POLLUTANT EMISSIONS MEASURED
Rising Transport Pollution in The Accra –Tema Metropolitan Area, Ghana.

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List of Abbreviations

ATMA	Accra Tema Metropolitan Area
AMA	Accra Metropolitan Area
TMA	Tema Municipal Area
BAU	Business As Usual
CBD	Central Business District
CLD	Causal Loop Diagram
CO	Carbon monoxide
CO_2	Carbon dioxide
CNG	Compressed Natural Gas
CEPS	Customs Excise and Preventive Service of Ghana
DVLA	Driver and Vehicle Licensing Authority of Ghana
ECD	Emission Control Devices
EPA	Environmental Protection Agency of Ghana
GPS	Global Positioning Satellite
HC	Hydro Carbon
HDV	Heavy Duty Vehicle
IVE	International Vehicle Emission
LPG	Liquefied Petroleum Gas
LDV	Light Duty Vehicle
MEET	Methodology for Estimating Air Pollutant Emissions from Transport
MT	Motorized Transport
MTTU	Motor Traffic and Transport Unit of the Ghana Police service
MMTC	Metro Mass Transport Company
MB	Metro Bus
NMT	Non Motorized Transport
NOx	Nitrogen oxides
NO_2	Nitrogen dioxide
NMT	Non Motorized Transport
PC	Private Car
PM	Particulate Matter
Pb	Lead
Pt	Platinum
PGE	Petroleum Group Elements
RVP	Reid Vapor Pressure (Fuel Volatility)
SAP	Structural Adjustment Programme
SO_2	Sulphur dioxide
UN-ECE	United Nations Economic Commission for Europe
UTP	Urban Transport Project
VOCE	Vehicle Occupancy Characteristic Enumerator
VOC	Volatile Organic Compounds
2-W	Two Wheel Vehicles

ABSTRACT

This study seeks to estimate the emissions of five pollutants from the operation of motor vehicles within the Accra -Tema Metropolitan Area of Ghana. It uses the methodology for estimating air pollutant emissions from transport, developed for use in the European Union, with some adjustments made to suit local conditions in Ghana, to estimate the current and projected emissions of carbon monoxide, carbon dioxide, volatile organic compounds, nitrogen oxides, and particulate matter, from motor vehicles. It also uses scenarios analysis with the aid of Microsoft Excel to explore current emission trends and three alternative mitigation measures to explore future pollutant emission levels, to ascertain whether or not these measures are effective enough towards reducing future pollutant emissions in the Accra -Tema Metropolitan Area.

The first measure shows how stringent regulations on the use of emission control technologies in vehicles can has on reducing emissions. The second measure looks at the use of metro mass transportation buses in place of passenger cars, and their effect on level of emissions, whiles the final measure stresses the promotion of non- motorized forms of transport, particularly walking and cycling. The results of these scenarios bring to light the essence of focusing attention on addressing the rising trend of emissions towards offsetting any future environmental impacts due to any growth in travel demand.

Keywords*:* Air quality; Pollutant emissions; Motor vehicles; Ghana; Accra -Tema.

1. INTRODUCTION

1.1 Study Area

Ghana is one of the most densely populated countries in West Africa. It has a population of 18.8 million people. The climate is tropical and there are two distinct rainy seasons: May–June and September–October. The average humidity is 80% all year round and temperatures range between 25ºC and 29ºC. Accra, the national capital, is located on Latitude 5º 331 N and Longitude 0º 131 W. Its current population based on a national population and housing census conducted in the year 2000 stands at 1,657,856 (Ghana Statistical Service, 2002). Eighteen miles to the east of the city of Accra is the port city of Tema with a population of 511,459 (Ghana Statistical Service 2000), this brings the total population of the Accra- Tema Metropolitan Area (ATMA)[1] to 2,169,315. These figures reflect the total population resident in the administrative areas defined here as Accra Metropolitan Area (AMA), Tema Municipal Area (TMA) and parts of the Ga district. Accra serves as the governmental and financial center, while Tema is an industrial and port center of the metropolitan are. There is a vibrant interaction between these two cities for obvious reasons, but urban sprawl is fast merging the two cities up in a manner that one hardly realizes any clear cut boundary between them now, as can be seen also from figure 1.1 below.

