would cause vapor lock in vehicles at temperatures exceeding 30ºC. At these temperatures, gasoline RVP is ideally kept below 70 kPa (10 psi). Gasoline with an RVP of 75 kPa (11 psi) will produce about twice the evaporative emissions of gasoline with an RVP of 60 kPa (8.7 psi). The four primary sources of evaporative emissions from vehicles are diurnal (daily) emissions, hot-soak emissions, resting losses, and running losses. Diurnal and hot-soak emissions have been controlled for some time in the United States, and such controls were included in the Consolidated Emissions Directive adopted by the European Community in 1991.

Evaporative emissions are controlled by venting the fuel tank (and, in carbureted vehicles, the carburetor bowl) to the atmosphere through a canister of activated charcoal. Hydrocarbon vapors are adsorbed by the charcoal, so little vapor escapes to the air. The charcoal canister is regenerated or "purged" by drawing air through it into the intake manifold when the engine is running. Adsorbed hydrocarbons are stripped from the charcoal and burned in the engine.

Hydrocarbon pollutants also escape into the air through fuel evaporation. With today's efficient exhaust emission controls and today's gasoline formulations, evaporative losses can account for a majority of the total hydrocarbon pollution from current model cars on hot days when ozone levels are highest. Evaporative emissions occur several ways:

- **Diurnal*:*** Gasoline evaporation increases as the temperature rises during the day, heating the fuel tank and venting gasoline vapors.
- **Running losses*:*** The hot engine and exhaust system can vaporize gasoline when the car is running.
- **Hot soak:** The engine remains hot for a period of time after the car is turned off, and gasoline evaporation continues when the car is parked.
- **Refueling:** Gasoline vapors are always present in fuel tanks. These vapors are forced out when the tank is filled with liquid fuel.

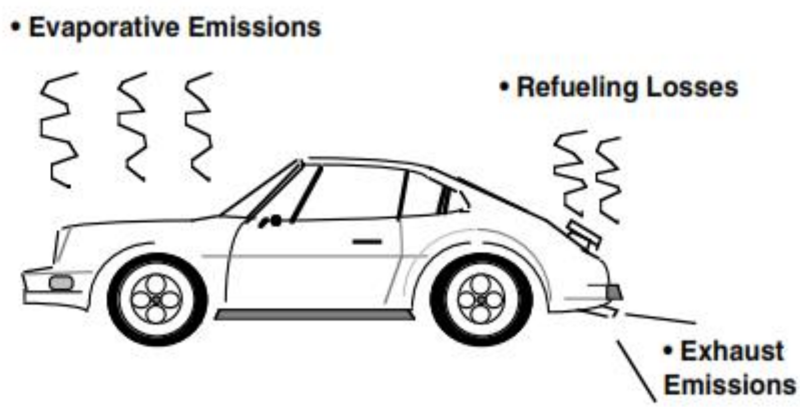
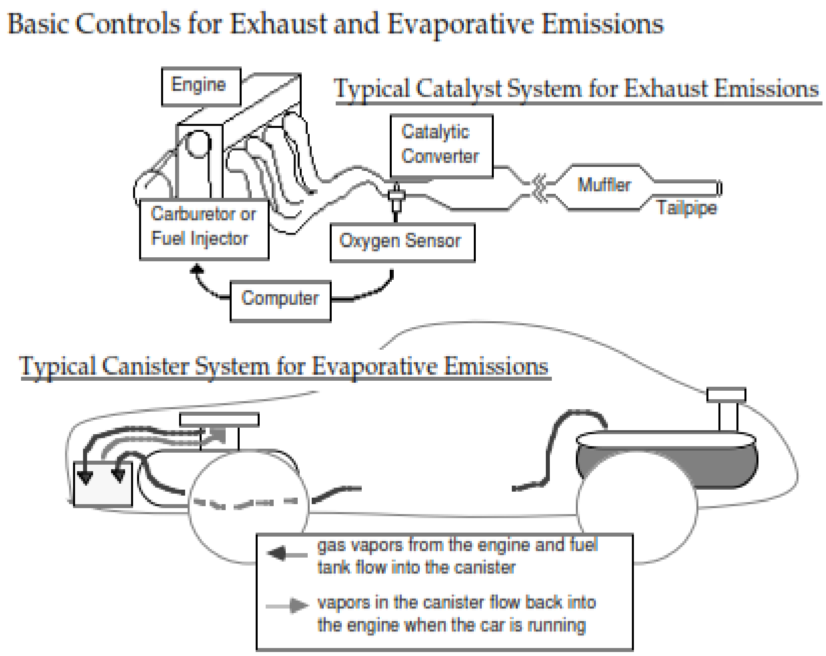


Figure 2: Source of emission

Fuel Dispensing/Distribution Emissions

As with evaporative emissions, emissions from fuel distribution are significant only for vehicles using volatile fuels, such as gasoline. These emissions result from fuel vapor contained in the headspace of the vehicle fuel tank. This vapor is displaced as fuel is added during refueling. Vapor emissions also occur when the service station tank is refilled from a tank truck, and when the tank truck is refilled at the bulk terminal. Sources and magnitude of hydrocarbon vapor emissions from gasoline distribution and dispensing are shown in figure 3. Technology to reduce gasoline distribution emissions involves two types of controls. One method controls vapors displaced from the receiving tank by venting them to the delivery truck tank. This is known as and is about 95 percent effective, reducing vapor emissions from 1.14 grams per liter dispensed to 0.06 grams per liter. International experience shows that the cost of retrofitting fuel storage tanks, delivery trucks, and service stations with vapor recovery devices is small and the payback period based on the benefit of fuel savings alone, is two to three years. Two alternatives are available to control fuel vapors displaced from *Stage I* control). One alternative are modifying the gasoline dispensing system to capture vapors. The other alternative captures vapor on board the vehicle in a charcoal canister similar to that used for controlling evaporative emissions [18].



Stage II

Figure 3: controlling methods of emission

2.5.3 Crankcase Emissions and Control

The blow by of compressed gases past the piston rings consists mostly of unburned or partly burned hydrocarbons. In uncontrolled vehicles, the blows by gases were vented to the atmosphere. Crankcase emission controls involve closing the crankcase vent port and venting the crankcase to the air intake system via a check valve. Control of these emissions is no longer considered a significant technical issue.

2.6 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 [19].

2.6.1 Carbon dioxide

While CO_2 is non-toxic, its main environmental effect is as a greenhouse gas. Each year an estimated 30 billion tons of CO_2 are emitted due to human activity, 2% of which originates from the United Kingdom. To illustrate the scale of impact of these emissions as a result of human activates, the atmospheric concentration of CO_2 (from all sources) has increased by 31% since 1750. By enhancing the greenhouse effect, greenhouse gas emissions are leading to increase of the Earth's atmospheric, land and sea temperatures. During the 20^{th} century the global average surface temperature 9th average of near surface air temperature over land and sea surface temperature) increased by 0.6 9+/-0.2) degree Centigrade

2.6.2 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 hemoglobin in the red blood cells [20]. 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 [21].

2.6.3 Nitrogen Oxide

NO_x 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. NO_x is categorized into three types that include; thermal NO_x, fuel NO_x and Prompt NO_x [22].

Thermal NO_x is formed by the oxidation of N_2 at high temperatures of about 1300K. The thermal NO_x 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. The second category called fuel NO_x is formed from the oxidation of nitrogen present in fuels. This is relatively independent of temperature at normal combustion temperatures. The third category, prompt NO_x, is formed by the reaction of hydrocarbon fragments with atmospheric nitrogen to yield products such as HCN and H_2CN. The products are subsequently oxidized to NO in the lean zone. NO can further react with oxygen to form NO_2 or N_2O. NO_2, along with volatile organic compounds, (VOCs), is a precursor of ground-level ozone and other photochemical pollutants [23]. Exposure to NO_x 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.

2.6.4 Tropospheric Ozone

The most important pollutants that play a role in the formation of tropospheric ozone include nitrogen oxides (NO_x) and volatile organic compounds (VOCs) as well as, to a lesser but still significant extent, methane and carbon monoxide. The pace of photochemical reactions forming ozone in the atmosphere depends on solar radiation and temperature. Inside and close to urban areas, ozone concentrations may be depressed because of reactions with NO_x but further downwind (in rural areas) both NO_x and VOCs tend to promote ozone formation. Emissions of NO_x occur in the most densely populated areas, particularly in north Western Europe. On the other hand, VOC emissions are more evenly distributed in Europe, the main anthropogenic sources being traffic and solvent use.

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 g/m3 (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 g/m^3 (0.05-0.06 ppm) is recommended [24].

2.6.5 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 [25].

2.6.6 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, tire wear, brake linings and suspension of road dust. PM is emitted directly (primary emissions) or formed in the atmosphere by conversion of gaseous precursors that is, nitrogen oxides, sulphur 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 manometers to tens of micrometers. Particles smaller than 1im have a number concentrations in the range of 100 —100 000 per cm^3, while those exceeding 1im 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. Particles larger than 10im 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 [26].

There is limited data on emissions or concentrations of PM as a result of energy usage in the transport sector. However, 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 lm) and PM_{10} (aerodynamic diameter 610 lm) are associated with a range of adverse health effects, including increased illness, hospitalization, and higher mortality rates [27]. The WHO limits on concentration for PM_{10} and $PM_{2.5}$ are 150 g/m^3 and 65 g/m^3, respectively. Table 2 summarizes the different impacts of different emissions types on human health.

Table 2: Summary of the impact of different emission types on human health

Health Outcome	Pollutant	Evidence	Comments
Mortality	Black smoke Ozone $PM_{2.5}$	Non	Non experimental studies
Respiratory diseases	Black smoke Ozone Nitrogen dioxide VOCs	Strong Strong	Strong experimental for inflammatory effect
Cardio Vascular diseases	Black smoke	Some	Smoke experimental for cardiovascular effect
Reproductive outcome	NO_2 CO SO_2 Total suspended particles	Some	Non

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.

2.7 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 analyzed 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. 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 morality from lung cancer indicating that exposure to diesel exhaust may have contributed to the observed increased risk of lung cancer [28].

A study was conducted in Rome where the mortality pattern of taxi drivers exposed to vehicle exhaust was analyzed [29]. An increase in lung cancer was observed. However, owing to statistical uncertainly, the result did not clearly indicate the association between the risk of lung cancer and exposure to vehicle exhaust among the taxi drivers. Compared the mortality in a cohort of petrol station attendants with that in the regional population. The data analysis indicated some increased risks in esophageal 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 number of sales of petrol per full time employee [30].

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 [31].

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.

2.8 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 re-suspended road dust. Emission levels depend on five major factors that are categorized as traffic characteristics, road characteristics, engine design characteristics, vehicle non- engine Components and fuel quality.

2.8.1 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 tire 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 [32].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.

2.8.1.1 Air /Fuel Ratio and Mixture Preparation

The air/fuel ratio has a significant effect on all three major pollutants (CO, HC and NO_x) from gasoline engines. In fact, CO emissions are almost totally dependent on air/fuel ratio whereas HC and NO_x emissions rates can be strongly influenced depending on other engine design parameters. For diesel vehicle, HC emissions have a dependence on the equivalence ratio that is defined as actual fuel verses air [33].

$$\emptyset = \frac{\left(\frac{mf}{ma}\right) actual}{\left(\frac{mf}{ma}\right)} \qquad (1)$$

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, NO_x emissions increase as air/fuel mixtures are enplaned up to the point of maximum or peak thermal efficiency; beyond this point, further enplanement can result in lower NO_x emission rates.

2.8.1.2 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.

2.8.1.3 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 NO_x 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 NO_x 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 [34].

2.8.2 Vehicle Non - Engine Components

2.8.2.1 Tires

Pneumatic tires 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 tire repeatedly deforms and recovers during its rotation under the weight of the vehicle. Energy is dissipated when a tire is deformed due to rubber hysteretic losses behavior. This phenomenon is called rolling resistance. About 20% of a motor vehicle's fuel is estimated to be used to overcome rolling resistance of tires. Globally, tires are responsible for an estimated 300 Mt CO_2 energy consumption and 800 Mt CO_2 emissions [34]. Additional fuel is required when tires are under-inflated. A study by the IEA revealed that in the EU tires 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 tires have since time immemorial been regarded more of a safety issue than an energy efficiency issue.

2.8.2.2 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.

2.8.2.3 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 Mt CO_2 per year and leads to the emissions of over 1230 Mt CO_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.

2.8.3 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. 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 [35].

2.8.4 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 NO_x were twice as high driving uphill whereas Kean et al, 2003 found that increase in NO_X 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 [36].

2.8.5 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.

2.8.5.1 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 sulphur content of 0.05% for gasoline which is very high. 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 [37].

2.8.5.2 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.

2.9 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 strokes. The two stroke engines produce considerable hydrocarbon and particulate emissions because of air fuel mixture short circuiting and two stroke lubricating oil. Emissions of CO and HC are highest when a motor cycle is in an idling state [38].

2.10 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 typical operating conditions. 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 Thus, the activity data required for emission inventory development would typically be an estimate of total vehicle Km travelled, total fuel consumed, or time spent for emissions process, respectively [39].

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 CO_2, 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 [40].

2.11 Mitigation Measures for Vehicular Emissions

Pollutant emissions from motor vehicles are determined by the vehicle's engine type and the fuel it uses. Spark-ignition and diesel engines are the two most common engines. Most passenger cars and light-duty trucks use spark-ignition (Otto cycle) gasoline engines. These engines are also used in heavy-duty trucks and buses in some countries, including China, Mexico, the Russian Federation and other republics of the former Soviet Union, and the United States. Other fuels used in spark-ignition engines include natural gas, liquid petroleum gas, alcohols, and hydrogen.

Spark-ignition gasoline engines have either a two strokes or four-stroke design. Two-stroke engines are cheaper, lighter, and can produce greater power output per unit of displacement, so they are widely used in small motorcycles, outboard motors, and small power equipment.

Two-stroke engines emit 20 to 50 percent of their fuel unburned in the exhaust, resulting in high emissions and poor fuel economy. Because the crankcase pumps the air-fuel mixture through the engine, two-stroke engines require that oil be mixed with the air-fuel mixture to lubricate bearings and pistons. Some of this oil appears as white smoke in the exhaust, resulting in high emissions of particulate matter.

All gasoline engines currently used in automobiles and larger vehicles use the four-stroke design, although advanced two-stroke engines are being developed. These advances pertain to fuel injection, combustion, and the lubrication system. Advanced two-stroke engines under development would achieve lower emissions and fuel consumption than four-stroke engines and retain the two-stroke's advantages of lower weight and cost per unit of power output.

The main pollutant emissions from spark-ignition gasoline engines are hydrocarbons, carbon monoxide, and nitrogen oxides. Carbon monoxide and nitrogen oxides are only emitted in the vehicle exhaust, while hydrocarbon emissions occur in the vehicle exhaust, the engine crankcase, the fuel system, and from atmospheric venting of vapors during fuel distribution and dispensing.

Particulate matter emissions from gasoline engines are caused by the condensation of oil vapor in the exhaust. These particulate matter emissions are usually small for four-stroke engines. Two-stroke engines and four- strokes with excess oil consumption can exhibit high particulate matter emissions. The use of lead as an antiknock additive in gasoline is being discontinued in many countries for environmental reasons. Where these compounds are still in use, lead aerosol emissions from gasoline engines are the major source of airborne lead in the environment.

Emissions from spark-ignition engines can be reduced through changes in engine design, combustion conditions, and catalytic after treatment. Some of the engine and combustion variables that affect emissions are the air-fuel ratio, ignition timing, and turbulence in the combustion chamber, and exhaust gas recirculation. Of these, the most important is the air-fuel ratio. Engine-out pollutant emissions can be reduced substantially from uncontrolled levels through appropriate engine design and control strategies. This involves tradeoffs among engine complexity, fuel economy, power, and emissions. The use of catalytic after treatment allows a further order-of-magnitude reduction in pollutant emissions and, by reducing the need for engine-out control, an improvement in power and fuel economy at a given emissions level [41].

2.11.1 Air –Fuel Ratio

The air-fuel ratio has an important effect on engine power, efficiency, and emissions. The ratio of air to fuel in the combustible mixture is a key design parameter for spark-ignition engines. An air-fuel mixture that has exactly enough air to burn the fuel, with neither air nor fuel left over, is , and has a normalized air-fuel ratio (*stoichiometric* λ) of 1.01 . Mixtures with more air than fuel are lean, with λ s higher than 1.0; those with more fuel are rich, with λ_s less than 1.0. A mixture with a λ of 1.5 has 50 percent more air than needed to burn all the fuel. Engines using lean mixtures are more efficient than those using stoichiometric mixtures. There are a number of reasons for this, including less heat loss, higher compression ratios (lean mixtures knock less readily), lower throttling losses at part load, and favorable thermodynamic properties in burned gases. Engines designed to burn very lean mixtures λ more than 1.2 (numeric air-fuel ratio of 17.60:1) are *lean burn*. The generalized variation of emissions with air–fuel ratio for a spark-ignition engine is shown in figure 4.

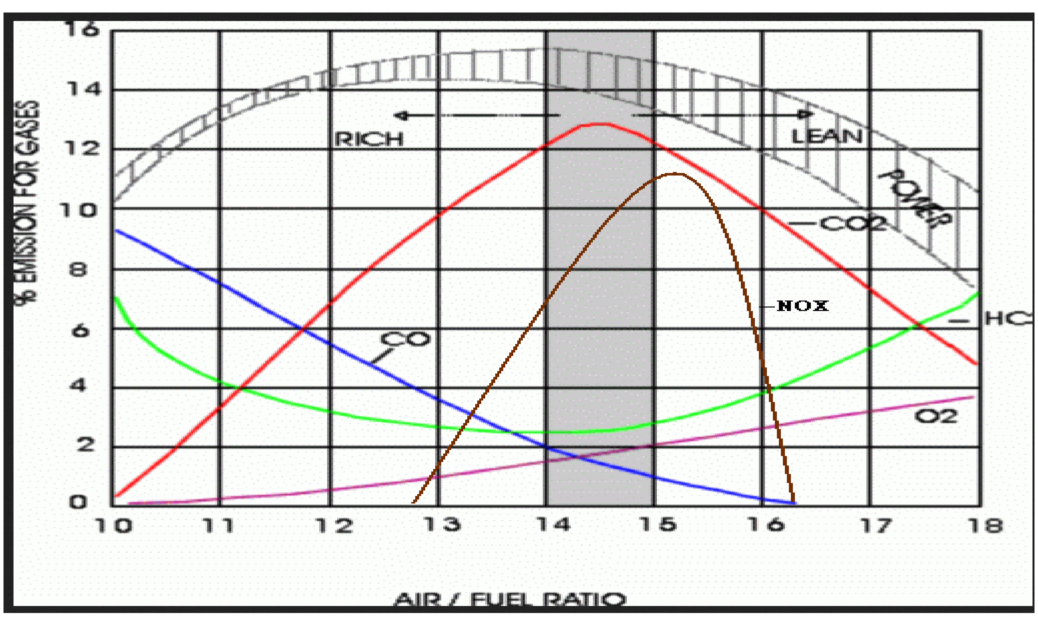


Figure 4: Effect of air- fuel ratio on Spark Ignition Engine Emission

2.11.2 Electronic Control Systems

Electronic control technology for stoichiometric engines using three-way catalysts has been extensively developed. Nearly all engine emission control systems used in the United States since 1981 incorporate computer control of the air-fuel ratio. Similar systems have been used in Japan since 1978 and in Europe since the late 1980s. These systems measure the air-fuel ratio in the exhaust and adjust the air-fuel mixture going into the engine to maintain stoichiometry. In addition to the air-fuel ratio, computer systems control features that were controlled by vacuum switches or other devices in earlier emission control systems. These include spark timing, exhaust gas recirculation, idle speed, air injection systems, and evaporative canister purging.

The stringent air-fuel ratio requirements of three-way catalysts made advanced control systems necessary. But the precision and flexibility of the electronic control system can reduce emissions even in the absence of a catalytic converter. Many control systems can self-diagnose engine and control system problems. Such diagnostics are mandatory in the United States. The ability to warn the driver of a malfunction and assist the mechanic in its diagnosis can improve maintenance quality. Self-diagnostic capabilities are becoming increasingly sophisticated and important as engine control systems become more complex. Computer-controlled engine systems are also more resistant to tampering and maladjustment than mechanical controls. The tendency for emissions to increase over time is thus reduced in computer-controlled vehicles [42].

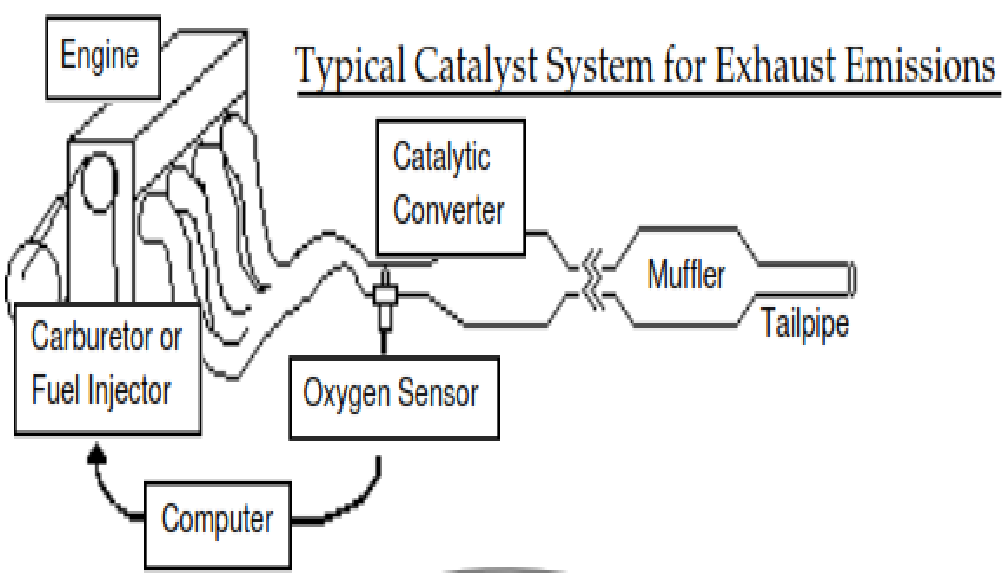


Figure 5: Electronically control emission system

2.11.3 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.