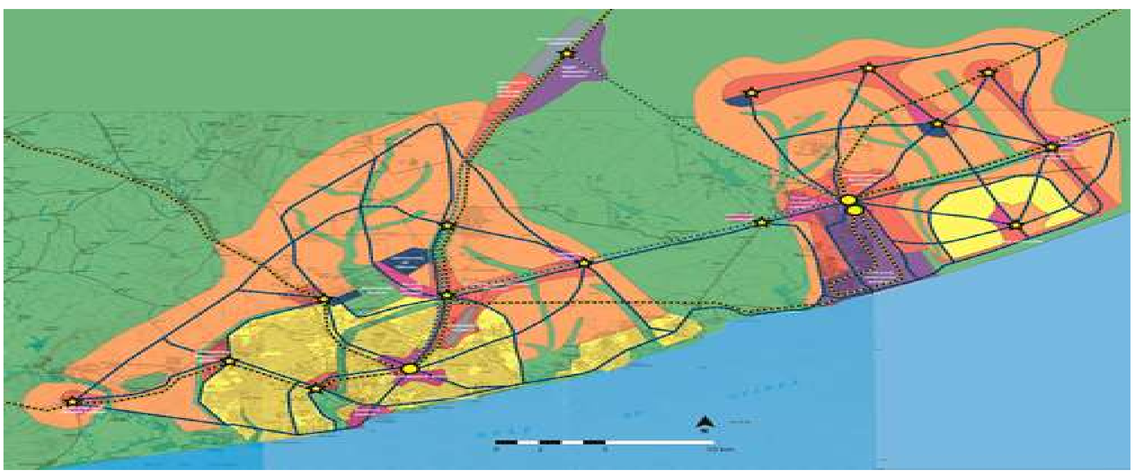


Figure 1.1: Map of the ATMA

Urban transport in the ATMA is synonymous with road transport. The road network in and around the city of Accra is based on a system of radial routes converging on the Central Business District[2] (Addo, 2002; Tamakloe, 1993), as can be seen from the abov figure. A major weakness of the road network is the lack of adequate east-west corridors. What is considered as local roads function principally as access to residential areas. At the moment there are four radials, three of which are heavily used and experience considerable congestion (Addo, 2002; Tamakloe, 1993). Traffic flow per minute on these arteries ranged from 10 to 14 in morning peak hours and 8-12 in evening peak hours in

[1] Administrative areas comprising of Accra Metropolitan Area, Tema Municipal Area, & parts of Ga District.

[2] Referring to the Central Business Districts of both Accra and Tema.

2000 (Segbefia, 2000). Travel speed in Accra is slow and constantly getting worse over the years as vehicle population keeps rising. In the central areas, average peak hour speeds declined by about 12.5% between 1987 and 1990 (Addo, 2002). Since then, there has been continued decline, and current evidence even suggests that travel speed in the Central Business District (CBD) is below 10 km/h. (Kwakye *et al,* 1997). This is mainly due to rising vehicular population, inadequate traffic management facilities and personnel among others.

The road network on the whole is fairly extensive; covering a total of about 950 km, 40% of which represents major and minor arteries while the remaining 60% is considered as local roads. The major and minor arteries experienced significant improvements in surface quality by the late 1990s under the government's urban transport project (Kwakye *et al.,* 1997). The network structure as a whole is however weakened by the haphazard location and management of most terminal and transit points. Most often, residential areas are developed without any consideration of public transport terminals (Addo, 2002; Oppong, 2000). This is, of course, the result of non-adherence to strict planning principles by private developers. Most transport terminals are therefore located either near streets or on privately owned land, which inhibits the development of permanent structures and contributes significantly to the slow flow of traffic in the cities.

1.2 Transport in Ghana

Transport is becoming a vital component of economic development in Ghana. In view of this, the government of Ghana has begun finding ways to make the transport system as efficient as possible to facilitate not only internal trade and industrialization, but also with the West African sub-region in mind. To this end, Ghana is taking advantage of its central geographical location, political and economic stability within the sub-region to market herself as the gateway to her landlocked neighbours by lunching the gateway project. This project, among other things is to develop and maintain transport services and infrastructure, re-organize and rationalize port and custom procedures to facilitated access to the landlocked countries. The project has already started achieving results as both transit freight traffic and trade with the neighbouring countries of Burkina Faso, Niger, and Mali has begun to increase rapidly (Ghana Shippers' Council, 2003.),which is benefiting the economy of Ghana tremendously.

Unfortunately, all this freight is currently handled by road transport, a greater part of which occurs within the ATMA, since the harbour is located in Tema. Even though no study has been conducted to ascertain the actual level of pollutants emitted as a result, it is believed to be a high contributor to the over all level of pollutant emission in the ATMA, not to talk of traffic congestion, road accidents and other environmental impacts as a result.

This is highly unsustainable and if road transport would truly play an effective role as a vital component of the economic transformation of Ghana, then it is important for solutions to be found so as to minimize these adverse impacts on both the environment and residents of the ATMA.

1.3 Rationale

The ATMA alone accounts for more that half the total vehicle population of Ghana, as shown in figure 3.2. The problem of vehicular emissions within the ATMA has been in existence for some time now, yet not much has been done to redress the problem, partly because limited research has been conducted to get the true dimension of the problem and also because, there has not been any formal policy regulating vehicular emissions and monitoring general air quality till now (Kylander *et al.,* 2003). This study therefore contributes towards understanding the enormity of emissions of pollutant substances from vehicles and the various interactions that exist between the various factors that result in this problem.

1.4 Aims and objectives

The main objective of this study is to estimate vehicular sources of pollutant emissions in the ATMA, and to find out if public and non-motorized transportation (in the form of metro-bus programme, walking and cycling) and a policy on the use of emission control devices can be effective measures at reducing current and future levels of pollutant emissions in the ATMA.

The specific objectives are:

1. To estimate the current and future level of pollutant emissions from vehicular sources in the ATMA.
2. To use current pollutant emission trends to run different scenarios with different approaches towards reducing future pollutant emissions from vehicles.
3. To find out through the scenarios whether the various measures are truly effective in reducing pollutant emissions.

1.5 Scope and data limitations

This study looks into the vehicle pollutant emission situation in the ATMA as a system. It looks specifically into sources of pollutant emissions from the various vehicle categories, the amounts generated over the years, policies, and the authorities involved in regulating the use of vehicles. The pollutants under consideration here are; Carbon monoxide (CO); Carbon dioxide (CO_2); Volatile Organic Compounds (VOC); Nitrogen oxides (NO_X); and Particulate matter (PM). Pollutant emissions from industrial activities and other sources are not included in this study. Likewise, agricultural, construction and mining equipments (vehicles) are not considered, as the policy tools and institutional framework regulating their use are totally different from normal vehicles.

2. LITERATURE REVIEW

2.1 Air pollution

Air pollution is the presence of pollutants in the atmosphere from man-made or natural substances in quantities likely to harm human, plant, or animal life; to damage man-made materials and structures; to bring about changes in weather or climate; or to interfere with the enjoyment of life or property (Elsom, 1987). The amount of pollutants released to the atmosphere by fixed or mobile man-made sources is generally associated with the level of economic activity. Meteorological and topographical conditions affect dispersion and transport of these pollutants, which can result in ambient concentrations that may harm people, structures, and the environment. In general, the effects on people are most intense in large urban centers with significant emission sources, unfavorable dispersion characteristics, and high population densities. Although urban air quality in industrial countries has been controlled to some extent during the past two decades, in many developing countries it is worsening and becoming a major threat to the health and welfare of people and the environment (WHO/UNEP 1992).