2.11.3.1 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 (NO_x) 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 (CO_2) 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.

The catalytic converter is one of the most effective emission control devices available. The catalytic converter processes exhaust to remove pollutants, achieving considerably lower emissions than is possible with in-cylinder techniques. Vehicles with catalytic converters require unleaded fuel, since lead forms deposits that “poison” the catalytic converter by blocking the access of exhaust gases to the catalyst. A single tank of leaded gasoline, can significantly degrade catalyst efficiency. Sulfur and phosphorous in fuel can also poison the catalytic converter. Converters can also be damaged by excessive temperature, which can arise from excess oxygen and unburned fuel in the exhaust. The catalytic converter comprises a ceramic support, a wash coat (usually aluminum oxide) to provide a very large surface area and a surface layer of precious metals (platinum, rhodium, and palladium are most commonly used) to perform the catalyst function. Catalysts containing palladium are more sensitive to the sulfur content of gasoline than platinum/rhodium catalysts [18]. Two types of catalytic converters are commonly used in automotive engines: oxidation (two-*way*) catalysts control hydrocarbon and carbon monoxide emissions and oxidation–reduction (three-*way two*-*way*) catalysts control hydrocarbons, carbon monoxide, and nitrogen oxides (figure 6). A new type of catalytic converter is the *lean nitrogen-oxide* catalyst, which reduces nitrogen oxide emissions in lean conditions where a three-way catalyst is ineffective.

Two-way catalysts: Oxidation catalysts use platinum, palladium, or both to increase the rate of reaction between oxygen, unburned hydrocarbons, and carbon monoxide in the exhaust. This reaction would normally proceed slowly. Catalyst effectiveness depends on its temperature, the air-fuel ratio of the mixture, and the mix of hydrocarbons present. Highly reactive hydrocarbons such as formaldehyde and olefins are oxidized more effectively than less-reactive ones. Short-chain paraffin's like methane, ethane, and propane are among the least reactive hydrocarbons and are difficult to oxidize.

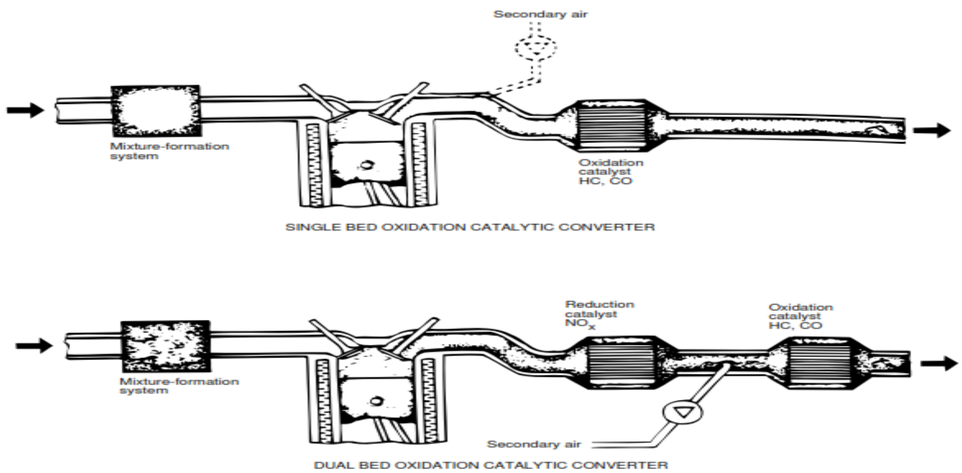


Figure 6: Types of catalytic convertor

Three-way catalysts: Three-way catalysts generally use a combination of platinum, palladium, and rhodium. In addition to promoting the oxidation of hydrocarbons and carbon monoxide, palladium and rhodium promote the reduction of nitric oxide (NO) to nitrogen and oxygen. For efficient NO reduction, a rich or stoichiometric air fuel ratio is required. At optimal conditions a three-way catalyst can oxidize hydrocarbons and carbon monoxide and reduce nitrogen oxides. The window of air-fuel ratios in which this occurs is narrow, and there is a tradeoff between nitrogen oxide and hydrocarbon/carbon monoxide control even within this window. The variation of three-way catalyst efficiency with the normalized air–fuel ratio (λ) is shown in figure 7. To maintain the precise air-fuel ratio required, gasoline cars use exhaust sensors (also known as oxygen sensors) with electronic control systems for feedback control of the air-fuel ratio.

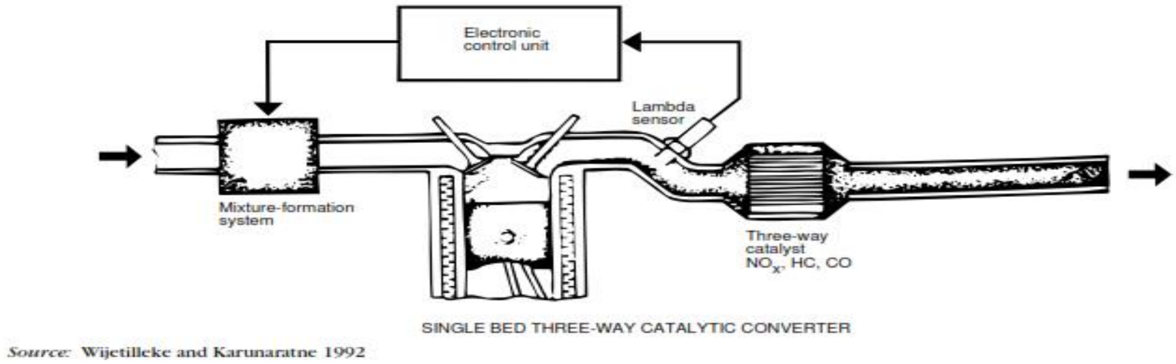


Figure 7: Three way catalytic convertor

Lean nitrogen oxide catalyst: Conventional three-way catalysts are ineffective at reducing nitrogen oxides under lean conditions. This has restricted the use of advanced lean-burn engines in passenger vehicles. Because of their superior fuel efficiency and low carbon monoxide emissions, lean-burn engines are otherwise an attractive technology. Researchers have developed zeolite catalytic materials that reduce nitrogen oxide emissions, using unburned hydrocarbons in the exhaust as the reluctant. Although the lean nitrogen-oxide catalyst is typically about 50 percent effective considerably less than a three-way catalyst under stoichiometric conditions the benefit is still significant. A few Automobile models using lean nitrogen-oxide catalysts have been introduced in Japan.

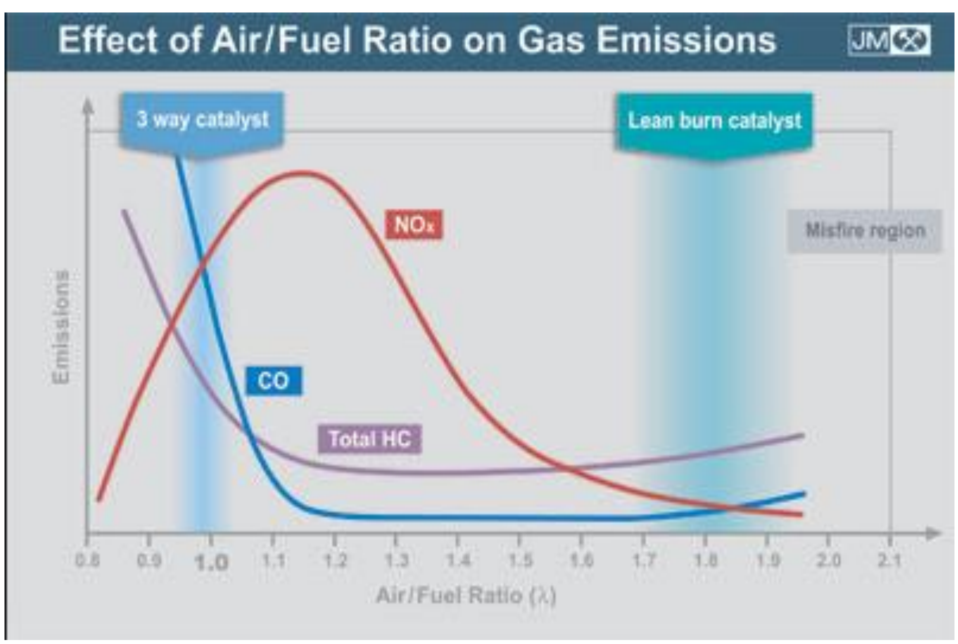


Figure 8: Effect of Air-Fuel Ratio on Three way Catalytic convertor

2.11.3.2 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 NO_x. 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 [41].

2.11.4 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 drivability. 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 Ethiopia'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. Ethiopia phased out leaded gasoline in 2011 and all fuel stations sell unleaded fuel.
- Reducing benzene to reduce air toxics and carcinogenic emissions
- Reducing volatility to reduce evaporative emissions
- Reducing sulphur to improve catalytic converter efficiency and reduce PM

For Diesel:

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

2.11.5 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% [43].

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 NO_X 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 NO_X 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) [14]. 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.

2.12 Ethiopian emission standards

The government of the Federal Democratic Republic of Ethiopia has placed a high premium on the environment. It has established the Environmental Protection Authority (EPA) by the proclamation no 9/1995 with statutory responsibility for overall protection of the environment. The Environmental Policy of Ethiopia was formulated and approved by the government in April 1997.

Implementation of the Policy is the next task that needs to be undertaken. Introducing these standards is part of the implementation of the Policy and the environmental pollution abatement strategy contained therein.

Environmental protection measures are only meaningful if the environment to be protected is adequately understood. Neither overprotection nor under protection of the environment is desirable. Ideally, standards are set based on country specific baseline data and information, which are scanty in the present circumstances. An alternative approach is to adapt the standards of developing countries having similar socio-economic, technological, and climatic conditions.

Ethiopians emission standards were adopted from different countries such as; - standards from the following developing countries have been consulted; Bangladesh, Pakistan, India, Jamaica, China, Thailand, Uganda, Nigeria, Zambia, and Kenya. Information was also obtained from development agencies such as The World Bank, United Nations Environment. Where the standards were deemed relevant and appropriate for Ethiopian conditions they have been adopted, where deemed inappropriate they have been modified on the basis of practical experience. These standards are being introduced to be used throughout the country subject to amendment as more information on the state of pollution is made available. The regional states can establish more stringent standards taking into consideration particular ecological conditions in their localities provided that these present standards are used as the minimum.

The purpose of introducing the standards is to prevent significant industrial pollution by indicating standards which must be observed and by indicating pollution limits beyond which the environment would not tolerate.

The Standards are presented in four parts as follows.

Part 1: Guidance on Interpretation of this Document on Standards

Part 2: Standards for Specified Industrial Sectors

Part 3: General Standards for all other Industrial Effluents

Part 4: Standards for all other Industrial Gaseous Emissions

Part 5: Standards for Noise Limits.

The limit values specified in the document are to apply to the following three types: emission to the atmosphere, emission to water and noise [44].

Table 3: Emission limits from combustion sources

Parameter		Limit value
Total particulates		
	Coal	500 mg/Nm^3
	Fuel oil	250 mg/Nm^3
	Gas	50 mg/Nm^3
Nitrogen oxides (as NO_2)		
	Coal	700 mg/Nm^3
	Fuel oil	1000 mg/Nm^3
	Gas	400 mg/Nm^3
Sulphur oxides (as SO_2)		
	Coal	4300 mg/Nm^3
	Fuel oil	5100 mg/Nm^3
	Gas	100 mg/Nm^3
Carbon monoxide		150 mg/Nm^3
Smoke		2 units on the Ringleman scale

2.13 The transport sector and traffic air pollution in Ethiopia

Ethiopia is currently undertaking huge investments to improve its urban and rural road networks. Ethiopia is currently undergoing rapid urbanization with huge investment in transport sectors with the purpose of increasing the road network and quality of service. The Ethiopian Road Authority report for the year 2014 years indicated that 72% of all national vehicles were automobiles and the overall annual vehicles increase rate was 7.7%. [45]. Of the total 587,453 vehicles in the country in 2014, only 20.5% had less than ten years of service, while nearly 40% were more than 30 years old. Vehicles with 15 years old produce five times more hydrocarbons and four times nitrogen oxides than those of new ones [46]. By the end of 2014 there were 233,084, vehicles nationwide, of which 70% were found in Addis Ababa. Petrol engine users were 56% and 60% in the country sides and Addis Ababa, respectively. The on-road vehicle increase rate in Addis Ababa varied from 4 to 6% per year (about 4000-5000 annually). The traffic volume along major roads is increasing at 20% per year, well above the forecasted level [47].

The increasing street venders, road side shoppers, drivers, commuters, pedestrians, traffic police, and residents within the vicinity of road networks are at the greatest risk to traffic air pollution exposure. According to urban mobility study, 70%, 21%, 8%, and 1% of the total population walk on foot, use public buses, taxis, and private cars, respectively [46]. Nowadays, many streets are over-crowded with pedestrians either waiting for taxis and buses or walking along the foot paths or crossing these streets. Pedestrians sharing the streets are increasing from time to time due to influxes of large population to the city in search of work.

Ambient air pollution assessment on the streets of Addis Ababa is very limited. It was possible to access few study. This study had ambient air sampling on 12 different sites and concluded that the 24-hourly PM_{10} and 8-hr average of CO were below US-EPA permissible levels, while the annual PM_{10} concentrations could exceed the guideline. The study found that the level of

PM10 ranged from 35 to 97µg/m^3 and peak 1-hr average CO concentrations were less than 7 ppm. The hourly average concentration of CO was less than 2 ppm. The studies had limitations in that the samples were limited and were taken at a distance of 50-100 meters away from streets, many of them representing low traffic densities [48].

A rapid assessment using grab sampling of indoor air in rural villages of Ethiopia suggested an excess level of CO, total respirable particulate matter and smoke [49]. Pilot samples in urban and rural settings had also indicated increased concentrations of indoor CO, $PM_{2.5}$ and PM_{10} [50]. The mean concentrations of these pollutants ranged from 640 to 2170 µg/m^3 for $PM_{2.5}$, and from 22.1 to 70.5 ppm for CO, which by large exceeded the international guideline.

The urban infrastructure of Ethiopia is inadequate to accommodate the large and growing number of vehicles. According to the Addis Ababa Road Authority, the city possesses one-land streets of 3.5 to 4.0 meters wide, with an average of 3.5-meter width. The average speed of vehicles in Addis Ababa is about 20-30 km per hour on many roads, especially at peak hours during 7.50-9:00 am and 14:00-19:00 pm [46]. The topography in Addis Ababa has a slope varying between 0.5 and 12% which also affects the speed and use of fuel. Frequent stopping, repeated accelerations and decelerations reduce engine efficiency, and therefore, increase emissions on the road.

3. MATERIALS AND METHODS

3.1 Methodology

Measuring the levels of HC, CO, NO_x, CO_2 and PM concentrations at three selected Adama sites for six days and conducting a roadside vehicle inspection by randomly pulling over in-use vehicles to inspect a representative sample of the Adama three wheelers and minibuses fleet are the two major steps in this study. The inspection included; a visual inspection of the ECS a measurement of their tailpipe exhaust emissions, on selected vehicles. Interviewing the drivers and obtaining responses for questioners distributed.

3.2 Study Area

Adama is one of the old cities in the region and has city administration consisting of 14 urban and 4 rural kebeles. City is located in Oromia National Regional State, East Shewa Zone at a distance of 100 km from Addis Ababa. Its astronomical location is 8º44’ North Latitude and 39º04’ East Longitude [51].

Figure 9: Adama city map

3.3 Data collection Methods

By the end of 2014 there were an estimated vehicles of 71,922 registered in Oromia National Regional state, of which 8% were found in Adama. Three wheelers and minibuses are around 3,642 or 4.82% in Adama [52].

The vehicle parc numbers were obtained from Adama City Administration, Road and Transport Authority. A questionnaire which was aimed at determining the age of vehicles and mileage and peoples’ perceptions on the impact of vehicle emissions was prepared and administered to 50 each minibuses and three wheelers operators. The interviewee sample size was selected based on the availability and co-operation of vehicles operators to respond to the study. The Vehicles were randomly selected based on the age, type and engine model. The experiment was conducted on- road at three areas namely Adama post office, Adama Bus station and Adama Mebrat Haile. Vehicles located in such places were easier to access compared to those in other area. The sample size tested comprised of 20 of vehicles in each types. Totally 240 (24%), vehicles were selected randomly which represents the total population. The emission test was conducted on seven model and 240 different vehicles which includes both categories of gasoline fueled minibus and three wheelers and Diesel minibus and three wheelers. Data collection started on December 2, 2015 and ended on December 11, 2015.

The data collected includes:

- Vehicle specific information such as make, model, model year, license plate number, odometer reading and ECS visual inspection results (Appendix -B).
- HC, CO, CO_2, NO_x and PM tailpipe exhaust gas readings (Appendix -E).
- Response of interview conducted on operator/drivers.
- Responses obtained from questioners distributed to operators/drivers (Appendix -A).

3.3.1 Procedure

Roadside inspectors and traffic controllers waved vehicles into the inspection lanes, where the in-use vehicles were given a visual and tailpipe inspection (Appendix- F).

3.4 Emission measurement

There are different methods to estimate CO, HC, NO_x, CO_2 and PM emissions. Each type of study has its own strength and weaknesses and these should be considered when they are used for the development of emission factors. Several techniques have been developed to measure vehicle emissions both in laboratory testing and in the real world driving conditions. By analyzing the advantage and disadvantages of the vehicle pollution measuring techniques, the researcher has chosen a direct on-road emission measurement techniques such as roadside monitoring, remote sensing measurements, and chase car experiment which provide useful information on emissions from on-road vehicles under different operating conditions. Emission measurements collected using these methods can be affected by factors such as wind conditions, turbulence from other vehicles, and emissions from other vehicles or road maintenance. To eliminate the effect of external factors, techniques have been developed to directly measure vehicle emissions in the tailpipe before emission is being discharged into the atmosphere [15].

3.4.1 Description of Materials

Two types of Gas analyzer equipment were used to sample emission for vehicular exhaust study. First, Portable five-gas analyzers, Model FGA4000XDS, manufactured by Infrared Industries was used for the study. The instrument weighed 6kg and it comprises of a 5-gas analyzer meter. The equipment measures the volume percentage of CO, CO_2, and O_2, whereas HC and NO_x are measured in ppm. The equipment records the oil temperature and the fuel/air ratio (Lambda). The instrument can be used for testing petrol, Compressed Natural Gas (CNG) and Liquid Natural Gas (LNG) exhaust gases. It can be powered with car battery. It is convenient for the outdoor use (with additional power convertor). It has an automatic recording function as shown in the Figure10.

Figure 10: Gas analyzer

These gas analyzers measure vehicular HC in parts per million, and CO in percent. They have printers to print the emissions readings at the end of the test [53].

- ❖ Six 12-Volts, 72 ampere-hour batteries to power the gas analyzers.
- ❖ Other accessories as needed and the specifications was stated in (Appendix -C).

Secondly, Model 6500IL, manufactured by Infrared Company, was used to measure particulate matter from diesel vehicles. Smoke Opacity meter is in full compliance with the requirement of SAE J1667 test criteria. It specifically, for dynamometer test cell and stationery testing of stack emissions. The LCD displays opacity in percentage value, and the analog output at the rear of the unit outputs 0-1VDC that corresponding to a digital readout. This analog output is used to go to a data acquisition system or a chart recorded measuring the opacity of smoke emitted by a diesel engine. The meter's simple design and rack mount makes it easy to access and obtain accurate measurements. It provides an accurate means (+/-1%) of detecting any measuring the opacity of smoke emitted by a diesel engine. The use of the model 6500IL promotes combustion efficiency for fuel economy and ensures compliance with diesel emission standards set by air quality codes [54] (Appendix- D).

Figure 11: Digital Smoke Opacity Meter

1.4.2 Description of Measurement Procedure

Totally 240, vehicles were selected randomly which represents the total population. The emission test was conducted on seven model and 240 different vehicles which includes both categories of gasoline fueled minibus and three wheelers and Diesel minibus and three wheelers. The tailpipe emissions were measured from the selected sample vehicles during test.

- The roadside inspectors: a team of engineers and automotive technicians worked this study. The first one was the greeter (who waved in the vehicles and greeted the motorists at the test lane), the second filled out vehicle-specific information, performed the visual inspection of the ECS and noted the findings on the Test Report (Appendix-B), and the third operated the vehicle and conducted the tailpipe exhaust emissions measurement.
- Three sites were selected for inspecting the in-use vehicles. Criteria for site selection included the following:
  - Roads with at least two parallel lanes so that traffic would not be blocked.
  - Sites that would result in a broad mix of vehicle types, model years, usage, etc.
- Each morning the analyzers' calibration were checked and re-calibrated if necessary.
- Each inspection team took its analyzer, 12-Volt Battery and traffic cones to the assigned site. Inspections were performed from 9:00 AM to 5:00 PM. Data collection was

limited to these hours because of the problems encountered in transporting inspectors and equipment from the laboratory to the test sites and back.