2.2 Vehicle Emissions

Motor vehicles produce more air pollution than any other single human activity (WRI, 1997). Nearly 50 % of global CO, hydrocarbons (HCs) and NO_2 emissions from fossil fuel combustion come from petrol and diesel engines. In city centres and congested streets, traffic can be responsible for 80-90 % of these pollutants and this situation is particularly severe in cities in developing countries (Whitelegg & Haq, 2003). Vehicle emissions mainly result from fuel combustion or evaporation. The most common types of transport fuels are gasoline (in leaded or unleaded form) for light-duty vehicles (such as cars) and diesel fuel for heavy-duty vehicles (such as buses and trucks). Other commercial fuels used in light-duty vehicles include alcohols (such as ethanol and methanol), gasoline-alcohol mixtures, compressed natural gas (CNG), and liquefied petroleum gas (LPG). For heavy-duty vehicles other commercially available fuels include gasoline, CNG, and LPG. Emissions from motor vehicles with spark ignition engines (for example, gasoline fueled vehicles) are from the exhaust, engine crankcase, and fuel system (carburetor, fuel line, and fuel tank). CO_2 and water vapor (H_2O), the main products of combustion, are emitted in vehicle exhaust (Onursal & Gautam, 1997). The major pollutants emitted from gasoline fueled vehicles are CO, HCs, NO_X, and lead (Pb) (only for leaded gasoline fuel), where as the presence of sulfur compounds in diesel fuel results in sulphur dioxide (SO_2) and PM emissions from the exhaust of diesel-fueled vehicles. Metal sulfates and sulfuric acid in the form of PM constitute 1 to 3 % sulfur emissions from heavy-duty diesel-fueled vehicles and 3 to 5 % of sulfur emissions from light-duty diesel fueled vehicles. They also account for about 10 % of PM emissions from these vehicles (Faiz *et al.,* 1996). In addition, SO_2 may also be present in exhaust gases. The air conditioning system, tires, brakes, and other vehicle components also produce emissions.

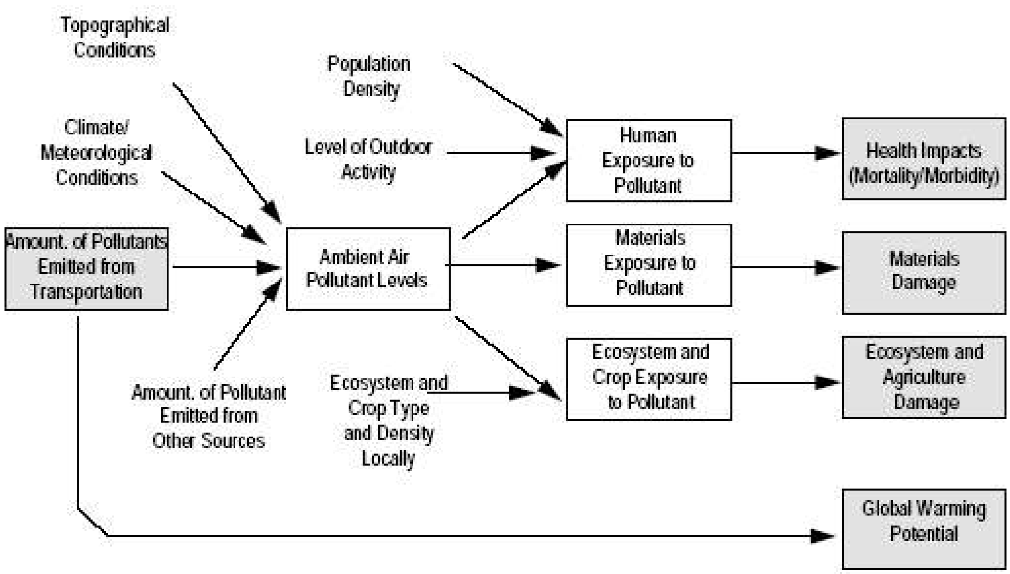
2.3 Vehicle Emission Factors

Real-world vehicle emissions are highly variable. Several factors account for the variability in emissions in different vehicles and the amount of environmental damage they can cause. However, due to relatively higher average temperatures, poor fuel quality, poor vehicle maintenance culture, and high proportion of old vehicles, the level of emissions from mobile sources are usually high.

Factors that influence the amount of environmental damage that occurs from air pollutant emissions include the factors listed below as illustrated in figure 2 below (U.S. EPA, 1996):

- Topographical conditions (hills, valleys, etc.) affect dispersion/dilution of pollutants.
- Climatic conditions (temperature, wind, rain, etc.) affect dispersion/dilution of pollutants and formation of secondary pollutants.
- Population density affects number of people exposed to pollution
- Sensitivity of local ecosystems.

Figure 2.1: Factors that influence the amount of environmental damage that occurs from air pollutant emissions



Source: United States Environmental Protection Agency, 1996.

Sharma and Roychowdhury (1996, p. 45), and Faiz *et al.,* (1996, p. 171) classifies factors influencing motor vehicle emissions into three main groups, namely, Vehicle characteristics, Fleet characteristics and Operating characteristics, as illustrated in figure 3 below.

Figure 2.2: Factors influencing Motor Vehicle Emissions

1. Vehicle/Fuel Characteristics

Engine type and technology—two-stroke, four-stroke; Diesel, Otto, Wankel, other engines; fuel injection, turbo charging, and other engine design features; type of transmission system.
Exhaust, crankcase, and evaporative emission control systems in place—catalytic converters, exhaust gas recirculation, air injection, Stage II and other vapour recovery systems.
Engine mechanical condition and adequacy of maintenance.
Air conditioning, trailer towing, and other vehicle appurtenances.
Fuel properties and quality—contamination, deposits, sulfur, distillation.
Characteristics, composition (e.g., aromatics, olefin content) additives (e.g., lead), oxygen content, gasoline octane, diesel cetane.
Alternative fuels.
Deterioration characteristics of emission control equipment.
Deployment and effectiveness of inspection/maintenance (I/M).
Anti−tampering (ATP) program.

2. Fleet Characteristics

Vehicle mix (number and type of vehicles in use).
Vehicle utilization (kilometers per vehicle per year) by vehicle type.
Age profile of the vehicle fleet.
Traffic mix and choice of mode for passenger/goods movements.
Emission standards in effect and incentives/disincentives for purchase of cleaner vehicles.
Adequacy and coverage of fleet maintenance programs
Clean fuels program.

TOTAL LEVEL OF VEHICLE EMISSIONS

3. Operating Characteristics

Altitude, temperature, humidity (for NOx emissions).
Vehicle use patterns—number and length of trips, number of cold starts, speed, loading, aggressiveness of driving behavior.
Degree of traffic congestion, capacity and quality of road infrastructure, and traffic control systems.
Transport demand management programs.

Source: Adapted from Faiz *et al.,* 1996, p. 171-172.

2.3.1 Ambient temperature and humidity

Ambient temperature has a large direct effect on evaporative HC emissions. Very low ambient temperatures (e.g., below 20 ^{O}F) can influence emissions at ignition and cause the catalytic converters of some vehicles to cool during short stops. Very high ambient temperatures can also have a secondary influence on exhaust emissions because engine load is increased by air conditioner use. Effects can include higher NOx and an increase in the frequency of commanded enrichment. The amount of water vapor in air can affect NOx emissions in older and malfunctioning vehicles, but it appears to have less effect on new vehicles with computer engine control.