- The setup at the site consisted of (1) placing the traffic cones to act as guides for directing the selected vehicles, (2) placing the analyzer on a table and connecting it to the power source,
- Turning on the analyzer and allowing it to warm up.
- Obtaining vehicles randomly to inspect
- Explaining to the vehicle's driver what would be done and getting his/her verbal consent to perform the inspection.
- Steps followed to ensure the accuracy of the data :
  - A team of people worked paying high attention to each activity
  - Experiments were repeated
  - Filter of analyzer was replaced time to time
- ***Visual Inspection:*** The vehicle's hood was raised and a visual inspection for the presence and condition of the ECS, such as the PCV, EGR, and catalytic converter, was performed and recorded on the Test Report, along with the vehicle's make, model name, model year, engine size, number of cylinders, odometer reading (mileage), license plate number, fuel type and vehicle type (*i.e.*, privately-owned passenger vehicle, taxi, government-owned vehicle, etc.).

Figure 12: Inserting opacity probe to vehicle tailpipe

3.5 Methods of Data Analysis

The emission data for CO, CO_2 and PM was retrieved from the gas analyzer in percentages. The data for HC and NO_x was in ppm. The data retrieved was entered into MS Excel sheet for further processing. The data obtained in % and ppm was converted into mg/m^3 using the formula given below (Eq.2).

$$PPM_{NTP} = \frac{\left(\frac{mg}{m^3}\right)(22.68)}{MW} \tag{2}$$

Where:

MW = is the molecular mass

NTP = Normal Temperature and Pressure (25^0C and 760 mmHg)

mmHg = millimeters of mercury and

Molar volume of air at NTP is 22.68 m^3

Different types of vehicle activity data i.e. total kilometers per day travelled were estimated for each vehicle from driver's interview conducted at road side. The mass of the exhaust components was calculated to five significant digits using the following equation.

Average mass of Hydrocarbon (HC): HC mass $=V_{mix}$ x $Density_{HC}$ x (HC_{conc}/1000, 000) (3)

Carbon monoxide mass (CO): CO mass $=V_{mix}$ x $Density_{CO}$ x (CO_{conc}/1000, 000) (4)

Nitrogen oxide mass (NO_x): NO_x mass= V_{mix} x Density $_{NO_2}$ x K_H x (NO_{xconc}/1000, 000) (5)

Carbon dioxide mass (CO_2): CO_2 mass = V_{mix} x Density $_{CO2}$ x (CO_{2conc}/100) (6)

Where:

- HC mass = hydro carbon emission in grams
- Density HC = Density of hydrocarbon is 16.33 g/ft^3
- Density of CO is 32.97g/ft^3 assuming @ STP
- Density of NO_2 is 54.16 g/ft^3 assuming they are the form of nitrogen @STP
- Density of CO_2 is 51.81 g/ft^3 @ STP
- Assuming carbon to hydrogen ratio of 1:1.85 @ 68^0F and 760mmHg pressure

- V_{mix} = the constant volume sampling flow in cubic feet per second corrected to standard temperature and pressure which is 2595ft^3.
- HC_{conc} = Average hydrocarbon concentration per test of the dilute exhaust sample measured were taken for all gas, respectively.
- K_H is absolute humidity which is 0.9424 grams of water pound (kilogram) of dry air.

The final reported test results for the mass particulate (M_p) in grams/miles shall be computed by using the following equations [55] [56].

$$M_P = \frac{V_{mix}+V_{ep} \; x \; P_e}{V_{ep}} \tag{7}$$

Where:

- M_p is Mass of particulate determined from the "transient" phase of the cold start test, in grams per test
- V_{mix} is total dilute exhaust volume in cubic meter per test, corrected to standard condition @ 5280R and 29.92 in Hg
- P_e is mass of particulate per test on the exhaust filter, grams.
- P_b is mass particulate on the "background" filter, grams is assuming zero.
- V_{ep} is total volume of sample pulled through the filter, cubic feet at standards.

By using the above equations all the value was calculated at the mean base emission rate. The corrected emission rate is obtained by multiplying the base emission rate for that category by each of correction factors. Defined for each vehicle technology category, as shown in equation 8.

For light- duty vehicles and three wheelers [57], the EF is given by equation

$$EF = BEF \; x \; SCF \; x \; TCF \; x \; ACF \tag{8}$$

Where:

- EF is emission factor in g/km:
- BEF is base emissions factor (also called ZML, zero mileage level) which includes a degradation factor; and
- SCF, TCF, and ACF are correction factors for speed, temperature, and altitude, respectively.

In order to obtain more practically approximated value, it has to be modified with some correction factors such as average vehicle speed, altitude and temperature factors, practically proved relation to obtain vehicle speed correction factors for both emissions are [58]:

$$V_{SCF}\ CO = 6.7479V^{-05313} \quad (9).$$

$$V_{SCF}\ HC = 30.34V^{-0693} \quad (10).$$

$$V_{FC}\ CO_2 = 44.011x \frac{FC}{12+1.008\ x\ 1.8} \quad (11).$$

$$V_{SCF}\ PM_{2.5} = 0.45\text{-}0.0086v + 0.000058v^2 \quad (12).$$

$$V_{SCF}\ NO_x = 1.19536V^2 \quad (13).$$

Where:

- V is the average vehicle speed
- V_{SCF} vehicle speed correction factor for each emission
- Fc is Fuel correction

The temperature difference in the city is almost insignificant value throughout the year therefore it is assumed that the temperature at which the test was made is not different. In addition to this temperature highly affects and applied only on heavy duty diesel vehicles and temperature factor is not taken in to account or considered as one [59]. If the average road gradient is large than a value or about 2%, the emission of ascending and descending vehicle do not balance each other, even if the traffic is the same in the two directions. That is the smallest emission is downhill do not balance the larger emission of the uphill direction [60]. So the software which calculates emission factor uses default values 1.2 for City Adama, road gradient is beyond 2% [61].

The grand (total) running emission of the HC, CO, NO_x, CO_2 and $PM_{2.5}$ by representative vehicles has been calculated using equation 13. The different categories of vehicles based on age and model are considered during the emission test to arrive at grand total pollution at different operating conditions.

$$E_t = \sum P_i\ x\ M_i\ x\ Mean\ EF \quad (14)$$

Where:

- E_t represent the emission (tons) of a particular pollution
- P_i is the population of vehicles in category i;
- M_i is the annual mileage (Km) for vehicles in Category i under driving condition; and
- EF is the emission factor (g/km) of vehicles in category i under driving condition.

Analyses have been used to identify the dirtiest polluting gasoline and diesel vehicles. Based on emission result, vehicles are compared each other with age and type categories. The result of them was compared with international standards like USA and Indian standards.

Finally the annual grand tail pipe running hydrocarbon emissions which are unburned particles of fuel lost to the atmosphere from gasoline vehicles, estimated to calculate the amount of wasted fuel using equation 15.

Volume of wasted gasoline fuel = Mass of wasted fuel/Density of wasted fuel

$$V_{HC} = M_{HC}/D_{HC} \quad \text{--.} \quad (15)$$

4. METHODS IN DETERMINATION OF VEHICLE EMISSION AND CONTRIBUTION TO URBAN AIR

4.1 Introduction Pollution

To gain a better understanding of emissions from motor vehicles, a number of methods and instruments have been developed to measure vehicle emissions and to derive emission factors from such measurements. In the past, emission factors were derived from measurement of vehicle fleet emissions at the roadside or within tunnels while measurement of emissions from individual vehicles was mainly carried out using a chassis dynamometer.

Development in rapid-response instruments has enabled measurements of particulate and gaseous emissions from individual vehicles under different traffic conditions to take place both at the roadside and on-board. Direct measurements of on-road vehicle emissions are made possible with the development of mobile emission laboratories and portable measurement instruments. Such developments enable comparison of emissions from vehicles operating under different conditions and fuels. The effect of vehicle weight, engine power, vehicle age, and road grade have on vehicle emissions can also be examined. Statistical techniques are applied to identify contribution of gaseous and particulate pollutants, measured at various districts within a city, from various urban emission sources. The dispersion of vehicle emission within the urban area can be simulated with the aid of dispersion models. Vehicle emission's contribution towards deterioration of air quality can be assessed by monitoring variations in air quality at roadside and background sites in the urban area.

In the following, prevalent methods in measuring emissions from both the vehicle fleet and individual vehicles are described and discussed. The methods used to derive emission factors from such measurements are outlined. A number of statistical techniques commonly used for identifying emission sources in the urban area and general descriptions of models simulating dispersion of vehicle emissions in the urban area are outlined. Monitoring of roadside and urban background air quality and how such measurements are applied in the study of vehicle emission and its dispersion in the urban area are discussed [62].

4.2 Measurement and Computation of Vehicle Fleet Emissions

4.2.1 Roadside measurements of fleet emissions

To study emissions from vehicles operating under real-world traffic conditions, mobile laboratories are developed to measure roadside air quality under different traffic conditions. These studies investigate gaseous and particle emissions from vehicles under both free-flowing and congested conditions and the measurements represent the total contribution from the full vehicle fleet travelling past the road segment where the mobile laboratory is stationed The roadside measurement campaigns are mainly carried out at roadways where the speed and acceleration of the vehicles travelling on it are similar. Traffic counts are carried out to measure the traffic composition, classified by either fuel or vehicle type [62].

Background air quality is measured concurrently with the roadside measurements to determine the contribution of vehicles towards the concentrations of particulate and gaseous pollutants at the roadside measurement site. Background air quality is generally monitored at a location far from the roadside measurement site or upwind of the roadside measurement site. Meteorological measurements such as wind direction are collected at the roadside measurement site and valid measurement periods are considered to be those where the wind direction is close to perpendicular to the roadway [63]. Since air quality measurements can be strongly affected by changes in wind direction, monitoring equipment can be placed on opposite sides of a roadway to increase the length of measurement periods.

Under such arrangements, the background and roadside measurement sites are determined from instantaneous wind direction [64]. Such measurement campaigns are carried out on roadways where wind direction is generally perpendicular to the roadway [65]. Differing traffic composition can often be observed on weekdays and weekend traffic generally consists of a smaller percentage of heavy-duty diesel vehicles than weekday traffic. Thus emission of vehicles of different fuel types and vehicle classes can be distinguished by examining roadside air quality measurements on different days.

4.2.2 Tunnel fleet emission studies

Roadside emission measurement results are often affected by variations in meteorological conditions at the roadside monitoring site. To monitor on-road vehicle emissions under more controlled conditions, emission measurements are often carried out within vehicle tunnels.

Monitoring of tunnel air quality within the tunnel may take place near the tunnel exit while background air quality is measured at the tunnel entrance or in the interior of the tunnel, near the tunnel entrance [66]. This is done to maintain the consistency of background measurements. Such arrangements, however, can result in background measurements being affected by vehicle traffic. In general all traffic within a tunnel bore travel in one direction and it is assumed that air travels from the entrance to the exit [67]; [68]. Thus the background measurement site is often considered upwind of the traffic measurement site. The air flow rate within the tunnel can be estimated by releasing an inert tracer gas at a constant rate at the background site and measuring the concentration of the tracer at the trafficked site [10]. Alternatively, air flow rate can be estimated from wind speed measurements collected within the tunnel [68]. The air fuel rate is then computed by multiplying the wind speed by the cross-section area of the tunnel. Monitoring may take place within the interior of a tunnel bore, far from the tunnel entrance and exit, by placing sampling probes at ventilation ducts near the tunnel ceiling [69]. Alternatively, measurement of gaseous and particulate emissions from vehicles can take place near the curb. Such measurements often take place near the midpoint of the tunnel so that interference from outside the tunnel has no effect on measurements [65] [69]. Ventilation fans generally operate continuously to provide fresh air to the tunnel. Background concentrations of pollutants are measured at the inlet of the ventilation tunnel, at a site near the tunnel entrance or at a site far from the tunnels [70]. Measurements may also be carried out at ventilation outlet to investigate size distribution of particulate matter at the roadside and the ventilation outlet. Since the tunnel length is known, vehicle speed can be estimated by comparing the entrance and exit times of random vehicles [71]. Traffic speed of the tunnel can also be estimated by driving a vehicle through the tunnel a number of times and recording the time needed to travel the length of tunnel. Speed measurements can also be obtained using road sensors. Total traffic volume and traffic composition can be acquired from video footage recorded from within the tunnel or vehicle license plate surveys, where license plates of random vehicles are recorded and matched with registration data [72].

At some tunnels, light-duty vehicles may travel in a dedicated bore, separate from heavy-duty vehicles. Thus measurement of air quality can be carried out in different bores to determine the emission factors of light- and heavy-duty vehicles. Since heavy-duty vehicles operate mostly on diesel, emission levels of diesel and petrol vehicles can also be derived from air quality and traffic measurements at different bores [73].

4.2.3 On-road measurement of fleet emissions

Instead of measuring fleet emissions at a stationary location, measurements of vehicle emissions can be carried out by driving a mobile laboratory on a fixed route. Compared to roadside and tunnel measurements, vehicle emission of gaseous pollutants and particulate matter under a wider range of traffic conditions can be measured using such methods. Mobile laboratories used for on-road measurements are usually in the form of a modified passenger car or van. Measurement instruments are installed within the laboratory and are connected to the sampling line. The sample intake is installed to the front end of the mobile laboratory to prevent contamination by the mobile laboratory's own exhaust and electric generators [74]. Separate inlets may be constructed for gaseous pollutants and particulate matter. The inlet for particulate matter is often set to a height where the sampled air would not be contaminated by road and tire wear while the gaseous inlet is often placed closer to the road surface Gaseous and particulate inlets may also be placed next to one another so that gaseous and particulate emissions within the same plume can be sampled [75]. The particle sample may pass through a filter, where it is diluted with ambient air at a fixed ratio, before measurement of particle number takes place. Separate monitors of one pollutant, commonly CO_2 detectors, may be connected to each inlet so that air quality measurements at separate inlets can be linked and compared [76]. Monitoring instruments are calibrated periodically. During road tests, concentrations of gaseous pollutants and particulate matter are constantly monitored by the mobile laboratory, which maintains a sufficiently large distance between itself and the preceding vehicle. This is done to avoid sampling exhaust from a single vehicle and to prevent impeding traffic flow [74]. Traffic volume, traffic conditions, and road type along the test route can be recorded manually or by video. Traffic volume can also be estimated by examining CO_2 concentrations while the number of petrol vehicles can be estimated from CO measurements collected during road tests. Traffic speed along the test route can be estimated by monitoring the speed of laboratory. Background air quality measurements are made at a fixed location along the route or a location far from the test route. Measurements are considered to be reflective of on-road air quality, rather than contribution from a single vehicle, if the difference between on-road CO_2 measurements and the baseline value, defined to be a low percentile value over a moving time period, is sufficiently small [74].

4.2.4 Derivation of fleet emission factors

The distance-based emission factors of the total vehicle fleet can be derived from traffic volume, mean vehicle speed of the roadway, and the net contribution of various pollutants from vehicle emissions, considered as the difference between roadside and background concentrations of each pollutant [77]. The emission index, in g/L fuel, can be derived from tunnel and on-road measurements as follows:

$$Elp = \frac{\Delta[P]}{\Delta[CO_2]+\Delta[CO]+\Delta[HC]} . \omega c . D fuel \qquad (15)$$

Where, Δ $[P]$ is the net contribution of vehicle emissions towards pollutant P, computed as the difference between roadside and background measurements and expressed in terms of ppm. ω_C is the carbon mass fraction of the vehicle fuel and D_{Fuel} is the fuel density in g/L [78]. Fleet emission factor can then be derived by multiplying emission indices by fuel consumption rate of the fleet.

When air quality measurements take place at the tunnel entrance and exit, fleet emission factors can be computed using the following:

$$EFp = \frac{C_{p.exit} . V_{exit} - C_{p.entr} . V_{entr}}{N.L} \qquad (16)$$

Where, $C_{P,\ exit}$ and $C_{P,\ entr}$ are concentrations of P at the tunnel exit and entrance, in µg/m^3, respectively. V_{exit} and V_{entr} are the air flow volumes, which are expressed in m ^{3}/h and computed from wind speed and cross section area of the tunnel bore, at the tunnel exit and entrance respectively. N is the hourly traffic volume and L is the tunnel length in kilometers. Air flow volume within the tunnel is sometimes considered constant throughout the tunnel. Emission factors of different vehicle types can then computed from the vehicle fleet emission factors and traffic composition by means of regression analysis. The emission factors of different vehicle types can then be estimated from fleet emission factor traffic count as follows:

$$EF = EF_L . N_L + EF_H . N_H \qquad \textbf{(17)}$$

Where N_L and N_H are the number of light- and heavy-duty vehicles, respectively, and EF_L and EF_H are the emission factors of light- and heavy-duty vehicles respectively [77]. Emission factors of petrol and diesel vehicles can be estimated in a similar manner.

The emission factors can also be computed from roadside measurements of total emission by reverse modeling using a line source model such as CALINE4 or OSPM. Traffic volume and meteorological conditions (wind speed and direction) are measured simultaneously as the air quality measurements. The cumulative emissions from vehicles over a period of time and the average wind conditions of this period are obtained from the measurements. Each set of measurements takes place over a long time segment (1 hour) to reduce the level of uncertainly in the computation. The emission factor for the model can then estimate by comparing the model output and the roadside air quality measurements, using background air quality measurements, and meteorological and traffic conditions as input for the. General descriptions of dispersion models are discussed in a later section. [63]

4.3 Indirect Measurements of Emissions from Individual Vehicles

Emission measurements from roadside and tunnel measurements can provide information on emissions under specific traffic conditions. Such measurements are reflective of the emission from the total vehicle fleet at the time testing takes place. However, emission factors of different types of vehicles are derived based on traffic measurements and may not be reflective of actual emissions. To establish a better understanding of emissions from different types of vehicles, a number of methods have been developed to monitor emissions from individual on-road vehicles.

4.3.1 Roadside and tunnel measurements of emissions from individual vehicles

Development of rapid response instruments has enabled on-road measurement of gaseous and particulate emissions from individual vehicles to take place. A laboratory containing measuring instruments is stationed near a roadway to monitor roadside air quality. Instead of monitoring cumulative emission over a period of time, concentrations of particulate matter and gaseous pollutants are recorded continuously.

As a vehicle travels past the mobile laboratory, emissions from the vehicle would result in an increase in concentrations of various pollutants, which would be detected by the measurement instruments. The contribution of various pollutants from the vehicle can then be obtained by comparing the concentrations of each pollutant prior to the vehicle's passage and the peak concentrations observed shortly after the passage of the vehicle. Placement of the sample inlets is determined by the type of vehicle being examined. Investigations of vehicle emissions using this method have been performed on roadways where local traffic consists mostly of one type of vehicle and within tunnels. During roadside tests, the mobile laboratory is placed at a spot where vehicles travelling past the laboratory operate at similar conditions. When measurements take place at a tunnel, the average speed of each vehicle can be estimated by recording its tunnel entry and exit times [79]

Gaseous and particle emission of vehicles can be determined by studying the emission ratio between the increase in concentration of a specific pollutant and the increase in concentration of a tracer gas. In general, the tracer gas chosen is CO_2 directly related to fuel consumption and its concentration under various operating modes are mostly. It is generally, as its emission is assumed that perfect combustion takes place, which is often the case for diesel vehicles. When CO_2 and NO_x is the tracer gas, emission factors of particulate mass (in grams per kilometer) can be derived from measurements values using Eq.18. Particle number emission factor can be computed using Eq. 19

$$EFp = \frac{\Delta[P]}{\Delta[CO2]} \cdot \frac{MWp}{MWCO2} . EFCO2 \tag{18}$$

$$EFp = \frac{\Delta Cp}{\Delta[CO2]} \cdot \frac{NA}{MWCO2} . EFCO2 \tag{19}$$

Where, Δ [P] is the difference between peak and background concentrations of a pollutant. P in ppm, ΔCP is the difference between peak and background particle number concentration (in number/µg^3), MWP is the molecular weight of P in g/mol, N_A is the Avocado number. The emission factor of CO_2 can be estimated from vehicle fuel consumption rates and fuel carbon content. Emission factors can also be obtained from emission inventories such as ADCC and the background concentration is considered the concentration immediately prior to the passage of the vehicle.

In addition to pollutant concentrations, wind direction is also monitored to determine whether shifts in gaseous and particulate concentrations are induced by vehicles travelling past the laboratory. A video camera may also be deployed to identify the vehicles being monitored. This way emission from vehicles of various age, fuel, and emission standards can be compared [80].

4.3.2 Remote sensing measurements

Roadside measurement of emissions from individual vehicles is carried out under the assumption that the vehicles travelling on the roadway have similar speed and acceleration at the time when they travel past the monitoring equipment. To obtain the operating condition of each vehicle as it passes through the monitoring site, a remote sensing system has been developed to measure both vehicle speed/acceleration and emission data. Using remote sensing techniques, concentrations of major gaseous pollutants CO, CO_2, HC, and NO emitted by moving vehicles can be obtained. A laser beam, containing an infrared and an ultraviolet beam, is emitted from a source detector module and reflected back to the module by a mirror on the opposite side of the lane. When a vehicle passes by the monitoring equipment, the vehicle's exhaust absorbs some of the light emitted. The strength of the beams is measured and the concentrations of gaseous emissions are determined by comparing the strength and waveform of the beams exiting and returning to the source detector module.