2.3.2 Fuel quality

Fuel composition can have a substantial impact on vehicle tailpipe and evaporative emissions. Regulations may require changes in fuel composition according to the season within a region as a strategy to reduce emissions. For instance, some urban areas introduce oxygenates in fuel to reduce CO emissions in the winter and decrease the volatility to reduce evaporative HC emissions in the summer. Legislations on stricter specifications for conventional market fuels in both USA and Europe by the year 2005 (ACEA, EUROPIA, EC, 1995) for instance, are expected to achieve fantastic cuts in vehicular emissions, as shown in table 2.1 below.

Table 2.1: Effect of improved gasoline on the emissions of non-catalyst vehicles

Property	**Change**	**Effect on pollutant emissions**				
		Pb	**CO**	**VOC exhaust**	**VOC evaporative**	**NOx**
Lead	0.15 - 0.08 g/l	-50%	0	0	0	0
Oxygenate	0 – 2.7% O_2	0	-20/-40%	-20/-10%	0/10%	-2/2%
Aromatics	40 – 25%	0	0	-2/-10%	0	-2/10%
Benzene	3 – 2%	0	0	0	0	0
Olefins	10 – 5%	0	-2 / 2%	2 /5%	-2 / 0%	-2/-10%
Sulphur	300-100ppm	0	0	0	0	0
RVP	70 – 60 kPm	0	0	-2/2%	-20%	0
E 100	50 – 60%	0	0/2%	-2/10%	-2/2%	0
E 150	85 – 90%	0	0	-10/-20%	0	2/10%

Source: Adopted from Samaras *et al*., (1998), In ACEA, EUROPIA & EC, 1995**.**

For instance, a 0.15 – 0.08 g/l reduction in the addition lead to fuels results in 50% cuts in lead emissions from vehicles as in table 2.1 above.

The quality of diesel fuel produced in developing countries is generally lower than in industrial countries. Because of the higher demand for diesel fuel in developing countries, refiners have expanded the distillate cut from the atmospheric distillation unit to include the heavier fraction. As a result, diesel fuel in developing countries generally has higher sulfur and more asphaltic and carbonaceous content (Wijetilleke & Karunaratne, 1992). Fuel composition could also vary spatially as some countries have been required or have chosen to adopt year-round reformulated gasoline standards as an emissions-control strategy. These activities undermine the quality of fuels used by motor vehicles which not only deteriorates the mechanical condition of vehicle engines, but also greatly affects the level of pollutants emitted by vehicles as shown in figure 2.2 above, under vehicle/fuel characteristics.

2.3.3 Maintenance and tampering

The degree to which owners maintain their vehicles by providing tune-ups and servicing according to manufacturer schedules can affect the likelihood of engine or emissions control system failure and therefore tailpipe emissions. Outright tampering with vehicles, such as removing fuel tank inlet restrictors to permit fueling with leaded fuel that will degrade the catalytic converter or tuning engines to improve performance, can have a large impact on emissions. Early inspection and maintenance (I/M) programs relied on visual inspection to discourage tampering. The advent of sophisticated on-board computers and sensors has greatly reduced the incentive to improve vehicle performance through tampering. In fact, tampering with the sophisticated electronics installed on today's vehicles will likely reduce performance as well as increase emissions. Requirements for extended manufacturer warranties have led to vehicle designs that are less sensitive to maintenance, at least within the warranty period. Nonetheless, there is evidence that maintenance can still affect real-world emissions from new vehicles, at least on some models (Wenzel, 1997). Improper maintenance or repair can also lead to higher emissions.

2.3.4 Vehicle age and mileage accumulation

As vehicles age and accumulate mileage, their emissions tend to increase all things being equal. This is both a function of the normal degradation of emissions controls of properly functioning vehicles, resulting in moderate emissions increases, and malfunction or outright failure of emissions controls on some vehicles, possibly resulting in very large increases in emissions, particularly CO and HC. This factor is particularly crucial in the case of Ghana where a chunk of the vehicle fleet is composed of second hand vehicles usually imported into the country with an average age of about 13 years before use in Ghana (Kylander *et al*., 2003). Two wheelers (2-W) make an average of 10000 km per annum, where as private cars (PCs), light duty vehicles (LDVs), and heavy duty vehicles (HDVs) make an average of 23000 km per annum (Field survey).

2.3.5 Driving mode and engine load

Vehicle emissions can vary greatly with changing engine load. The relationship between emissions and load depends on the fuel-delivery and emissions-control technology, but as a general rule NOx emissions almost always increase with increasing load. Under high speed and acceleration requirements, today's vehicles are designed to have excess fuel injected into the engine cylinder. This "enrichment" of the air/fuel mixture leads to elevated CO and HC formation during combustion, with no oxygen available for pollutant conversion to CO_2 and water in the catalyst. The result is a temporary "puff" of high tailpipe CO and HC emissions (Goodwin & Ross, 1996). In some vehicles, fuel injection is cut off during rapid decelerations. This can lead to cylinder misfire and a temporary "puff" of high HC emissions (An *et al.,* 1997). Roadway grade and accessory use, such as air conditioning and heaters, put additional loads on the engine and can affect emissions. Small changes in how a vehicle is driven can also affect emissions. For instance, how a driver shifts gears on a vehicle with a manual transmission or how smoothly a driver depresses and releases the accelerator, may affect emissions rates (Shih & Sawyer, 1997).

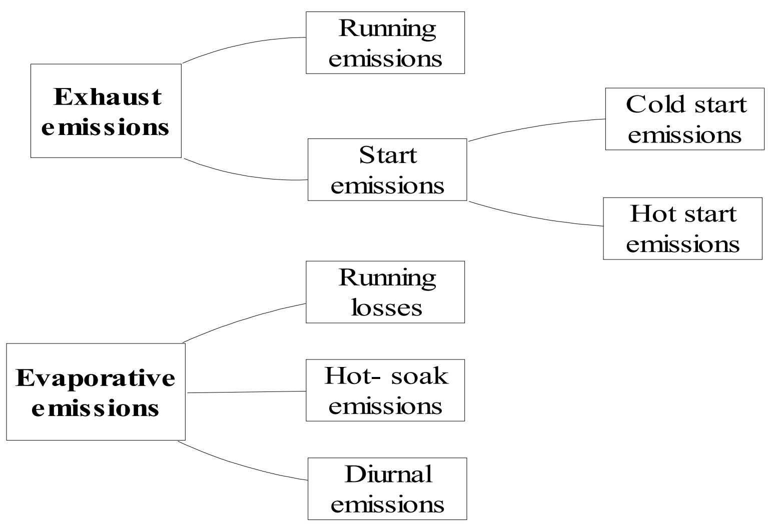
2.4 Forms of Vehicle Emissions

Emissions from motor vehicles are mainly divided into two categories: exhaust (tailpipe) emissions and evaporative (vapour) emissions (Van des Westhuisena *et al.,* 2004), as illustrated in figure 2.3 below.

2.4.1 Exhaust emissions

Exhaust or tailpipe emissions, one of the major forms of emissions from motor vehicle operation, include vehicle start-up emissions (classified as cold or hot starts depending on how long the vehicle has been turned off)[3] and running emissions, which occur when the vehicle is warmed up and operated in a hot stabilized mode (Sierra Research, 1993, p. 18, 19). Start emissions are further broken down into cold start and hot start emissions depending on the engine temperature during starting the vehicle, as shown in figure 2.3 below.

Figure 2.3: Forms of motor vehicle emissions



Source: Adapted from Faiz *et al*., 1996.

2.4.2 Evaporative emissions

Evaporative or vapour emissions, the other major form on the other hand, consist entirely of VOCs. They include running losses, which occur when the vehicle is operating in a hot stabilized mode; hot soak emissions, which results from fuel evaporation from the still-hot engine at the end of the trip; and diurnal emissions, which results from evaporation of fuel from the gasoline tank whether the vehicle is driven or not[4] (Sierra Research, 1993, p. 19, 20), as can be seen from figure 2.3 above.