In addition to emission measurements, a remote sensing system can also record the speed and acceleration of each vehicle travelling past the system. A speed sensor, containing an emitter bar, which emits two laser beams, and a detector bar, is used to determine the speed and acceleration of each vehicle travelling past the measurement system. The speed and acceleration measurements can help determine the vehicle's driving modes and the derivation of distance-based emission factors. A video recorder records the license plate information of each vehicle travelling past the remote sensing system. Registration information of each vehicle (vehicle and fuel type, for example) can then be retrieved from a vehicle registration database. The vehicle‘s speed and acceleration provide information on the vehicle‘s operating conditions. By matching license plate numbers of the vehicles being measured to the vehicle registration database, the vehicle type, fuel type, and age of each vehicle being tested can be obtained. CO, NO, and HC emission indices of each vehicle, expressed in terms of grams per liter of fuel, travelling past the remote sensing system can be determined from the following [81]:

$$EIp = \frac{[P]}{[CO]+[CO2]+3.\frac{[HC]}{0.5}} \cdot \frac{MWp}{MWFuel} . DFuel \tag{20}$$

Where, $[P]$ is the measured concentration of pollutant P in ppm, MW_P is the molecular weight of P in g/ (mol C), and D_{Fuel} is the fuel density in g/L [81]. HC concentration is divided by a factor of 0.5 in Eq. 18 due to discrepancies in HC concentrations measured by NDUV and those measured with a flame ionization detector (FID), commonly used in dynamometer tests. A vehicle's gaseous emission factors can be derived from its emission indices using the following:

$$EFp.fuel = EIp.fuel.FCfuel \tag{21}$$

Where, FC_{fuel} is the fuel consumption rate in L/km.

Remote sensing techniques were originally developed to measure gaseous pollutants, but not particulate matter. Techniques have been developed to measure particulate matter emitted by individual vehicles travelling along a roadway. Particle mass can be measured with an ultraviolet

Lidar (light detection and ranging) system. A laser pulse is transmitted from the light source towards the opposite side of a traffic lane. The pulse is then reflected back to an oscilloscope, where the waveform of the pulse is measured. A series of waveforms collected immediately before and after the passage of a vehicle is analyzed and the increase in PM mass concentration as the result of the vehicle‘s passage can be computed based on assumptions on particle size distribution and bulk density [82]. Testing often takes place on busy roadways where vehicles are expected to be operated under higher engine load, such as highway on-ramps and inclined roadways, to increase the data capture rate [83]. A method in identifying particle number and size distribution using remote sensing techniques has yet to be found, mainly due to the differing particle distribution of exhaust emissions from vehicles of different types and weight classes [84].

4.3.3 Chase car experiments

While remote sensing measurements can capture emissions from large number of vehicles operating under a wide range of operating conditions, such measurements only provide emission information of the vehicle the instant the vehicle passes through the monitoring equipment. To monitor an on-road vehicle's emission over a longer period of time, mobile laboratories can be deployed to monitor emissions from individual vehicles. The mobile laboratory used for such studies is generally similar to the one used for on-road measurement of fleet emissions. The sample inlets are located at the front end of the mobile laboratory and directed forwards so that the air sample is not contaminated by the mobile laboratory's exhaust. The inlet for particulate matter is often placed on top of the vehicle while the gaseous inlet is often placed near to the road surface. Power to instruments on-board is supplied by electric generators. The laboratory records instantaneous concentrations of gaseous pollutants and particulate matter to observe rapid changes in on-road air quality caused by a preceding vehicle [85].

During chase car experiments, the mobile laboratory travels along a route and air samples are captured continuously. This way, emissions from the vehicles preceding the mobile laboratory can be captured. Concentrations of gaseous and particulate pollutants are logged at short intervals to identify periods when emissions from a preceding vehicle are being captured. While the mobile laboratory chases a vehicle, the distance between the two vehicles should be kept small so that the driving pattern of the laboratory mimics that of the preceding vehicle [86].

Instruments with high temporal resolution are needed as it has been shown that, under normal urban traffic conditions, the time a vehicle spends trailing another vehicle is below 45 seconds and the period in which the laboratory captures a vehicle‘s emission lasts no longer than 15 seconds.

The peak concentration observed during the period where emissions from the preceding vehicle are captured is often considered the combined contribution from the vehicle and ambient air. Meteorological conditions such as wind direction may also be monitored so that gaseous and particulate emission measurements are not contaminated by emissions from the generator, used to provide power to the instruments within the mobile laboratory, or emissions from the laboratory's own tailpipe [87]. To reduce contamination of air samples by emissions from the laboratory's tailpipe at times when the mobile laboratory is stationary, the mobile laboratory is generally in the form of an electric vehicle. The range of electric vehicles 2 hours and 120 km under highway driving conditions indicates that such vehicles are capable of measuring vehicle emissions on highways in Hong Kong. Such vehicles may also be suitable for emission experiments on urban streets of Hong Kong over shorter distances 15-20km.

By monitoring the speed of the laboratory, the operating conditions of the vehicle preceding it can be estimated. This way measurements obtained throughout the period in which the laboratory follows a vehicle can be used to investigate emissions of the vehicle under different traffic conditions. During on-road tests, license plate number of the vehicles being followed may be recorded to facilitate comparison of emissions from different types of vehicles, classified by vehicle or fuel type [86].

Instantaneous emission indices and factors of vehicles being chased can be computed using Eq. 18 and 19 respectively. The cumulative emission factor can be computed from instantaneous emission factors by dividing the weighted sum of instantaneous emission factors, where weightings are defined to be vehicle speed, by the total distance the vehicle is being chased.

Since emissions from other vehicles can interfere with chase car measurements, emission measurement using chase car techniques are sometimes carried out on roadways closed to traffic such as racetracks. To maintain consistency of results, the distance between the test vehicle and the mobile laboratory is kept approximately constant during testing by attaching the two vehicles. The distance between the two vehicles may vary between tests so that the dilution ratios at different distances can be investigated.

On-road emissions of a vehicle under steady driving conditions can also be measured by attaching a capture trailer, which contains a conductive sampling bag and a sampling probe tube, to the vehicle. The sampling probe tube opening is set a short distance away from the exhaust pipe. During on-road experiments, the vehicle's exhaust is captured by the sampling probe tube and stored in the sample collection bag. A remotely-controlled valve is constructed within the trailer to divert the emission sample to a bypass vent while the emission is not being collected. The valve also prevents contamination of the filled sampling bag by ambient air after sample collection is completed. The sampling bag can be transported to a laboratory upon completion of a road test. At the laboratory, the sampling bag is replaced and their content is analyzed. The test vehicle is driven repeatedly in a circuit prior to the first test run to warm up the engine. Between test runs the vehicle is kept at idling mode. Collection of emission takes place while the test vehicle travels at steady speed. Gaseous and particle mass emission factors can be estimated as stated in Eq. 18, assuming that exhaust flow rate can be approximated by the air flow rate to the engine [88].

$$EFp = \frac{[Tracer]exhaust}{[Tracer]bag} . \frac{FR.[P]}{v} . Dfuel \qquad (22)$$

where $[Tracer]_{exhaust}$ and $[Tracer]_{bag}$ are the tracer gas, chosen to be NO_x, concentrations (in ppm) within the exhaust and sampling bag respectively, $[P]$ is the concentration of a pollutant P within the sampling bag in ppm, FR is the air flow rate in L/s, calculated from air velocity measurements and sampling duct dimensions, v is the vehicle speed and $D\ fuel$ is the fuel density in g/L [88].

4.4 Direct Vehicle Emission Measurement Techniques

In direct on-road emission measurement techniques such as roadside monitoring, remote sensing measurements, and chase car experiments provide useful information on emissions from on-road vehicles under different operating conditions. Emission measurements collected using these methods can be affected by factors such as wind conditions, turbulence from other vehicles, and emissions from other vehicles or road maintenance. To eliminate the effect of external factors, techniques have been developed to directly measure vehicle emissions in the tailpipe before emission is being discharged into the atmosphere.

4.4.1 Dynamometer testing

To measure vehicle emission under a controlled setting, emissions from a vehicle can be and the vehicle's exhaust pipe is attached to a sampling line. A number of sampling probes, each connected to an analyzer, are placed inside the sampling line. Instead of directly connecting the sampling line to the exhaust, a vehicle's emission may pass through a dilution tunnel before its contents are sampled. Within the dilution tunnel a vehicle's exhaust is diluted by ambient air, which is pre-cleaned with the filter so that particles are removed [89].

The flow rate of the dilution tunnel can be adjusted to accommodate different types of vehicles. During a test, flow rate within the dilution tunnel is generally kept constant. Thus the higher the exhaust flow rate, the lower the dilution ratio. Concentrations of regulated gaseous pollutants (CO, CO_2, NO_x, and HC) can be measured directly from the sampling line or at the end of the dilution tunnel. Further dilution may be necessary when measuring concentrations particulate matter. This is done so that measurements would not exceed an instrument's detection range. The dilution factor can be determined by the ratio between the concentrations of a tracer gas, typically CO_2 the dilution tunnel [90]. CO and CO_2, in the raw exhaust and within emissions of a vehicle are measured by non-dispersive infrared (NDIR) absorption. Concentration of HC is measured by a flame ionization detector (FID). Exhaust sample is transported to the sensor through a heated line, whose temperature is maintained at 190ºC. NO_x concentration is measured by a chemiluminescence detector. Particulate matter emitted by a vehicle is collected with filters, which are heated to approximately 47ºC, and particle mass concentration is measured by weighing the filters. Particle number within the exhaust is measured using a particle counter. The sample may be heated during transport to remove volatile particles.

Tests measuring emissions from a vehicle operating under steady state conditions or conditions defined by established driving cycles generally take place using a chassis roll dynamometer. Drive cycles are a fixed set of acceleration, deceleration, and cruise segments that a driver attempts to follow. Cold-start emission of a vehicle is generally higher than emission from a warmed up vehicle, due to that engine temperature is not sufficiently high for the catalytic converter to function effectively. Thus cold start operation is incorporated into a number of drive cycle emission tests [91]

Prior to a cold-start emission test, a vehicle's engine is kept off and the vehicle is stored in a temperature-controlled room for a minimum of 12 hours. The vehicle is then moved to the dynamometer immediately before testing begins meanwhile, emission under steady state conditions are generally carried out after the vehicle is sufficiently warmed up so that measurements are more stable. This is generally done by leaving the vehicle at idle mode or driving the vehicle at constant speed for a period of time shortly before testing begins. Between tests a vehicle is left at idle mode or kept running at constant speed. Total emission of a vehicle for the duration of a drive cycle can be determined by collecting the vehicle's exhaust in sampling bags and analyzing the contents immediately after the completion of a cycle [92].

Studies comparing emission from vehicles fuelled by conventional fuels such as gasoline and diesel and alternative fuels such as compressed natural gas (CNG), liquefied petroleum gas (LPG), alcohols, and biodiesel are often carried out using a dynamometer. In such investigations, vehicles are operated under conditions defined by drive cycles or steady state conditions (constant vehicle speed) and the vehicle's emissions using different test fuels are examined and compared. Prior to testing of a vehicle running on a specific type of fuel, the vehicle's fuel tank is drained to reduce contamination. The vehicle's emission levels under specific modes of a driving cycle and over the entire cycle can be found and the vehicle's emission while running on different types of fuel can then be compared [93].

4.4.2 Mobile emission laboratory

A vehicle's emission under a wide range of conditions can be obtained from a chassis dynamometer measurement system. However, such tests cannot simulate parameters such as variations in road geometry and topography [94]. The dynamometer may also be less effective in simulating large variations in speed and rapid speed changes, situations that frequently arise under urban driving conditions. As a result, techniques and instruments have been developed to continuously monitor a vehicle's exhaust emissions while on-road.

On-road measurements of emissions from individual heavy-duty vehicles can be carried out by attaching the vehicle and its exhaust to a mobile laboratory, in the form of a cargo trailer. The test vehicles may be operated under conditions defined by standard driving cycles. Ideally, such measurement should be carried out on a closed circuit or roadways with free-flowing traffic so that measurements would not be disrupted by other vehicles. Measurements can also take place on pre-defined routes to mimic actual traffic conditions [95]. By comparing emissions of a vehicle operating of different types of fuel, fuel effect on emissions can also be investigated using a mobile emission laboratory [96].

Measurement instruments similar to those used for dynamometer tests are installed within the trailer. The test vehicle's exhaust is transported to the trailer through a sampling line. Inside the trailer, sampling probes connect the sampling line to various instruments and the concentrations of gaseous pollutants and particulate matter are monitored in real time. The exhaust flow rate and temperature are measured by a flow meter, placed near the point where the vehicle's exhaust pipe connects with the sampling line, so that the vehicle's emission rate can be measured [62] [95]. The vehicle's speed may be recorded to investigate the vehicle's emission under different operating conditions.

The gaseous emission indices of the vehicle can be derived using Eq. 18. Instantaneous emission rates, expressed in terms of g/s and factors can be determined from emission and flow rate measurements as follows:

$$ERp = [P].FR.\rho p \quad (23)$$

$$EFp = \frac{ERp}{v} \quad (24)$$

Where, $[P]$ is the concentration of the gas P in ppm, FR is the exhaust mass flow rate in L/s, ρ_P is the standard density of P in g/L, and v is the vehicle speed in km/h. Trip emission factor can be computed from the following:

$$EFp = \frac{\sum ERp}{D} \quad (25)$$

Where, $\sum$SERP is the sum of instantaneous emission rate of P over the entire trip and D is the trip length in km.

4.4.3 On-board measurement devices

Mobile laboratory may not be suitable for measuring emission from light-duty vehicles because of the size and weight of the monitoring equipment. As a result, more compact emission measurement instruments have been developed to facilitate on-board measurement of emissions from light-duty vehicles.

To measure emissions directly from light-duty vehicles, measurement device monitoring gaseous emissions are installed to the test vehicle. A sampling probe is inserted into the test vehicle's tailpipe and a small portion of the tailpipe exhaust is transported to the portable measurement device for analysis. Gaseous emissions are monitored continuously using an on-board measurement device such as a five-gas analyzer, which monitors emissions of CO, CO and HC using a non-dispersive infrared monitor and concentrations of O_2 and NO_x using electrochemical transducers [90]. Emissions can also be monitored using a Fourier-transform infrared (FTIR) spectrometer. The spectrometer is capable of measuring concentrations of major species of volatile organic compounds and gaseous pollutants such as ammonia, CO, NO_x, and THC in a vehicle's exhaust in real-time [97]. The spectrometer releases beams over a wide range of wavelengths and a specific range of wavelengths corresponds to a single pollutant. Concentration of each pollutant is determined using the classical least-squares method [97].

The speed of the test vehicle is recorded to examine the vehicle's emissions under different operating conditions. To compute the vehicle's emission rate, the vehicle's instantaneous exhaust flow rate is measured by connecting a flow meter to the exhaust connecting a fuel meter to the vehicle's fuel supply line so that instantaneous emission rate can be determined from the air and fuel flow rates.

It has been shown that HC emissions obtained from FTIR measurements can be lower by a factor of 2 or larger compared to the actual HC concentration [98]. Likewise, NDIR measurements of HC concentrations are approximately half the actual concentration [99]. To improve the accuracy of HC measurements from on-board emission measuring instruments, portable emission measurement systems (PEMS) incorporating the flame ionization detector (FID), commonly used for measurement of HC emissions from vehicles in dynamometer tests, have been developed [100]. Simultaneous measurements shows that instantaneous concentration measurements of gaseous pollutants obtained from a PEMS and a chassis dynamometer are highly correlated and, on average, within 5% of each other. Meanwhile, on-road tests have shown that PEMS measurements of gaseous pollutants generally have a slight positive bias compared to measurements from a mobile emission laboratory while second-by-second PEMS measurements correlate well with measurements obtained from a mobile emission laboratory [101].

In addition to major gaseous pollutants, measurements of toxic pollutants such as mercury can also be carried out using portable measurement devices. During a test, a vehicle travels on a designated route, generally chosen to be a route with low traffic volume. Emissions of vehicles can be determined by collecting a sample from the exhaust. The sampled exhaust passes through filters and impugners, where the toxic pollutant is collected and measured [102]. By computing the emission rate of vehicles running on different types of fuel, fuel effects on toxic emission can be examined. On-board instruments measuring particle mass emission from vehicles have also been developed. A small portion of a vehicle's exhaust is drawn through a filter unit. The exhaust flow rate is measured by a built-in flow meter. The ratio between exhaust and sample flow is kept constant by mixing the vehicle's exhaust with ambient air. The flow rate within the sample inlet is controlled by a series of solenoid valves. Particulate matter is collected using filters or vibrating quartz crystals. The particle mass concentration is determined by measuring changes in filter mass or the crystal's vibration frequency. To date measurement of particle mass emission from vehicles using on-board instruments is carried out mostly on diesel vehicles. A vehicle's instantaneous emission indices can be computed using Eq. 20 while instantaneous emission rates and factors are derived from Eqs. 23 And 24 respectively [103].

4.5 Evaluation of emission measurement and computation methods

4.5.1 Advantages and shortcomings of emission measurement methods

When emission from the total fleet is measured at the roadside or within tunnels, the derived emission factors can be segregated into emission factors of different vehicle types based on the composition of traffic at the roadway where emission measurement takes place. By carrying out measurements at periods where traffic composition differs, emission factors of various vehicle types can be determined. On-road measurement of fleet emissions generally enables measurement of emission under a wider range of traffic conditions than roadside and tunnel measurements. Measurement of fleet emissions assumes that operating conditions are similar for all vehicles.

The amount of air quality measurements collected at the roadside are highly dependent on variations in wind direction. To remedy this, measurement campaigns in which air quality monitors are placed on the two sides of a roadway had been carried out the monitoring station located on the windward side of the roadway is considered the background station and the station on the leeward side is considered the roadside station [104]. In some tunnel studies, background air quality measurements may take place at the interior of the tunnel or at the tunnel entrance. This can result in background measurements that are directly influenced by vehicle emissions. Since the measurement data used in the derivation of emission factors through reverse modeling are obtained from the roadside, issues such as accumulation of emissions due to traffic congestion may arise. Factors such as meteorological conditions, traffic composition and conditions, fuel characteristics, choice of background measurement site, and particle size range (for PN emission factors) can also have an effect on on-road emission measurement results and therefore emission factors derived using modeling methods [105]. Roadside measurement of emissions from individual vehicles enables rapid collection of emission data from a large number of vehicles. This way, emissions from different types of vehicles can be compared and high emitters can be identified. Similar to roadside measurement of total fleet emissions, the operating condition is often assumed to be the same for all vehicles. Thus roadside measurement of emissions is best suited for roadways where vehicles operate under similar conditions, such as free-flowing highways. Tunnel measurement of emissions are sometimes preferred over roadside measurements due to that wind has a smaller effect on emission measurements within a tunnel than at the roadside. Traffic at the measurement site should be sufficiently sparse. Otherwise peaks associated with each vehicle's passing may be difficult to distinguish [106].

Emission data from vehicles of various types operating at a vast variety of conditions can be measured at a single location using remote sensing techniques. Since remote sensing techniques measure a vehicle's emission over an instant (~0.5s), remote sensing is capable of measuring emissions from a higher number of vehicles in comparison with roadside measurements of individual vehicles. It is assumed that particle size distribution are the same for vehicles of different type, although it has been shown that particle size distribution may be different for petrol and diesel vehicles. As particle number measurements cannot be made by remote sensing techniques, remote sensing is less effective in measuring particulate emissions compared to other emission measurement methods [107].

A common limitation of roadside, tunnel, and remote sensing measurements of emissions from individual vehicles is that they only provide instantaneous emission characteristics. However, the measurements can be conducted at roadways with different traffic composition so that emission factors of the total vehicle fleet can be estimated [107]. Emission measurements of individual vehicles under different real world traffic conditions can be obtained through chase-car experiments. In particular, a vehicle‘s emission level under a large range of traffic conditions (idle, cruising, stop-and-go) can be observed rapidly through such experiments. The number of vehicles being tested would be smaller than roadside or remote sensing measurements and the representativeness of the vehicles being tested would depend on traffic at the time of measurements. The laboratory should be set up so that the air sample is not contaminated with the laboratory's own exhaust emissions. Chase car techniques can be considered for measurement of on-road emission from a specific vehicle type such as buses, where the mobile laboratory travels on a route frequently travelled by the specified vehicle type [86].

Direct measurement of vehicle emissions collects a vehicle‘s exhaust from its tailpipe. Thus interference by external factors such as wind and traffic turbulence is mostly eliminated. Dynamometer testing of vehicle emissions enables measurement of emissions under a controlled setting. Thus emissions of vehicles operated under steady state conditions or conditions prescribed by drive cycles are best measured using a chassis dynamometer. However, a dynamometer may be less effective in simulating certain conditions, such as uphill and downhill driving [108].

On-board emission measurements, such as those collected using mobile emission laboratory or portable measurement devices, tend to be more reflective of the actual operating condition of the test vehicle than measurements obtained from chase-car experiments, as the exhaust sample is obtained directly from the test vehicle's exhaust pipe. Such techniques also enable measurement of emissions from a wider range of operating conditions compared to chase-car methods. However, the number of vehicles that can be tested tends to be small due to time and cost constraints.

4.5.2 Examination of emission computation and comparison of emission factors

When measurement of vehicle fleet emissions is carried out at the roadside, background air quality measurements should reflect ambient air quality in the neighborhood of the roadway. Thus monitoring of background air quality preferably should take place at a location upwind and near the roadside measurement site [65].

The computation of vehicle fleet emissions from tunnel measurements (Eq. 16) assumes that pollutants emitted by vehicles travelling within the tunnel are accumulated towards the exit. This is generally the case as vehicles travel in the same direction within a tunnel bore [66]. However, vehicle traffic travels in both directions in some tunnels. Under such circumstances, it may be preferable to replace P_{entr} in Eq. 16 by measurements outside the tunnel and assume that air flow rate is constant throughout the tunnel. Alternatively, fleet emission factors within the tunnel can be derived using Eqs. 15 and 21. When emissions of individual vehicles are measured at the roadside or tunnels (Eqs. 18 and 19), the background concentration is often defined as the concentration shortly before the vehicle's passage. Background air quality measurements can be influenced by residual emissions from a previous vehicle or instrument signal noise [62].

To reduce the influence from these factors, background concentration can be considered as a low percentile value over a short period prior to the vehicle's passage. CO_2 is considered as the tracer gas in the roadside and tunnel measurement of emissions from individual vehicles. The emission index of CO_2 is incorporated in the computation of gaseous and particulate emissions (Eqs.18 and 19). This is based on the assumption that vehicle engine combustion is stoichiometric, which may not necessarily be the case [108]. If CO concentration is also monitored by the mobile

Laboratory, gaseous and particle emissions from individual vehicles can be computed using Eq. 15 instead. Emission factors can then be derived from Eq. 21.

If a vehicle's fuel consumption rate is known, a vehicle's emission factors can be computed from emission indices using Eq. 21. A vehicle's fuel consumption rate can be retrieved from the vehicle manufacturer, direct measurements, or estimations. Fuel consumption rates provided from manufacturer are generally a single value and may not reflect fuel consumption under different conditions. Direct measurements generally yield more accurate fuel consumption rates. A vehicle's fuel consumption can be estimated from CO_2 emission rate or the ratio between emission factor and index of vehicles of the same type. Estimation of fuel consumption rates under different speeds should be made so that fuel consumption estimations better reflect a vehicle's operating conditions [49].

Variations in the dilution ratio between tracer gas concentration in the exhaust and that in sampling bag can have a large effect on emission factors derived from Eq. 22. Thus exhaust and sampling measurements of tracer gas concentrations is best carried out under calm wind conditions, under which exhaust flow rate and air flow rate within the sample tube are not affected by perpendicular winds and therefore better correlated [109].

Instantaneous emission of a vehicle can be computed using Eqs. 23 and 24. Lags in exhaust emission and flow rate measurements, caused by instrument response delays, can result in inaccurate emission factors. Thus exhaust flow rate and emission and speed measurements can be aligned so that the instantaneous emission factors derived from on-board measurements correspond with actual driving conditions better. This would also improve the accuracy of trip emission factor, derived from Eq. 22.

4.6 Measurement of pollution levels in Addis Ababa city- Baseline studies

A study on effect of motor vehicles on air pollution in Addis Ababa Baseline studies confirms that exhaust gases from vehicles pollute Addis Ababa’s air, and that improperly maintained vehicles contribute significantly to this pollution. The health effects of Ethiopia’s urban air pollution are a strong contributor to its people’s average life expectancy of only 56.19 years [110].

A study on indoor air pollution in a rural Butajira and traffic air pollution in Addis Ababa was done by PhD candidate. About 70% of NO_2 indoor measurements were more than double the currently proposed annual mean of WHO air quality guideline. Ecology and fire-fuel use household characteristics were important determinants of indoor air pollution. Although average CO concentrations were below the US-EPA and WHO ambient air quality guidelines, there is a strong indication that CO concentrations will exceed or approach these guidelines shortly.

Further studies in the description of burden of diseases attributed to indoor air pollution are highly recommended. Interventions targeting at improving the design and utilization of fuel stove efficiency and ventilation are essential. The measurement of traffic particulate matter in high traffic areas is suggested given the high proportion of on-road diesel-engine vehicles in Addis Ababa [49].

5. RESULTS AND DISCUSSION

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 [111]. An estimated 3,462 taxi in Adama from these 480 three wheelers diesel minibuses, 400 both diesel and gasoline fuel minibus and the rest 2,582 three wheelers gasoline taxi [112]. With the increasing urban population and there is an increasing demand for transportation vehicles in Adama necessitating increased air pollution around the city. Most of the minibus vehicles used in Adama has very low energy efficiencies, mainly because they are imported into the country when quite old. No proper assessment has been carried out to establish the level and impact of air pollution from the vehicles. The main objective of this study is to investigate on emission caused by the engines of gasoline and diesel fueled vehicles in Adama. The measured vehicle emissions have been analyzed in detail and the analysis is divided into two sections, measuring at idle/2500rpm test for three wheelers and minibuses gasoline fueled vehicles emissions like HC and CO. At free acceleration concentration of NO_x and CO_2 for gasoline fueled three wheelers and minibus and PM emission for Diesel fueled minibus vehicles and three wheelers.

Measuring the levels of HC, CO, NO_x, CO_2 and PM concentrations at three selected Adama sites for six days and conducting a roadside vehicle inspection by randomly pulling over in-use vehicles to inspect a representative sample of the Adama three wheelers and minibuses fleet are the two major steps in this study. The inspection included; a visual inspection of the ECS a measurement of their tailpipe exhaust emissions, on selected vehicles. Interviewing the drivers and obtaining responses for questioners distributed.

The sample size tested comprised of 20 of vehicles in each types. Totally 240, vehicles were selected randomly which represents the total population. The emission test was conducted on seven model and 240 different vehicles which includes both categories of gasoline fueled minibus and three wheelers and Diesel minibus and three wheelers. Data collection started on December 2, 2015 and ended on December 11, 2015.

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5.1 Vehicle parc age and mileage

A total of 240 unique vehicles were tested ranging from model year 1981 to model year 2015, of which 120 (50%) were gasoline-powered and 120 (50%) were diesel-powered. Among gasoline powered vehicles, 40 (33.33%) were minibus taxi and 80 (66.67%) were three wheelers. And from a total of 120 diesel powered vehicles, 60 (50%) were minibus taxi and the reaming 50% were three wheelers taxi. In this study diesel powered vehicles were tested for only particulate matter ($PM_{2.5}$). Because the exhaust gas measuring equipment used for this study was designed to measure exhaust gas from gasoline powered vehicles. The few diesel powered vehicles that were tested clogged the exhaust gas measuring equipment and the vehicle testing had to be stopped until the equipment cleared up and was ready to measure exhaust gas again.

From table 4 as shown the field survey revealed that most of the minibuses taxis for public transport are imported into the county as second hand overhauled vehicles. Out of the 50 vehicle owners interviewed, 92% indicated that they had purchased their vehicles from other existing owners. 90% of the minibuses vehicles lie between 11-32 years indicating that the Adama vehicle parc is quite old but the age of three wheelers lie between 1-8 years. The vehicle owners mentioned that at the time of purchase, 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 15,988 km and 695,910 km with an average of 294,703.32 km and standard deviation of 157,418.6 km.

The vehicle mileage for the three wheeler vehicles ranged between 1,111kM and 67, 162kM with an average of 25,736.1kM and standard deviation of 16,112.64kM. The results show that on an average minibus cover longer distances compared to three wheeler vehicles. This is because minibuses are used for long period of time within the city center for public transportation necessitating them to drive more compared to three wheeler vehicles.

The impact of the dropping mileage with age is significant in assessing the environment impacts of transport and the potential impact of environment polices. NO_x and PM emissions of passenger cars drop by more than 20% when a decreasing function of mileage with age is used, instead of a fixed mileage for each environment class. Also, the emission contribution from old vehicles decreases which worsens the cost-effectives of air related policy measures targeting such old vehicles. These findings demonstrate the importance of performing precise estimates of mileage per vehicle class if robust road transport emission inventories need to produce [113].

5.2 Characteristics of the respondents.

Table 4: Respondent’s by their vehicle type, and fuel used by the vehicles

Item		Vehicle Type & No. of Response		Percentage	
		3 Wheelers	Minibus	3 Wheelers	Minibus
1. How did you purchase your car?	a) brand new car	39		78	
	b) Used but never driven in Ethiopia		4		8
	c) Already registered	11	46	22	92
	Total	50	50	100	100
2. How long are you driving this vehicles?	a) Less than 1 year	30	36	60	72
	B) 1- 2 years	13	3	26	6
	C) 2-3 years	7	6	14	12
	d) above 3 years	6	5	12	10
	Total	50	50	100	100
3. Does your vehicle odometer is functional?	a) Yes	32	46	64	92
	b) No	18	4	36	8
	Total	50	50	100	100
4. How often do you take your car for servicing?	a) Rarely	27	34	54	68
	b) Sometimes	17	12	34	24
	c) often	6	4	12	8
	Total	50	50	100	100
5. Averagely how much do you spend on fuel?	In liter/per day	5Petrol /7Diesel	21Petrol /18Diesel		
6. Do you know the impact of emission on humans?	a) Yes	41	18	82	36
	b) No	9	32	18	64
	Total	50	50	100	100
7. Are you willing to participate in any measures aimed to reducing vehicle emissions in Adama?	a) Yes	48	46	96	92
	b) No	2	4	4	8
	Total	50	50	100	100
8. Do you feel the pollution from vehicle in Adama	a) Yes	34	41	68	82
	b) No	16	9	32	18
	Total	50	50	100	100

From table 4 Item 3 during the roadside inspection, the odometer reading of every vehicle that was inspected was recorded. And 92% of the sampled minibus vehicles and 64% three wheelers had odometer gauges that had either stopped working (registered no value) or were mechanically disabled. It would be reasonable to note that these vehicles would have accumulated a large quantity of miles had the odometer been functioning.

As shown from table 4 Item 1 the three wheeler vehicles are categorized as TVS, Bajaj and Force based on capacity, model, Manufacturer and fuel used. 78% of three wheeler vehicles are imported into the country as brand new with zero mileage. However, the remaining of the buyers purchased their three wheeler vehicles second hand from owners within the city. The results show that three wheeler vehicles have lower mileages as compared to the minibuses due to service years. Three wheeler vehicles are used as a quick form of transport to move between short distances. They do not operate long routes out of the city, they are new short routes emerging transport option for the country which substitute horse cart and hence the low mileage values.

From table 4 Item 2 the duration of the driver with a vehicle 72% of the minibus and 60% of the three wheelers driver were stay in one vehicle less than a year. These show that the one vehicle frequently handle by different drivers, this may led to defect the vehicles and may aggravate the emission levels and affect fuel consumption of the vehicles.

From table 4 Item 4 vehicle service frequency, minibus drivers responded 68% rarely maintained, 24% they maintain occasionally and the rest 8% were maintained regularly. And for three wheelers 54% they maintain rarely their vehicles, 34% occasionally and 12% regularly.

These indicate that most of the taxi in Adama are being maintained only when they are defected and the tendency to take preventive maintenance is low. So, we can conclude that this practice may lead to raise the emission rate.

As shown from table 4 Item 6, from the three wheeler drivers respond 82% of the respondent and 64% of the minibus respondent they know the impact of emission on human being the reaming the did not know the impact. So, these indicate that few drivers need some training regarding emission impact.

From the responds of the driver about emission concentration feeling in Adama, under table 4 Item 8, the minibus drivers responds 82% and three wheeler drivers 68% respondent they feel the pollution from the vehicles during they moving here and there. So, it alarm to understand the existing emission level in the City.

5.3 Vehicular exhaust emissions

Idle tests: - The most common emissions test in I/M programs is a measurement of hydrocarbon and carbon monoxide concentrations in the exhaust while the vehicle is idling. Many inspections in Finland, Germany, Sweden, and the United States supplement this measurement with a second measurement carried out with the engine running at 2500 rpm with no load. Austria has adopted a 3000 rpm high idle. These measurements do not require a dynamometer or other expensive equipment [114].

The idle test was originally developed for vehicles with little or no emission control, and for these vehicles it can detect a large proportion of malfunctioning or maladjusted engines. These vehicles are normally equipped with mechanical carburetors or fuel injection systems, where the air-fuel ratio at idle is related to the air-fuel ratio under load. Thus measurements of hydrocarbon and carbon monoxide emissions at idle and 2500 rpm provides a reasonable indication of the emissions under normal operating conditions for vehicles with mechanical air-fuel ratio control systems. These vehicles include older technology cars and light trucks, and most heavy-duty gasoline vehicles commonly used in developing countries.

The idle/2500 rpm test procedure does not give satisfactory results for vehicles using electronics air-fuel ratio control systems [114].

The analysis of the emissions from different vehicles showed that CO_2, CO, HC and NO_x 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.

5.3.1 HC emissions

Figure 4 shows the level of HC emissions from the three vehicle types. The level of HC emissions observed is highest during idle operating condition in the minibuses 2Y model at 840.25 ppm followed by minibuses 3Y model at 776.05 ppm, three wheeler Bajaj 2010-12 model at 567.45 ppm, three wheeler Bajaj 2013-15 model at 422.3 ppm, three wheeler Bajaj 2006-09 model at 335.2 ppm, and three wheeler TVS 2011-15 model at 206.85 ppm. However, the high amounts observed at idle rpm in the minibuses correspond to those with the highest mileage and very old.

But comparing the three wheelers each other at idle condition the high amount observed in Bajaj 2010-12 models.

When come to HC, emission level observed highest at 2500 rpm operating condition in the minibuses 2Y model at 361.75 ppm followed by, at three wheeler Bajaj 2010-12 model at 340.2 ppm, three wheeler Bajaj 2006-09 model at 314.5 ppm, three wheeler Bajaj 2013-15 model at 223.5 ppm, minibuses 3Y model at 204.1 ppm and three wheeler TVS 2011-15 model at 142.1 ppm. Even if, the high amounts observed at 2500 rpm in the minibuses 2Y model correspond to those with the highest mileage and very old. The three wheeler special all the observed Bajaj model HC emission level at 2500 rpm is higher than with minibuses 3Y model even though there capacity and service year is less than Toyota 3Y but there parc number is 6.25:1 ratio. So, this show that the total parc number of the three wheelers vehicle 6.25 times more than the minibuses and the number of turn over frequency per day much more in line with this the amount of pollution rate is higher than the minibuses and also beside this the traffic conjunction will be high.
Generally, an excessively high hydrocarbon (due to incomplete combustion) causes carbon monoxide emissions to be high. Hydrocarbon emissions result from spark plug misfires, incorrect ignition timing, wrong air-fuel mixture, etc. These findings further suggest that the lack of regular vehicular preventive maintenance is one of the major aggravators of Adama air pollution.

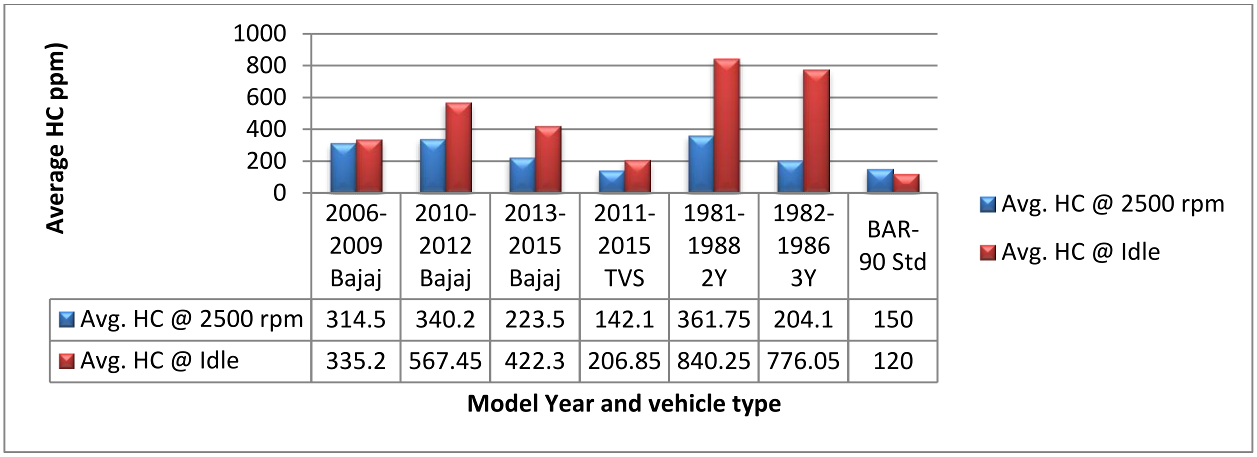


Figure 13: Average idle/ 2500 rpm HC Emission

From emission standards, gross polluter standards, dilution thresholds and maximum idle rpm limits for California BAR-90 two- speed idle test [115].

Pass/Fail standards- emission standards used to determine if a vehicle passes the emission portion of the inspection. A vehicle passes if the emission levels are equal to or less than the hydrocarbon standards for the idle or 2500 rpm inspection.

Gross polluter standards- emissions standards used to designate a vehicle as a gross polluter. A vehicle is designated as a gross polluter if the emissions level at the time of the inspection, are greater than the gross polluter standards for hydrocarbon for the idle or 2500 rpm inspection.

From the standard table the value of maximum hydrocarbon at idle 270 ppm and at 2500 rpm 300 ppm. So, the pollution rate of all the tested minibuses 2Yand 3Y models were gross polluter, all the tested Bajaj models failed as per standards and TVS passed the HC emission test (Appendix -G).

The overall weighted average vehicle tailpipe HC emissions were 840 ppm and 362 ppm respectively, which is almost equal to the maximum allowable standards for the oldest vehicles (1966-1967) in the California BAR-90 Smog Check program for idle for 2500 rpm [115].

5.3.2 CO emissions

Emission of carbon monoxide is an indicator of incomplete combustion in the engine. Figure 14 shows the level of carbon monoxide emitted by the three vehicle types. The level of CO emissions observed is highest at 2500 rpm operating condition in three wheeler Bajaj 2013-15 model at 7.808 ppm followed by three wheeler Bajaj 2010-12 model at 5.809 ppm, three wheeler

Bajaj 2006-09 model at 3.735 ppm, minibuses 2Y model at 2.352 ppm, minibuses model at 1.594 ppm, and three wheeler TVS 2011-15 model at 1.467 ppm. However, the high amounts observed at 2500 rpm in the three wheelers Bajaj, even if they are new and low mileages. But comparing the minibuses each other at 2500 rpm condition the high amount observed 2Y models.

When come to CO, emission level observed highest during idle operating condition in the three wheeler Bajaj 2010-12 model at 3.221 ppm followed by three wheeler Bajaj 2013-15 model at 2.705 ppm, minibuses 2Y model at 2.434 ppm, three wheeler Bajaj 2006-09 model at 2.297 ppm, minibuses 3Y model at 2.085 ppm and three wheeler TVS model at 0.865 ppm. The three wheelers Bajaj emitted more carbon monoxide than the three wheelers TVS and minibuses vehicles.
CO results from spark plug misfires, incorrect ignition timing, and wrong air-fuel mixture etc. Incomplete combustion in the engine due to reduction in the level of oxygen may reflect in more CO emission.

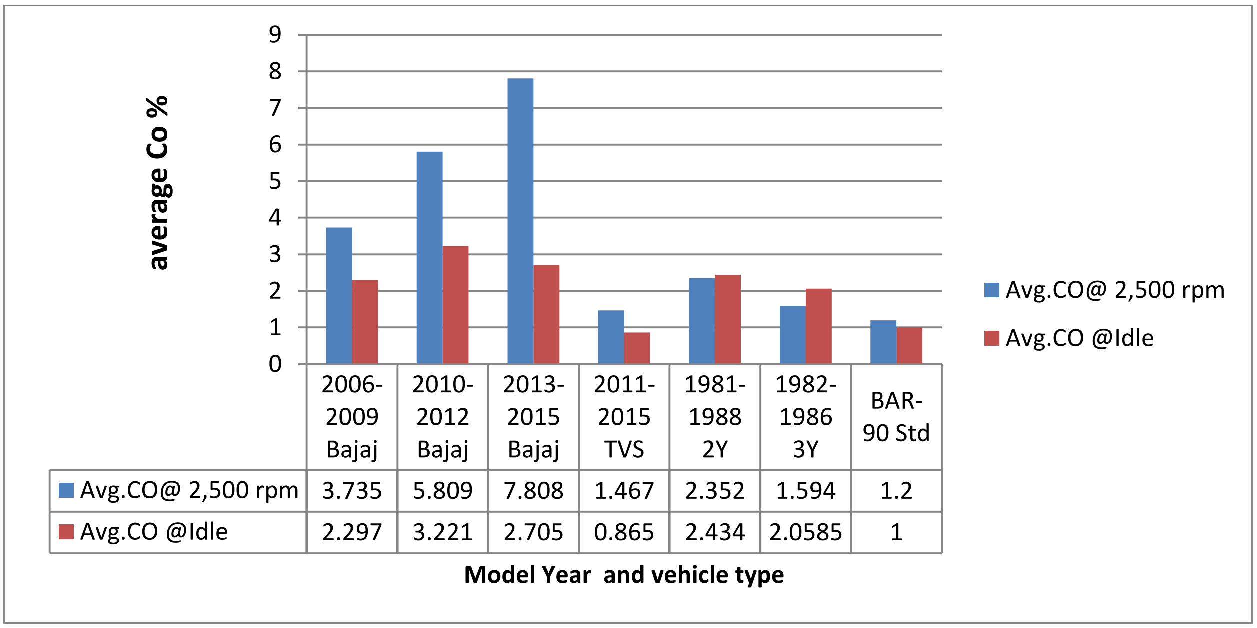


Figure 14: Average CO at Idle/2500 rpm Emission

From emission standards, gross polluter standards, dilution thresholds and maximum idle rpm limits for California BAR-90 two- speed idle test.

Pass/Fail standards- emission standards used to determine if a vehicle passes the emission portion of the inspection. A vehicle passes if the emission levels are equal to or less than the carbon monoxide standards for the idle or 2500 rpm inspection (Appendix -G).

Gross polluter standards- emissions standards used to designate a vehicle as a gross polluter. A vehicle is designated as a gross polluter if the emissions level at the time of the inspection, are greater than the gross polluter standards for carbon monoxides for the idle or 2500 rpm inspection. From the standard table the value of maximum carbon monoxide at idle 2.5% and at 2500 rpm 2.7%. So, the pollution rate of all the tested Bajaj model were gross polluter and TVS and both minibuses 2Y and 3Y models failed as per the standards.

The overall weighted average vehicle tailpipe CO emissions were 2.7% and 7.8%, respectively, which is almost equal to the maximum allowable standards for the oldest vehicles (1966-1969) in the California BAR-90 Smog Check program for idle and for 2500 rpm.

5.4.3 Carbon dioxide emissions

From Figure 15, it is observed that the maximum amount of CO_2 emitted at 2500 rpm from the three wheelers Bajaj 2013-15 models is 18.42% and minibus 3Y model 16.21%, the rest were under the standards. Also, it is observed that the CO_2 emission level highest during idle rpm operating condition in the minibuses 3Y model is 14.95%, the remaining models were under the stated standards. From the results the Bajaj 2013-15 model 1.151 times and 3Y model 1.013 times at 2500 rpm and 3Y minibuses 1.246 times at idle emitted carbon dioxide higher than the given standards.

In generally the tests indicating that CO_2 emission levels in three wheelers Bajaj is more compared to both the minibuses vehicles and TVS vehicles. The minibuses emitting more CO_2 compared to the TVS vehicles.

This is supported by the findings from the survey where vehicles owners were asked how often they carried out maintenance work on their vehicles. Majority of the operators are ignorant in having a regular maintenance schedule, with some doing it after 3-4 weeks. However, the survey showed that vehicles owned by individuals were well maintained with a weekly maintenance schedule. The operators viewed the maintenance program as costly and hence they are reluctant to have vehicles regularly maintained. Poor maintenance results in poor engine performance.

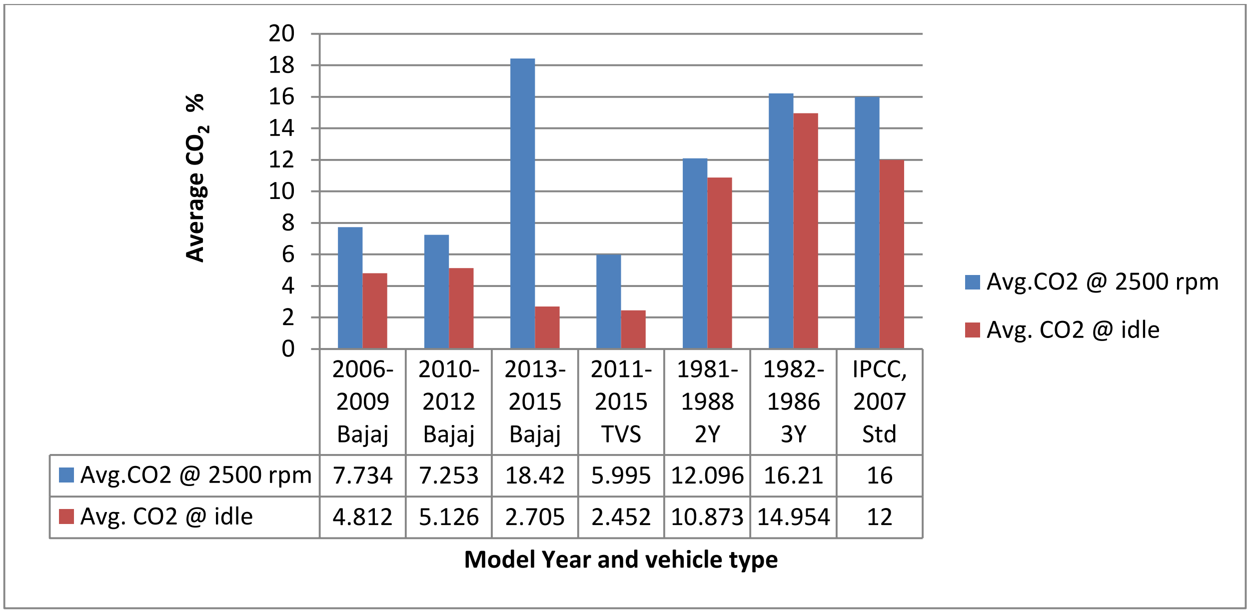


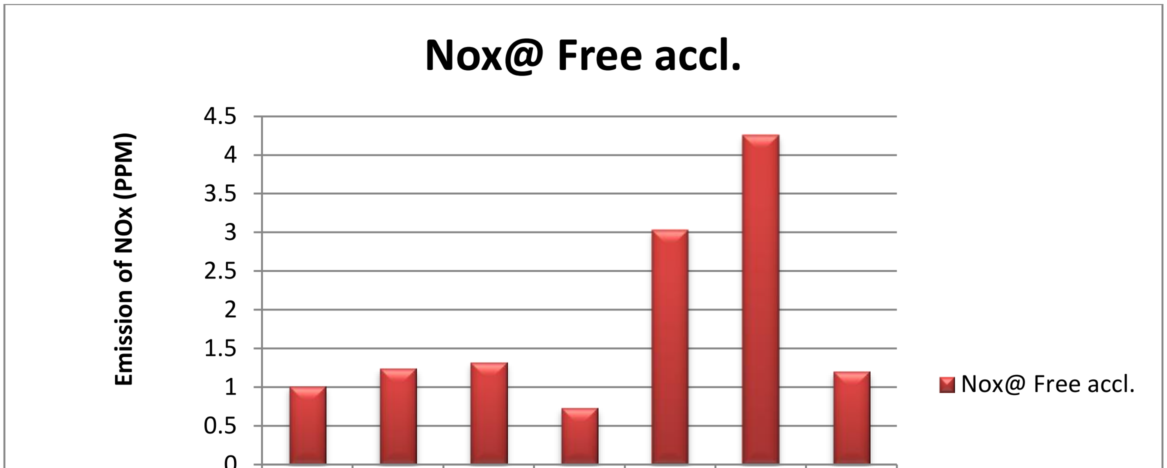
Figure 15: Average CO_2 at Idle/2500 rpm emission

Carbon Dioxide (CO_2) - non-toxic gas but contributes towards acidification of oceans and one of the most important greenhouse gases. Governments around the world are pursuing policies to reduce CO_2 emissions to combat global warming.

5.3.4 NO_x emissions

Figure 16 shows the NO_x emissions for the different automobiles. The highest level of NO_x observed was from the minibuses 3Y at 4.26 ppm, minibuses 2Y at 3.03 ppm, three wheelers Bajaj 2013-15 model at 1.32 ppm, three wheelers Bajaj 2010-12 at 1.24 ppm, and three wheelers Bajaj 2006-09 model at 1.01 ppm and TVS at 0.73 ppm.

From Indian emission standards for passenger cars & light commercial vehicles under "Type V" test for fixed deterioration factors for free acceleration test of NO_x for gasoline/ gasoline fueled engine the maximum value for NO_x is 1.2 ppm (ARAI, 2011). However, the high amounts observed in the minibuses correspond to those with the highest mileage and very old. But comparing the three wheelers each other Bajaj 2010-12 and 2013-15 model were out of the limits and the rest are under the standards (Appendix -F).



	2006-2009 Bajaj	2010-2012 Bajaj	2013-2015 Bajaj	2011-2015 TVS	1981-988 2Y	1982-1986 3Y	Indian .Std
Nox@ Free accl.	1.01	1.24	1.32	0.73	3.03	4.26	1.20

Figure 16: Average NOx at free acceleration emission

NO_x 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.

Since gasoline is a mixture of hydrocarbons, if it burned (exploded) completely, the resulting mixture would be carbon dioxide (CO_2), water (H_2O) and nitrogen (N_2). This assumes that 14.7 pounds of air had been mixed with every pound of gasoline the ideal ("stoichiometric") ratio to completely burn the fuel without wasting any air.

Unfortunately, complete burning is impossible in a real engine because of imperfect mixing, dead spots, temperature differences in the cylinder, etc. This incomplete burning or combustion results in the tailpipe exhaust gas containing various hydrocarbons (HC), carbon monoxide (CO), and nitrogen oxides (NOx), in addition to the CO_2 and H_2O. The NO_x is formed due to dissociation of molecules when the engine is running hot enough that the oxygen in the air combines with the nitrogen in the air, rather than burning the gasoline. The CO_2 and H_2O are not pollutants; the HC, CO and NO_x are pollutants. How much pollution a vehicle emits depends on its engine's age, condition, state of tune, and the presence and functionality of all of its pollution control devices (e.g., the catalytic converter).

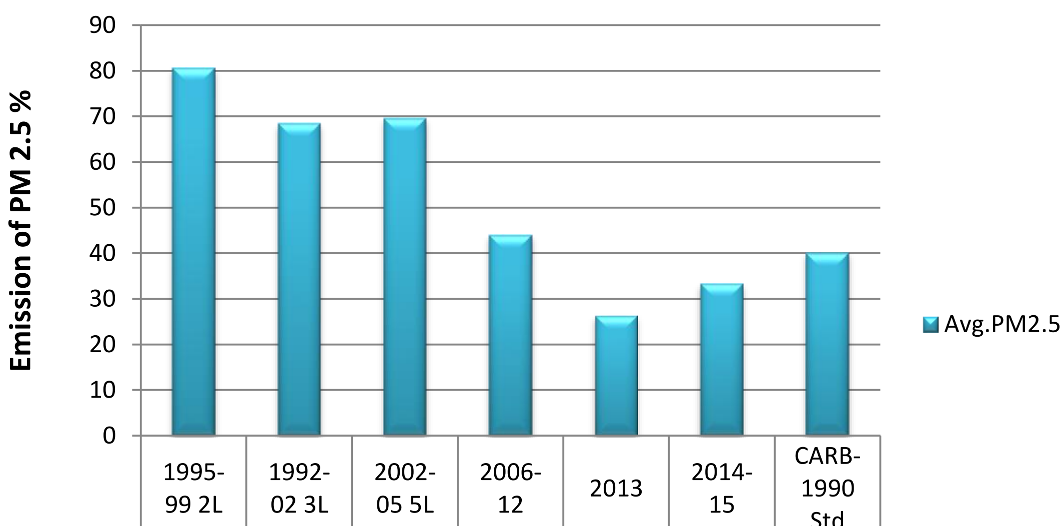
The overall weighted average vehicle tailpipe NO_x emissions were 3Y 4.26 times, 2Y 3.03, Bajaj 2013-15 model 1.1 and Bajaj 2010-12 model 1.033 times higher than the maximum allowable standards for gasoline/gasoline fueled engine in the Indian ARAI-2011emission standards for passenger cars & light commercial vehicles respectively, which is almost equal to the maximum allowable standards for the oldest vehicles for fixed deterioration factors respectively [116].

5.3.5 Particulate Matter (PM)

Light duty gasoline vehicles have made many great technological advance, leaving diesel engines responsible for a growing fraction of mobile source PM emissions.

The conclusion reached from the study is the RSD smoke Factor looks every promising to identify diesel smoking vehicles. Correlation to a formal opacity based inspection test was reasonably good, despite the different measurement techniques and vehicle loading conditions.

Figures 17 show the particulate matter readings for three wheelers Force and minibuses (2L, 3L & 5L) model diesel vehicles, respectively. These graphs show several PM reading values for both vehicles. However, note that there are more emissions for 2L at 2.0145 times followed by, 1.74 times, 1.711 times and 1.0375 times 5L, 3L and three wheelers 2006-12 model higher than CARB standards, respectively. The result shows that the vehicle age and mileage were factor for increasing particulate matter emission for the minibuses.



	1995-99 2L	1992-02 3L	2002-05 5L	2006-12	2013	2014-15	CARB-1990 Std
Avg.PM2.5	80.58	68.44	69.55	43.94	26.3	33.34	40

Figure 17: Average PM2.5 at free acceleration

5.4. Vehicular Emissions Control Systems (ECS's)

Table 5 shows the various ECS's and the number of vehicles which that have equipped with ECS. As shown in the table 5, 198 (82.5%) of the inspected vehicles have Positive Crankcase Ventilation (PCV) and 57 (23.75%) have Thermostatic Air Cleaners (TAC). The function of PCV system is that it can protect environment by extracting the crankcase's mixture gas and exhaust gas and send it to engine cylinder with fresh air which is helpful for better combustion in engine cylinder and also PCV helps in preventing the escape of HC emissions from an engine's crankcase into the atmosphere. Without the PCV, these emissions would amount to about 20 percent of total HC pollution from motor vehicles [117].

The TAC preheats the air coming into the carburetor during engine cold start and warm-up, thus improving fuel vaporization and distribution. Thus process results in reducing both CO and HC emissions.

Table 5: Number of Vehicle Inspected and Emissions Control Systems (ECS's)

Emission control system	Existing	Percentage of Existing	Not Existing	Broken	Disconnected	NO code Recorded	Total
PCV	198	82.5%	12		17	13	240
EGR	33	13.75%	4			203	240
Carburetor	120	50 %				120	240
Catalytic convertor	137	57.083%	13			90	240
Thermostatic Air cleaner(TAC)	57	23.75%	2		1	180	240
Air injection							240
Fuel injection							240
Other Emission Related components							240

When the engine is operating, some combustible mixture gas and exhaust gas can creep into crankcase by means of piston ring. So the engine oil will be diluted because of the mixture gas's coagulation. The exhaust gas's high temperature, acidity substances and water vapor can erode engine component and alchemize engine oil. On the other hand, the mixture gas also can increase the crankcase's inner pressure and temperature, and this can cause engine oil seepage, which forms engine malfunction. These emissions benefits are only achieved if the PCV, TAC, and other emissions control devices function properly. Although functional checks of the ECS's were not done during the study, it is encouraging to note that most of the tested vehicles had these systems on their engines, which indicates that vehicle (owners) generally do not remove the factory-installed ECS's.

The California biennial Smog Check Inspection and Maintenance (I/M) program requires that every vehicle must pass the visual and functional checks of the applicable ECS's in order to pass the inspection Regulations [118]. Vehicles that failed any part of the inspection must be repaired. The benefit in terms of cleaner air that is gained from properly working ECS's is substantial; visual and functional inspections must therefore be a major component of a vehicle inspection and maintenance (I/M) program.

5.5 Estimating Annual base vehicular emission in Adama

The average value base running emission value of three wheelers and minibuses vehicles are as shown table 6. These value do not indicate the real average gasoline and diesel tailpipe emission of Adama. In order to obtain more practically approximated value, it has to be modified with some correction factors such as vehicle speed, altitude, fuel, altitude and temperature factors, practically proved relation to obtain vehicle speed correction factors for both emissions are:

Vehicle speed correction factor for CO, HC, NO_x, and CO_2 for different categories of gasoline vehicles as well $PM_{2.5}$ for Diesel different Categories vehicles and for average speed are as shown in table 6.

Table 6: The average corrected emission rate of the two categories of vehicles *[59]*.

Type	Average vehicle speed	V_{SCF} CO = 6.7479V-0.5313	$V_{SCF\,H}$C = 29.025V-0.932	V_{SCF} NO_x = 1.173+ 0.225v-0.0014v^2	VF_{CC} CO_2 = 44.011 x 1.47/(12.011+1.008x1.8)	V_{SCF} PM =0.45-0.0086v+0.000058v^2
Three wheelers	35	1.02	1.06	1.789	4.68	0.22
Minibuses	30	1.1	1.22	1.722	4.68	0.2442
Average	32.5	1.06	1.14	1.755	4.68	0.2321

Where:

- V_{SCF} CO- The average speed correction factor for CO,
- V_{SCF} HC – The average speed correction factor for HC and
- V_{SCF} NO_x - The average speed correction factor for NO_x.

Table 7: The distribution of annual mass of tailpipe emissions of gasoline and diesel vehicles

Vehicle Type	EF of CO(g/k)=BEF x ACF x SCF x TCF	EF of HC(g/k)=BEF x ACF x SCF x TCF	EF of NO_x (g/k)=BEF x ACF x SCF x TCF	EF of CO_2(g/k)=BEF x ACF x SCF x FC	EF of PM(g/k)= BEEF x ACF x SCF x TCF
Three wheelers	11.362 x 1.2 x 1.02 x 1= 13.9	5.131 x 1.2x 1.06 x1=6.53	0.53x 1.2x 1.789x 1=1.14	3.5897x 1.2x 4.68= 20.16	2.03x1.2x0.22x1=0.54
Minibus	6.353 x 1.2 x 1.1 x 1= 8.4	4.0672 x 1.2 x 1.22x 1= 5.96	1.665 x 1.2 1.722 x 1 =3.44	6.402x1.2x4.68=35.96	4.46x1.2 x 0.2442x1=1.3

Where:

- EF- Emission factors Rates,
- BEF- Base Emission Rate
- ACF- Altitude Correction Factors
- SCF- Average Speed Correction and
- TCF- Temperature correction factors

To estimate the annual average tailpipe running emission, vehicles were classified in to two main categories such as, three wheelers and Minibuses. From survey data per day fuel consumption of gasoline vehicle estimated 21 liter, for diesel vehicle 18 liter and for three wheelers gasoline fueled vehicles 5 liter and for diesel three wheeler 7 liter. From this we can estimate averagely that gasoline minibus they run per liter 7 km, diesel minibus 8 km, for three wheelers gasoline field 25 km and for diesel three wheelers 20 km. So, the average minibus and three wheelers travel per day are 96.4 km and 104 km per day respectively and accordingly the annual mileage travel is related 35186 km and 37960 km respectively.

From Ethiopian driving rules and regulations speed limits, general rules driving is on the right hand -side of the road. The speed limit for cars and motorcycles is **30-50 km/h** in towns and villages and **100 km/h** outside towns. So, we can take the average urban speed and acceleration for three wheeler 35 km/hrs and Minibus vehicles 30 km/hrs [119].

The result indicated that the total annual mass of HC, CO, NO_x, CO_2 and $PM_{2.5}$ emitted from each categories are as shown blow table 8 in tones. Even though the taxi number in Adama is smaller in numbers but emitted considerably higher pollutant. The cumulative mass of emission is the sum of annual emission mass of CO, HC, NO_x, CO_2 and $PM_{2.5}$ for two categories of vehicles, which are shown in table 8. The result indicated that the average annual mass of tailpipe emission of CO, HC, NO_x, CO_2 and $PM_{2.5}$ are 1599.407, 775.61, 1016.01, 2214.81 tons and 15.353 tons respectively. This does not take into account evaporative hydrocarbon emissions caused by vapor leaks from most fuel tanks and fuel lines, nor does it account for truck and other diesel emissions.

Table 8: Table distribution of annual mass of tailpipe emission of three wheelers and minibus taxi

Vehicle Type	Emission	Calculation (Avg. Emission rate x Annual mileages x No. of Vehicles)	Annual mass Emission in tones
Three wheelers	CO	13.90 g/km x 37960Km x 1.1/10^6 x 2582	1498.62
	HC	6.53 g/km x 37960 KM x 1.1/10^6 x 2582	704.1
	NO_x	1.14g/km x 37960Km x 1.1/10^6 x 2582	122.91
	CO_2	20.16g/km x 37960x 1.1/106x2582	2173.53
	PM2.5 for Diesel	0.54g/km x 37960x 1.1/10^6 x480	10.83
Minibuses	CO	8.4g/km x 35186Km x 1.1/10^6 x 310	100.787
	HC	5.96 g/km x 35186Km x 1.1/10^6 x 310	71.51
	NO_x	3.44g/km x 35186KM x 1.1/10^6x 310	893.1
	CO_2	35.96g/km x 35186 x 1.1/10^6 x 310	41.28
	$PM_{2.5}$ for Diesel	1.3g/km x 35186x 1.1/10^6 x 90	4.523

Beyond the direct adverse of health effects, there are others concerns with HC vehicles' emissions. Among these economic impact is the least but not the last. Since HC is escaping fuel through tail pipe without being burned in the combustion chamber, this unburned fuel can be stated as wasted liquid fuel. The total amount of wasted fuel is 775.61 tone (775610 kg) per year. It can be converted in to volume (liter) using equation 10. By assuming density of gasoline fuel is 0.780 kg/L at 15 degree Celsius (Ethiopian petroleum agency) and hence 994371.79 liters of fuel annually wasted to the atmosphere due to only running emission of gasoline vehicles in Adama. It can be further estimated the cost with current price 0.78 dollar per liter which is almost equal to $775,609.99 US dollars.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main aim of this research was to determine the level of emission from vehicle exhaust gases in Adama. The analysis of emissions was done on three wheelers and public minibuses taxi vehicles which amount to 80% of the automobile population in Adama city. It was found that emissions from both types of vehicles like CO, NO_x, HC, PM and CO_2 levels are well above worldwide standards for human and environmental health. This indicates that improper functioning and maintenance of causes for pollution from vehicles in Adama.

The emissions study has given basic information about emission and vehicle conditions from vehicles were tested. The key findings of the results are:

- The gasoline minibus and three wheelers generate 100.787 tons and 1498.62 tons of CO respectively.
- The gasoline minibus and three wheelers generate 71.51 tons and 704.1 tons of HC respectively.
- The gasoline minibus and three wheelers generate 893.1 tons and 122.91 tons of NO_x respectively.
- The gasoline minibus and three wheelers generate 41.28 tons and 2173.53 tons of CO_2 respectively.
- The diesel minibus and three wheelers generate 4.523 tons and 10.83 tons of $PM_{2.5}$ respectively.
- The average CO corrected emission rate of minibuses and three wheelers are 8.4 g/km and 13.9 g/km respectively.
- The average HC corrected emission rate of minibuses and three wheelers are 5.96 g/km and 6.53 g/km respectively
- The average NO_x corrected emission rate of minibuses and three wheelers are 3.44 g/km 1.14 g/km respectively
- The average CO_2 corrected emission rate of minibuses and three wheelers are 35.96 g/km and 20.16 g/km respectively
- The average $PM_{2.5}$ corrected emission rate of minibuses and three wheelers are 1.3 g/km and 0.54 g/km respectively

- ❖ Gasoline three wheelers vehicles contribute to a disproportionally high share CO and HC emissions. But minibus taxis are major contributors of NO_x emissions. The finding indicate that almost all vehicles do not pass the standard put by different countries, USA Euro I, and India.
- ❖ Diesel minibus vehicles are the major contributor to $PM_{2.5}$ and CO_2 emissions.
- ❖ Only a few of new gasoline and diesel vehicles meet the international standards of USA and India.

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 3.44 g/km, HC emissions at 6.53 g/km, CO at 13.9 g/km, $PM_{2.5}$ at 1.3 g/km and 35.96 g/km 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.

- ➢ Introduction of more efficient automobiles with improved fuel economy.
- ➢ Introduction of tail pipe emission standards,
- ➢ Use of alternative fuels such as biofuels
- ➢ Encouraging alternative modes of transport such as walking and cycling and,
- ➢ Carpooling to allow more occupants per vehicle

The situation is serious enough that urgent regulatory actions are strongly needed, as recommended below.

6.2 Recommendations

Adama has an older vehicle population comprising many vehicles which are imported from other countries. Such vehicles usually with high mileage and long years of service. From this study it was found that those old vehicles being used in Adama are polluting the atmospheric air at a much higher rates than the similar vehicles within the United States, this implies the poor state of maintenance of vehicles in Adama. Taxicabs, which seem to be a common means of transportation for many of Adama residents, appear to be the worst in terms of pollution.

Several mitigation methods that can be considered for implementation at policy level to ensure a sustainable transport sector in Adama have been reviewed under chapter two. 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 Adama 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 Adama city.
- The country should introduce a limit on the type of vehicles that are imported. Currently, there are no standards, what so ever, on the vehicle importation.
- Even though the countries introduce emission standards. However, the stated standard more focused on industrial sector and in vehicle emission the dominant polluter like HC does no stated so, they must clearly specify each emission types at different vehicle operating conditions.
- To ensure compliance with applicable exhaust emission standards, a vehicle inspection and maintenance (I/M) program should be implemented. A program requiring annual inspections of all three- wheel, two-wheel and other vehicles subject to emissions regulations is recommended.

To address air quality problems within Adama, emissions from motor vehicles should be the primary focus. In many countries, vehicle emission problems for older vehicles will tend to be resolved in time simply through vehicle fleet turnover; new vehicles replacing retiring older vehicles. Given the economic distress in Ethiopia, this is not a reasonable expectation, at least in the short run. For the same reason, it can be expected that most vehicle owners do not have the resources to repair the oldest and dirtiest vehicles.

6.2.1 Short-Term

Expand and enhance automotive education and training programs to build a core of competent, knowledgeable engineers and technicians.

i) Three wheeler suppliers or dealer must give better training to the technicians /mechanics especially in the aspects of maintaining ignition and fuel system.

ii) Institute an ongoing public awareness program to make the public aware of the poor state of their vehicles, the consequences of this state of disrepair, i.e., that it can cause severe health problems and cause poor fuel economy.

iii) Instead of starting a full citywide vehicle inspection program, start one for taxis only. To be registered initially, and periodically afterward, taxis would have to be in good enough repair to pass the inspection.

iv) If an Inspection and Maintenance program is implemented, a government subsidy could be granted to at least partially cover the cost of repairs, as California currently does. Initially, no penalties should be attached to failing the inspections, but within a year, very loose pass/fail standards should be implemented based on the data gathered. Gradually, over a period of years, the standards should be tightened.

v) In Ethiopia there is no statutory restriction on the number of years a vehicle can be on road. Statutory age limits for all vehicles should be passed by the government but compulsory inspection was done by private organization starting before two year these need government attention to assure whether the vehicle fulfill the requirements.

vi) The annual vehicle inspection program should consider emission rather than inspecting other exterior parts.

vii) Government should encourage purchase of new vehicle than old vehicles by reducing new vehicle taxation and by doubling the old vehicle tax.

6.2.2 Long-Term

- Set governmental standards requiring an ever-increasing fraction of the imported vehicles to be new; i.e., not previously driven.
- Develop better mass transportation: busing, trains, bike lanes, etc.
- After 6.2.1 (ii) is well underway, start encouraging people to use public transportation, to walk, and to bicycle. Emphasize the health benefits.

- Start a government-sponsored program to at least partially fund upgrading the buses, perhaps converting them to run on compressed natural gas (CNG) or some other alternative fuel.

6.3 Further work

This research has attempted to fill in some of the gaps concerning emission studies in Adama city. The biggest achievement has been the characterization and quantification of vehicles emissions in Adama 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 vehicle growth rates.
- The emission measurements from heavy duty vehicles, which is also to be done in future work, to thoroughly understand the pollution level in Adama.
- There is a 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.
- Characterization of PM emission variation from the exhaust during different operation modes may lead to the identification of variables affecting PM levels in the exhaust.
- This study does not include Evaporative emission losses from vehicles and refueling area.

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APPENDIXS

Appendix –A- Questioners for operators/derivers **ለአሽከርካሪዎች የተዘጋጀ መጠይቅ**

Dear Respondent,

Your response to the following short questions about your vehicle will be highly appreciated. / ስለተሽከረካሪያችሁ ለተጠየቃችሁት አጭር ጥያቄ ለምትመልሱት መልስ በመጀመሪያ ምስጋናዩ የላቀ ነው/

Please tick besides the appropriate answer or fill in the space where necessary. /እባኮትን በተሰጡት አማራጮች ላይ መልስ ይሆናል ያሉት በማክበብ ወይም በተሰጠው ክፍት ቦታ መልሰን ያስቀምጡ

Vehicle type/የተሽከርካሪው ዓይነት: ☐ Minibus Taxi **/ሚኒባስ ታክሲ** ☐ Three-wheelers/ሦስት እግር

Fuel used/የሚጠቀመው የነዳጅ አይነት: ☐ Diesel /ናፍጣ ☐ Gasoline **/ቤንዝል**

1. How did you purchase your car? /በምን አይነት ሁኔታ ነው ተሽከርካሪዎትን የገዙት
   a) Brand new car/በአዲስነቱ
   b) Used car but never used in Ethiopia/ያገለገለና ሆኖም ያለጠፈ
   c) Already registered/ያገለገለና የለጠፈ

2. How long have you had your car?/ለምን ያህ ጊዜ ተሽከርካሪዎት ተጠቅመውበታል/አሽከርክረውታል
   a) Less than 1 years/ከአንድ ዓመት በታች
   b) 1— 2years/ከአንድ እስከ ሁለት ዓመት
   c) 2—3 years /ከ ሁለት እስከ ሦስት ዓመት
   d) More than 3 years/ ከሦስት ዓመት በላይ

3. Does your vehicle odometer is functional? የተሽከሪካሪዎ ኦዲዮ ሜትር በትክክል ይሠራል
   a) Yes/ አዎ በትክክል ይሠራል /
   b) No/ አይ አይሠራም /

4. How often do you take your car for servicing? በምን አይነት አጋጣሚ ነው የተሽከርካሪዎን ጥገና የሚያካሄዱት
   a) Rarely/ከብዙ ቆይታ በኃላ
   b) Sometimes/አልፎ አልፎ
   c) Often/ብዙ ጊዜ/በተደጋጋሚ

5. Averagely how much do you spend on fuel per day/የነዳጅ ፍጆታህ በቀን ምን ያከል ነው/
   Per day? /በቀን/ ---

6. Do you know about the impact of emissions on humans?/ ከተሽከርካሪ የሚወጣው ጭስ በሰዎች ላይ የሚያሳድረው ተጽዕኖ ያውቃሉ/
   a) Yes /አዎ አውቃለሁ
   b) No/አይ አላውቅም

7. Are you willing to participate in any measures aimed at reducing vehicle emissions in Adama city?/በአዳማ ከተማ ላይ የተሽከርካሪ የጭስ ልቀት መጠን ለመቀነስ ለሚደረገው እርምጃ ለመተባበር ፈቃደኛ ኖት

a) Yes / አዎ ፈቃደኛ ነኝ /
b) No/ አይ ፈቃደ አይደለሁም /

8. How do you feel the pollution from vehicle in Adama? በአዳማ ከተሽከርካሪ የሚለቀቀው ጭስ ተሰምቶህ ያውቃል

a) Yes/ አዎ በደንብ ተሰምቶኝ ያውቃል
b) No/አይ ምንም ተሰምቶኝ አያቅም

Appendix – B- Test Report

Test Information

Test date: --------------------& Time:-------------------   *Test site:----------------------------*

Inspector's name---------------------------   *Exhaust analyzer Model ---------------------*

Vehicle information

License #:----------------   *Model year:---------------*   *Engine capacity:-------------------*
Manufacturer:----------------------   *Model:-------------------*   *Mileage:----------------Km*
No. of cylinder:----------------   *Vehicle type:* ☐ *Taxi Mini bus* ☐ *Three wheelers*
Fuel used: ☐ *Gasoline, leaded* ☐ *Gasoline, unleaded* ☐ *Diesel fuel*

Visual Inspection: Emission Control system

Emission control system	***Existing***	***Broken***	Not existing	Disconnected
PCV				
EGR Valve				
Thermostatic Air Cleaner				
Carburetor				
Fuel Injection				
Air Injection				
Catalytic Convertor				
Fuel Evaporative Controls				
Other Emission-Related Comp.				

Tailpipe Emissions Test

Targeted RPM	*Actual RPM*	*Co_2%*	*CO %*	HC (ppm)	NO_x (ppm)	$PM_{2.5}$ %
2500						
Idle						

Comments: ---- --

Inspector signature ------------------

Appendix – C- FGA 4000XDS Specifications

Portable Automotive Exhaust Gas Analyzer Manufactured by Infrared Industries

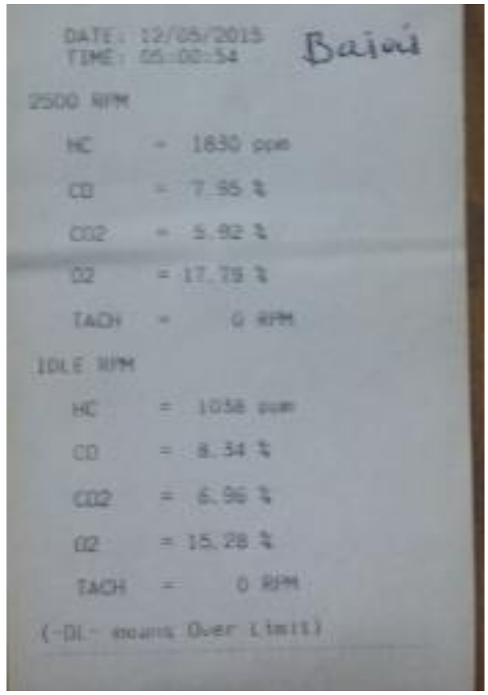
Specification	
Gases and Ranges	(within 1% full- scale accuracy)
Hydrocarbons (HC)	0-10,000 PPM (n-Hexane)
Carbon Monoxide (CO)	0-10%
Carbon Dioxide (CO_2)	0-20%
Oxygen (O_2)	0-25%
Tachometer	(Displayed as KRPM = 1,000 RPM) 0-30,000
Air to Fuel Ratio	0-50%
Display Six windows	4-digit LEDs
NDIR	HC, CO, CO_2
O_2	Chemical cell
Accuracy -	BAR-90 Certified. Meets BAR-97 Performance Specifications and Canada's Air Care Certified
Warm-Up Time	Five minutes or less
AC Power	110VAC / 220VAC +/- 10%, 50/60 Hz 0.5A / 0.3A max
AC Voltage Range	90V – 240V
DC Power	10VDC – 16VDC, 1.5A nominal, 3.5A max
Weight	9 Lbs. (4.1 kg)
Size	(W x L x D) 13.2″ x 10.8″ x 6.5″ (33.5 cm x 27.4 cm x 16.5 cm)
Temperature	40^0C

Appendix –D- Smoke Opacity Meter Specifications

Portable Smoke Opacity Meter Specifications
Manufactured by Infrared Industries

Specification	
Light source	Led-Green Gallium Phosphide 570 NM
Light Sensor	Si Photo Diode with IR Filter
Display	(Backlit) Liquid Crystal Display (LCD)
Meter Accuracy	+/-1.0% Normal. +/- 10 digit
Peak hold	No Drift
Recorder Output	0-1 Volt or 0-1 MA
Charging Transformer	120 VAC 22 Watts in /18 VDC @ 800 MA out
Control Unit Dimensions size	4" W x 8" D x 4" H
Range	0.0%-100% Opacity
Warm-Up Time	Negligible
Response Time /Display	0.45 seconds for 0-90% Opacity
Linearity	+/- 1% from 0-100% Opacity
Zero Stability (Drift)	Less than 1% in 60 minutes
Temperature Stability	+ / – 1% from 32^0 F-120^0 F
AC Power	110VAC / 220VAC +/- 10%, 50/60 Hz 0.5A / 0.3A max
Weight	(2 kg)

Appendix –E- Sample Exhaust Gas Analyzer Printout



DATE: 12/05/2015
TIME: 05:00:54

Bajaj

2500 RPM

HC = 1830 ppm
CO = 7.95 %
CO2 = 5.92 %
O2 = 17.79 %
TACH = 0 RPM

IDLE RPM

HC = 1058 ppm
CO = 8.34 %
CO2 = 6.96 %
O2 = 15.28 %
TACH = 0 RPM

(-OL- means Over Limit)

Appendix –F – Indian Emission Standards for Passenger Cars & Light Commercial Vehicles

Automotive Vehicles / Engines

I) Emission Standards for 2 & 3 Wheeler Vehicles

Scope : 2W (Gasoline), 3W (Gasoline & Diesel)

Type I Test :
Exhaust emissions (IDC)

Type II Test :
Spark Ignition - Idle CO - HC
Compression Ignition (3W only) - Free acceleration Smoke

Deterioration Factors

Engine category	CO	HC+NOx	PM
2W (Gasoline engines)	1.20	1.20	-
3W (Gasoline/ Gaseous fuelled engines)	1.20	1.20	-
3W (Diesel engines)	1.10	1.00	1.20

Type V Test
The durability of Anti Pollution Device is determined either by an actual durability run over 80 000 km or by application of a fixed deterioration factor

Fixed Deterioration Factors

Engine category	CO	HC	NOx	HC+NOx	PM
Gasoline/Gaseous fuelled engines	1.2	1.2	1.2	NA	-
Diesel Engines	1.1	NA	1	1	1.2

Appendix –G – Emission Standards Limits for Bar-90 Two-speed Idle Test

TABLE III

Emission Standards, Gross Polluter Standards, Dilution Thresholds and Maximum Idle RPM Limits for BAR-90 Two-Speed Idle Test

(Effective with 1996 ET Software Update)

ESC	MODEL YEAR GROUP	VEHICLE TYPE (by GVWR) PASSENGER	TRUCK (includes motorhome, minivan, sport utility)				PASS/FAIL STANDARDS				GROSS POLLUTER STANDARDS				MIN $CO+CO_2$	MAX IDLE RPM
		<6,001	<6,001	6,001 to 8,500	8,501 to 14,000	>14,001	IDLE HC	IDLE CO	2500 HC	2500 CO	IDLE HC	IDLE CO	2500 HC	2500 CO		
1	1966-1967	X	X				700	5.5	600	4.5	950	8.0	850	7.0	8.0	1100
2	1968-1970	X	X				650	5.5	600	4.5	900	8.0	850	7.0	8.0	1100
3	1971-1974	X	X				550	5.0	400	4.0	800	7.5	650	6.5	8.0	1100
4	1975-1980	X					220	2.0	180	1.7	470	4.5	430	4.2	8.0	1100
5	1981-1983	X					120	1.5	150	1.5	270	3.0	300	3.0	8.0	1100
6	1984-1986	X					120	1.0	150	1.2	270	2.5	300	2.7	7.0	1100
7	1987-1992	X					120	1.0	140	1.0	270	2.5	290	2.5	7.0	1100
8	1993+	X					100	1.0	130	1.0	250	2.5	280	2.5	8.0	1100
9	1975-1978		X				250	2.5	200	3.0	500	5.0	450	5.5	7.0	1100
10	1979-1983		X	X			250	2.0	200	2.0	400	3.5	350	3.5	8.0	1100
11	1984-1987		X	X			150	1.2	180	1.2	300	2.7	330	2.7	7.0	1100
12	1988-1992		X	X			120	1.0	180	1.0	270	2.5	330	2.5	8.0	1100
13	1993+		X				100	1.0	170	1.0	250	2.5	320	2.5	7.0	1100
14	1993+			X			100	1.0	180	1.1	250	2.5	330	2.6	7.0	1200
15	1966-1969			X	X	X	700	5.5	750	5.0	950	8.0	1000	7.5	7.0	1200
16	1970-1973			X	X	X	550	5.0	600	4.5	800	7.5	850	7.0	8.0	1200
17	1974-1978			X	X	X	300	3.0	350	3.5	550	5.5	600	6.0	7.0	1200
18	1979-1983				X	X	250	2.2	250	3.0	400	3.7	400	4.5	7.0	1200
19	1984-1986				X	X	250	1.5	200	1.6	400	3.0	350	3.1	7.0	1200
20	1987-1990				X		220	1.5	200	1.6	370	3.0	350	3.1	7.0	1100
21	1991+				X		150	1.2	150	1.5	300	2.7	300	3.0	7.0	1100
22	1987-1990					X	250	2.5	200	1.6	400	4.0	350	3.1	7.0	1100
23	1991+					X	150	1.5	150	1.5	300	3.0	300	3.0	7.0	1100

Legend:

ESC = Emissions Standards Category

GVWR = Manufacturer's Gross Vehicle Weight Rating

MIN. $CO + CO_2$ = Minimum $CO + CO_2$ dilution threshold

MAX. IDLE RPM = Maximum Idle RPM limits

PASS/FAIL STANDARDS = Emission standards used to determine if a vehicle passes the emissions portion of the inspection. A vehicle passes if the emission levels are equal to or less than the hydrocarbon or carbon monoxide standard for the idle or 2500 RPM inspection.

GROSS POLLUTER STANDARDS = Emissions standards used to designate a vehicle as a gross polluter. A vehicle is designated as a gross polluter if the emissions levels at the time of the initial inspection, are greater than the gross polluter standards for hydrocarbon or carbon monoxide for the idle or 2500 RPM inspection.

NOTE:

If test data on emission pass/fail rates or gross polluter identification rates indicate adjustments are required, the emission standards may be increased or decreased by the bureau by 30% or by the following tolerances, or standards may be set for any specific vehicle and engine configuration which the bureau determines has excessive errors of commission or omission, whichever is necessary to comply with section 44001.5 of the Health and Safety Code.

HC = 150 ppm, CO = 1.50%, NO = 350 ppm, $CO+CO_2$ = 5%, Maximum Idle RPM = 500 rpm

Appendix- H- Maintenance and Inspection schedule for three wheelers

Bajaj had pointed out that their analysis clearly shows that the primary cause of smoke emission is lack of proper maintenance of the vehicle as per recommended schedules and use of sub-standard change parts.

A method to reduce emission from three-wheelers

- Use quality engine oil

The visibility level of smoke can be controlled by using the latest quality of oil that is optimally required by the engine.

- **Replacing proper Piston Rings**

In three-wheelers, visible smoke emission is due to excessive lube oil consumption because of abnormal wear of piston rings/cylinder liner. The purpose of piston rings is to maintain a pressure tight seal between the piston and cylinder wall, to aid in controlling oil, to permit proper lubrication of the cylinder and to assist in the cooling of the piston. The quality of the piston ring is important factor. With poor quality piston rings, it is possible that lubricating oil leaks from oil sump to the combustion chamber causing smoke. Piston rings are designed with faces of different widths to satisfactorily maintain compression and reduce oil consumption.

- **Periodical adjusting ignition/ injection timing**

We know that ignition/injection timing has direct impact on both HC and NO_x emission of a given engine. So to alleviate this problem periodic inspection or adjustment is required.

- **Frequently cleaning of air intake system**

Air filters need to be inspected regularly and replaced as often as needed, regardless of mileage or time. Dirty air filters can increase fuel consumption and exhaust emissions. Optimisation of engine air intake system, including improvement of air cleaning system or periodically cleaning the air cleaner.

- **Optimisation of engine cooling system**

  Replacing coolant on a regular basis will prolong the life of the radiator and other cooling system components.

- **Checking the condition of sparkplug frequently**
- **Recommendations for changing filters**
- **Maintain engine overhaul based on stated time/miles**

Appendix- I- Maintenance and Inspection schedule for minibuses

- Improved maintenance, which leads to lower emissions
- Repairs to emissions equipment made before an emissions test in anticipation of the test
    - Repair of a vehicle's emissions systems as a result of failing a test
    - Length of time repairs last for a vehicle repaired as a result of failing an I/M test
- Early scrapping or transfer of high emitting vehicles outside the I/M region (fleet effects)
- Inspect or adjust valve clearance periodically
- Use quality grade engine oil and replace timely
- Replace genuine oil and fuel filter
- Clean the air cleaner periodically
- Check cooling system and coolant level
- Adjust ignition/injection timing
- Check the functionality of catalytic convertor
- Clean and adjust sparkplug gap
- Maintain engine overhaul based on stated time/miles

Appendix – J- Exhaust Emission Inspected Data for Diesel PM

Test sample for different vehicle types (Diesel)							
Around Adama Post office, Meberate Haile and Bus Station							
At full Acceleration Average value							
	Date	Manufacturer	Model	odo meter R.	Year of Manu.	$Pm_{2.5}$ (%)
1	5/12/2015	Toyota	2L	183425	1995	95.20%
2	5/12/2015	Toyota	2L	695910	1998	14.30%
3	5/12/2015	Toyota	2L	206497	1999	89.40%
4	5/12/2015	Toyota	2L	159331	1999	96.70%
5	5/12/2015	Toyota	2L	15988	1997	97.10%
6	5/12/2015	Toyota	2L	305754	1997	95.00%
7	5/12/2015	Toyota	2L	282646	1996	30.90%
8	5/12/2015	Toyota	2L	176838	1997	96.70%
9	5/12/2015	Toyota	2L	220849	1999	86.50%
10	5/12/2015	Toyota	2L	167431	1996	88.60%
11	5/12/2015	Toyota	2L	357997	1995	100.00%
12	5/12/2015	Toyota	2L	221352	1997	74.87%
13	5/12/2015	Toyota	2L	2527783	1997	96.70%
14	5/12/2015	Toyota	2L	186989	1997	71.80%
15	5/12/2015	Toyota	2L	197503	1999	100.00%
16	5/12/2015	Toyota	2L	182928	1998	93.80%
17	5/12/2015	Toyota	2L	274256	1999	78.20%
18	5/12/2015	Toyota	2L	220690	1998	98.30%
19	5/12/2015	Toyota	2L	183963	1997	100.00%
20	5/12/2015	Toyota	2L	262677	1995	7.50%
21	6/12/2015	Toyota	3L	625236	2002	14.52%
22	6/12/2015	Toyota	3L	285412	2001	41.00%
23	6/12/2015	Toyota	3L	213092	2001	54.80%
24	6/12/2015	Toyota	3L	500000	2002	91.20%
25	6/12/2015	Toyota	3L	493198	2002	15.90%
26	6/12/2015	Toyota	3L	850505	1997	72.60%
27	6/12/2015	Toyota	3L	60878	1992	58.40%
28	6/12/2015	Toyota	3L	277002	2000	99.30%
29	6/12/2015	Toyota	3L	416230	2001	42.90%
30	6/12/2015	Toyota	3L	154000	2001	100.00%
31	6/12/2015	Toyota	3L	429026	2001	72.90%
32	6/12/2015	Toyota	3L	179376	2000	77.90%
33	6/12/2015	Toyota	3L	220000	2001	93.30%
34	6/12/2015	Toyota	3L	229071	2001	100.00%
35	6/12/2015	Toyota	3L	515365	2000	46.60%
36	6/12/2015	Toyota	3L	281086	1999	100.00%
37	6/12/2015	Toyota	3L	14000	2001	44.50%

38	6/12/2015	Toyota	3L	188000	2001	64.50%
39	6/12/2015	Toyota	3L	609916	2000	91.10%
40	6/12/2015	Toyota	3L	380,000	1999	87.30%
41	7/12/2015	Toyota	5L	402836	2004	98.30%
42	7/12/2015	Toyota	5L	193000	2005	96.60%
43	7/12/2015	Toyota	5L	438678	2004	78.20%
44	7/12/2015	Toyota	5L	605897	2004	57.40%
45	7/12/2015	Toyota	5L	187660	2003	97.00%
46	7/12/2015	Toyota	5L	175183	2002	100.00%
47	7/12/2015	Toyota	5L	386038	2003	26.60%
48	7/12/2015	Toyota	5L	200000	2004	99.00%
49	7/12/2015	Toyota	5L	316045	2004	69.80%
50	7/12/2015	Toyota	5L	200000	2005	54.30%
51	7/12/2015	Toyota	5L	272648	2003	86.60%
52	7/12/2015	Toyota	5L	488153	2002	44.20%
53	7/12/2015	Toyota	5L	125830	2005	67.60%
54	7/12/2015	Toyota	5L	390727	2005	28.00%
55	7/12/2015	Toyota	5L	500000	2004	57.40%
56	7/12/2015	Toyota	5L	182861	2003	37.00%
57	7/12/2015	Toyota	5L	316472	2005	66.90%
58	7/12/2015	Toyota	5L	173701	2004	80.40%
59	7/12/2015	Toyota	5L	100712	2003	67.42%
60	7/12/2015	Toyota	5L	192909	2002	78.25%

Test sample for different vehicle types (Diesel)						
Around Adama Post office, Meberate Haile and Bus Station						
At full Acceleration Average value						
	Date	Manufacturer	Model	odo meter R.	Year of Manu.	$Pm_{2.5}$ (%)
1	12/4/2015	Force	RE45	14467	2011	51.10%
2	12/4/2015	Force	RE45	32498	2010	0.20%
3	12/4/2015	Force	RE45	47494	2008	82.10%
4	12/4/2015	Force	RE45	6523	2008	31.10%
5	12/4/2015	Force	RE45	13854	2012	21.80%
6	12/4/2015	Force	RE45	33951	2012	87.90%
7	12/4/2015	Force	RE45	6337	2009	15.91%
8	12/4/2015	Force	RE45	24838	2008	61.50%
9	12/4/2015	Force	RE45	27674	2010	11.70%
10	12/4/2015	Force	RE45	17325	2007	83.90%
11	12/4/2015	Force	RE45	6180	2012	0.30%
12	12/4/2015	Force	RE45	12473	2006	39.10%
13	12/4/2015	Force	RE45	15000	2010	46.60%
14	12/4/2015	Force	RE45	5238	2010	0.50%
15	12/4/2015	Force	RE45	14147	2011	95.60%
16	12/4/2015	Force	RE45	40281	2010	68.90%
17	12/4/2015	Force	RE45	67162	2011	27.20%
18	12/4/2015	Force	RE45	65956	2008	15.30%
19	12/4/2015	Force	RE45	25289	2012	96.00%
20	12/4/2015	Force	RE45	3072	2012	42.02%
21	12/4/2015	Force	RE45	1111	2014	39.90%
22	12/4/2015	Force	RE45	14000	2014	63.30%
23	12/4/2015	Force	RE45	41794	2014	55.20%
24	12/4/2015	Force	RE45	54042	2014	46.90%
25	12/4/2015	Force	RE45	46959	2014	6.40%
26	12/4/2015	Force	RE45	11783	2014	4.50%
27	12/4/2015	Force	RE45	7389	2015	0.30%
28	12/4/2015	Force	RE45	28976	2015	65.70%
29	12/4/2015	Force	RE45	19587	2015	27.40%
30	12/4/2015	Force	RE45	32654	2015	68.20%
31	12/4/2015	Force	RE45	18972	2014	16.40%
32	12/4/2015	Force	RE45	49388	2014	27.60%
33	12/4/2015	Force	RE45	53211	2014	24.60%
34	12/4/2015	Force	RE45	18975	2014	65.60%
35	12/4/2015	Force	RE45	29874	2014	9.50%
36	12/4/2015	Force	RE45	21456	2015	22.80%
37	12/4/2015	Force	RE45	34956	2014	65.00%
38	12/4/2015	Force	RE45	33498	2014	0.50%

39	12/4/2015	Force	RE45	7920	2015	40.80%
40	12/4/2015	Force	RE45	9873	2015	16.10%
41	12/4/2015	Force	RE45	39872	2013	12.50%
42	12/4/2015	Force	RE45	16320	2013	27.80%
43	12/4/2015	Force	RE45	31596	2013	4.70%
44	12/4/2015	Force	RE45	26541	2013	22.30%
45	12/4/2015	Force	RE45	28352	2013	3.60%
46	12/4/2015	Force	RE45	36897	2013	6.20%
47	12/4/2015	Force	RE45	19876	2013	56.80%
48	12/4/2015	Force	RE45	18632	2013	32.00%
49	12/4/2015	Force	RE45	16743	2013	0.40%
50	12/4/2015	Force	RE45	35799	2013	28.10%
51	12/4/2015	Force	RE45	28976	2013	35.60%
52	12/4/2015	Force	RE45	19587	2013	32.20%
53	12/4/2015	Force	RE45	32654	2013	40.00%
54	12/4/2015	Force	RE45	18972	2013	44.50%
55	12/4/2015	Force	RE45	49388	2013	17.60%
56	12/4/2015	Force	RE45	53211	2013	0.20%
57	12/4/2015	Force	RE45	18975	2013	92.30%
58	12/4/2015	Force	RE45	29874	2013	0.20%
59	12/4/2015	Force	RE45	21456	2013	21.60%
60	12/4/2015	Force	RE45	34956	2013	47.40%

Appendix -H- Exhaust Emission Inspected Data for gasoline Vehicles

Test sample for different vehicle types (Gasoline)											
Around Adama Post office, Meberate Haile and Bus Station											
				odo meter R.	At 2500 rpm			At Idle			@ Full accl.
	Date	Model	Year		HC ppm	CO%	CO_2%	HC ppm	CO%	CO_2%	Nox ppm
1	3/12/2015	Bajaj	2012	14467	153	8.82	9.3	1138	5.68	6.05	0.87
2	3/12/2015	Bajaj	2012	32498	284	9.94	9.38	434	2.52	3.03	1.13
3	3/12/2015	Bajaj	2010	47494	499	8.95	5.85	304	4.76	3.91	1.45
4	3/12/2015	Bajaj	2010	6523	111	1.22	7.71	544	0.29	8.32	0.89
5	3/12/2015	Bajaj	2012	13854	274	8.73	7.08	121	2.07	3	1.09
6	3/12/2015	Bajaj	2010	33951	259	0.68	2.89	363	0.62	3.18	1.01
7	3/12/2015	Bajaj	2012	6337	369	6.07	8.6	140	5.25	10.57	1.15
8	3/12/2015	Bajaj	2010	24838	216	3.48	9.86	158	3.73	11.17	0.96
9	3/12/2015	Bajaj	2010	27674	214	7.34	7.14	628	0.27	2.27	0.95
10	3/12/2015	Bajaj	2011	17325	259	0.68	2.89	363	0.62	3.18	1.03
11	3/12/2015	Bajaj	2010	6180	1916	7.21	4.9	2591	2.16	1.06	5.24
12	3/12/2015	Bajaj	2012	12473	255	8.47	6.44	292	2.67	2.86	1.09
13	3/12/2015	Bajaj	2012	15000	199	6.39	6.63	612	0.43	1.72	0.93
14	3/12/2015	Bajaj	2011	5238	539	8.35	8.29	471	8.02	7.61	1.36
15	3/12/2015	Bajaj	2012	14147	262	10.23	9.19	892	7.69	5.08	1.11
16	3/12/2015	Bajaj	2012	40281	271	10.74	6.94	483	3.88	3.44	1.12
17	3/12/2015	Bajaj	2012	67162	38	0.22	11.34	75	1.09	1.32	0.46
18	3/12/2015	Bajaj	2010	65956	228	3.38	9.66	164	3.73	11.17	0.98
19	3/12/2015	Bajaj	2011	25289	118	1.22	7.71	544	0.29	8.32	0.87
20	3/12/2015	Bajaj	2012	3072	340	4.06	3.27	1032	8.65	5.27	1.04
21	3/12/2015	Bajaj	2013	1111	75.8	9.42	17.93	243	7.46	9.24	1.07
22	3/12/2015	Bajaj	2013	14000	126	9.39	16.57	182	6.31	10.13	1.12
23	3/12/2015	Bajaj	2014	41794	197	13.2	16.28	266	1.08	2.75	1.09
24	3/12/2015	Bajaj	2013	54042	1004	9.25	14.18	920	3.14	4.06	1.23
25	3/12/2015	Bajaj	2013	46959	185	6.16	19.58	243	10.15	7.09	1.21
26	3/12/2015	Bajaj	2013	11783	249	12.42	17.95	826	0.07	2.74	0.97

27	3/12/2015	Bajaj	2015	7389	96	12.09	16.24	78	1.08	2.93	0.68
28	3/12/2015	Bajaj	2013	28976	104	4.38	4.38	276	9.71	7.64	1.3
29	3/12/2015	Bajaj	2014	19587	148	10.18	18.47	283	1.09	1.95	1.11
30	3/12/2015	Bajaj	2015	32654	217	12.22	18.38	245	3.25	8.76	1.24
31	3/12/2015	Bajaj	2013	18972	309	9.56	20.67	176	0.78	1.07	0.97
32	3/12/2015	Bajaj	2013	49388	119	7.74	16.98	149	0.45	0.98	0.98
33	3/12/2015	Bajaj	2013	53211	187	7.14	17.34	628	0.27	2.27	1.05
34	3/12/2015	Bajaj	2013	18975	168	2.89	29.71	363	0.62	3.18	1.12
35	3/12/2015	Bajaj	2014	29874	127	4.9	18.02	2591	2.16	1.06	5.4
36	3/12/2015	Bajaj	2015	21456	98	6.44	20.68	292	2.67	2.86	1.31
37	3/12/2015	Bajaj	2014	34956	182	6.78	19.53	197	0.54	12.69	1.43
38	3/12/2015	Bajaj	2014	33498	231	4.56	18.51	287	0.76	3.17	0.87
39	3/12/2015	Bajaj	2015	7920	118	3.68	22.59	157	0.58	2.33	0.95
40	3/12/2015	Bajaj	2015	9873	171	3.77	24.4	44	1.94	2.62	1.02
41	5/12/2015	Bajaj	2007	39872	126	6.19	6.39	329	2.68	2.37	1.06
42	5/12/2015	Bajaj	2007	16320	87	6.19	7.85	456	1.41	1.95	1.21
43	5/12/2015	Bajaj	2006	31596	171	5.73	8.05	164	0.25	1.73	1.03
44	5/12/2015	Bajaj	2007	26541	129	3.71	6.83	148	1.67	1.94	1.09
45	5/12/2015	Bajaj	2007	28352	277	3.75	3.46	193	4.13	3.8	0.98
46	5/12/2015	Bajaj	2007	36897	1830	7.95	5.92	1038	8.34	6.96	3.23
47	5/12/2015	Bajaj	2008	19876	355	2.28	11.25	141	0.39	11.62	0.68
48	5/12/2015	Bajaj	2007	18632	290	3.81	6.05	145	4.36	8.37	0.79
49	5/12/2015	Bajaj	2008	16743	303	4.08	3.68	134	4.53	6.25	1.11
50	5/12/2015	Bajaj	2007	35799	159	5.74	5.88	855	1.29	1.09	0.94
51	5/12/2015	Bajaj	2007	28976	501	4.21	5.12	347	1.16	7.5	0.48
52	5/12/2015	Bajaj	2007	19587	69	2.53	14.83	114	0.14	6.62	0.75
53	5/12/2015	Bajaj	2008	32654	462	4.87	6.87	457	3.41	6.35	1.34
54	5/12/2015	Bajaj	2007	18972	105	3.13	9.06	167	2.63	6.81	1.08
55	5/12/2015	Bajaj	2008	49388	102	2.19	8.13	158	1.95	5.07	0.63
56	5/12/2015	Bajaj	2008	53211	120	3.86	11.03	242	1.69	3.42	1.04
57	5/12/2015	Bajaj	2008	18975	71	0.25	9.12	138	2.45	4.19	0.85
58	5/12/2015	Bajaj	2009	29874	173	4.11	4.64	78	1.04	1.97	0.49

59	5/12/2015	Bajaj	2009	21456	93	1.52	9.3	609	0.13	2.57	0.09
60	5/12/2015	Bajaj	2009	34956	867	0.25	11.23	791	2.3	5.66	1.4
61	5/12/2015	TVS	2013	17325	149	0.5	12.5	105	1.04	5.94	0.71
62	5/12/2015	TVS	2012	6180	207	0.23	10.67	196	0.32	0.71	0.91
63	5/12/2015	TVS	2011	12473	522	1.82	6.78	197	0.54	12.69	1.6
64	5/12/2015	TVS	2015	15000	124	2.3	4.56	287	0.76	3.17	0.78
65	5/12/2015	TVS	2011	5238	170	0.18	3.68	157	0.58	2.33	0.98
66	5/12/2015	TVS	2013	14147	128	1.71	3.77	44	1.94	2.62	0.81
67	5/12/2015	TVS	2013	40281	90	0.22	10.82	458	0.32	1.19	0.68
68	5/12/2015	TVS	2014	67162	92	3.06	5.71	168	0.77	1.16	0.51
69	5/12/2015	TVS	2012	65956	158	3.79	3.72	387	2.78	2.36	0.81
70	5/12/2015	TVS	2015	25289	118	0.13	6.16	174	0.3	0.93	0.61
71	5/12/2015	TVS	2012	3072	49	0.04	0.12	24	0.01	0.03	0.48
72	5/12/2015	TVS	2013	1111	88	0.29	10.15	114	0.25	0.6	0.75
73	5/12/2015	TVS	2011	14000	274	2.18	5.33	434	0.75	2.5	0.92
74	5/12/2015	TVS	2013	41794	134	3.07	3.02	396	0.98	0.83	0.67
75	5/12/2015	TVS	2013	54042	65	2.79	4.91	181	0.53	1.14	0.56
76	5/12/2015	TVS	2012	46959	191	3.14	4.13	105	1.14	3.6	0.69
77	5/12/2015	TVS	2013	11783	75	2.16	1.9	134	1.28	1.03	0.85
78	5/12/2015	TVS	2013	7389	15	0.27	8.05	138	1.25	1.23	0.49
79	5/12/2015	TVS	2015	28976	3	0.17	9.58	226	0.79	1.54	0.09
80	5/12/2015	TVS	2013	19587	190	1.29	4.34	212	0.98	3.44	0.69

Test sample for Toyota vehicle types (Gasoline)											
Around Adama Post office, Meberate Haile and Bus Station											
					At 2500 rpm			At Idle			@ Full accl.
	Date	Model	Year	odo meter R.	HC ppm	CO%	CO2%	HC ppm	CO%	CO2%	Nox ppm
1	5/12/2015	3Y	1981	162278	34	0.44	8.82	577	1.46	7.36	2.1
2	5/12/2015	3Y	1986	503771	105	0.14	6.79	369	0.72	6.19	9
3	5/12/2015	3Y	1987	189011	276	1.86	13.86	981	1.6	12.93	2.2
4	5/12/2015	3Y	1987	180433	0	0.87	59.9	320	1.71	60.92	3.25
5	5/12/2015	3Y	1984	652924	375	1.58	60.88	3265	5.08	66.4	7.1
6	5/12/2015	3Y	1985	30748	436	1.93	59.95	777	1.18	59.5	10
7	5/12/2015	3Y	1984	118643	13	0.12	6.93	133	0.42	3.13	7.1
8	5/12/2015	3Y	1985	258809	64	0.71	7.87	290	0.6	5.81	7
9	5/12/2015	3Y	1986	230794	400	3.72	12.53	912	4.57	10.78	6.2
10	5/12/2015	3Y	1983	383439	1436	3.1	5.38	1422	0.29	4.72	8.1
11	5/12/2015	3Y	1988	278993	104	1.18	8.93	408	0.35	6.45	1.4
12	5/12/2015	3Y	1986	264019	49	0.41	8.72	1497	3.91	5.33	2.3
13	5/12/2015	3Y	1986	211970	59	3.2	7.13	190	1.64	5.36	0
14	5/12/2015	3Y	1986	428563	149	1.01	8.52	970	1.98	6.55	5.2
15	5/12/2015	3Y	1988	284936	70	0.95	8.2	215	1.08	7.91	1.3
16	5/12/2015	3Y	1986	342520	61	1.92	8.04	207	1.78	7.84	2.6
17	5/12/2015	3Y	1985	284018	141	2.96	7.5	624	4.53	4.9	3.3
18	5/12/2015	3Y	1988	208907	153	1.07	8.8	1928	4.08	4.37	5.4
19	5/12/2015	3Y	1983	375525	63	3.01	7.13	190	1.64	5.36	0.8
20	5/12/2015	3Y	1983	150999	94	1.7	8.32	246	2.55	7.27	0.75
21	5/12/2015	2Y	1982	108045	911	2.13	11.97	1670	1.35	10.76	7.2
22	5/12/2015	2Y	1985	169820	728	8.3	8.64	653	5.93	9.32	6.8
23	5/12/2015	2Y	1985	11446	222	0.62	14.08	1210	0.29	12.33	0.6

24	5/12/2015	2Y	1984	415738	177	2.99	7.19	1231	3.81	5.05	0.95
25	5/12/2015	2Y	1983	170943	140	2.27	7.39	267	0.67	6.97	1.3
26	5/12/2015	2Y	1984	250231	1891	9.08	6.5	1769	6.67	6.81	0.87
27	5/12/2015	2Y	1986	150215	219	2.97	13.94	423	4.57	12.67	1.03
28	5/12/2015	2Y	1985	113552	243	2.83	14.12	447	4.68	13.76	1.21
29	5/12/2015	2Y	1983	199520	36	0.54	8.82	527	1.36	7.36	2.03
30	5/12/2015	2Y	1985	89305	108	0.85	6.79	369	0.72	6.19	9
31	5/12/2015	2Y	1983	274304	273	1.86	13.86	881	1.6	12.93	2.2
32	5/12/2015	2Y	1985	299975	101	0.87	59.9	320	1.71	60.92	3.25
33	5/12/2015	2Y	1983	331763	155	1.01	8.32	889	1.98	6.55	5.23
34	5/12/2015	2Y	1984	362617	1352	3.1	5.43	1322	0.28	4.52	8.3
35	5/12/2015	2Y	1983	266338	112	1.18	8.25	403	0.35	6.55	1.4
36	5/12/2015	2Y	1984	289344	51	0.41	8.72	1473	3.91	5.33	2.3
37	5/12/2015	2Y	1983	288909	71	3.2	7.13	192	1.64	5.36	0
38	5/12/2015	2Y	1984	468395	163	1.01	8.52	987	1.98	6.55	5.03
39	5/12/2015	2Y	1984	262584	232	0.78	14.08	1213	0.45	12.33	0.83
40	5/12/2015	2Y	1984	342358	50	1.04	8.27	559	4.73	5.2	1.06