[3] EPA considers a cold start for a catalyst equipped vehicle to occur after the engine has been turned of for 1 hr. For noncatalyst vehicles, a cold start occurs after the engine has been turned off for 4 hr.

[4] Refueling losses, crankcase emissions, and resting losses are also generally considered in the evaporative emissions category.

2.5 Vehicle Emission Control Technologies

There are several types of emission control technologies in use now. However, not all of them are common. In developing countries especially, only catalytic converters and fuel injection systems are common.

2.5.1 Catalytic converters

The catalytic converter is one of the most effective emission control devices available. It 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 washcoat (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 (ACEA/EUROPIA, 1996).

2.5.2 Fuel injection systems

Fuel injection systems were developed and widely used from the mid 1980s', as a replacement to the use of carburetors which were found not to be efficient in maintaining air-fuel ratio control under all conditions (Faiz *et al.,* 1996). Fuel injection systems provide rapid and precise control of air-fuel ratio. Fuel is provided to the injectors at constant pressure by a pump and pressure regulating valve. The injectors themselves are solenoid valves, which are controlled by the engine computer. The computer controls the quantity of fuel injected by varying the length of time the valve remains open during each revolution of the crankshaft. This reduces emissions enormously as compared with carburetors. However, majority of vehicles in developing countries have earlier developed injectors which are not as efficient as the engine computer controlled ones currently in use in developed countries.

2.5.3 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.

2.5.4 Vertical exhaust pipes

The exhaust pipes on heavy-duty vehicles are either vertical (so that the exhaust is emitted above the vehicles) or horizontal. Although the choice of exhaust location does not affect overall pollutant emissions, it can have a significant effect on local concentrations of pollutants. A vertical exhaust pipe reduces the concentration of exhaust pollutants at breathing level, reducing human exposure to high local concentrations. Vertical exhausts can reduce exposure to high local concentrations of pollutants by 65% to 87% (Weaver *et al.,* 1986). Vertical exhausts also make it easier to enforce on-road smoke limitations.

2.6 Previous Studies

Different studies have been done in the field of motor vehicular emissions in the different regions of the world, especially to establish the level of air pollution from the operation of motor vehicles and the general urban air quality as a whole. Three of such studies which have relevance to this study due to similarities in regional climatic conditions, and socio-economic circumstances are: the vehicle activity study in Nairobi, Kenya, conducted in March 2001 by the U.S. EPA, CE-CERT[5], and GSSR[6]; the evaluation of evaporative emissions from gasoline powered motor vehicles under South African conditions, conducted in 2003 by Van des Westhuisena *et al*., (2004); and the impact of automobile emissions on the level of platinum and lead in Accra, Ghana conducted in 2001 by Kylander *et al*., (2003).

2.6.1 Nairobi study

The aim of this study was to collect important vehicle related data to support development of an accurate estimate of on-road vehicular emissions for Nairobi. The study considered emissions from on-road vehicles to vary considerably depending upon three factors namely; vehicle type; driving behavior; and local geographic and climatic conditions (U.S. EPA, 2002), as shown in figure 3.2 above.

Based on these factors, data on on-road driving patterns, vehicle distribution, vehicle start-up patterns and vehicle counts were collected using GPS[7], digital videos, VOCE[8], and parking lot surveillance, to help define vehicle types and driving behavior in Nairobi. The collected data was then formatted and put into the International Vehicle Emission (IVE) Model (U.S. EPA, 2002) for estimating the criteria, toxic, and global warming pollutants from on-road vehicles.

This study came up with information on the overall fleet activity distribution of Nairobi city, and vehicle technologies used in the IVE model, under classifications such as vehicle type, engine sizes, type of fuel consumed, Vehicle make and model, registration year, model year, odometer reading, availability of catalyst, air/fuel control systems capability, frequency of maintenance, weight, age, exhaust control capability, evaporative control capability.

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[5] University of California at Riverside College of Engineering – Center for Environmental Research and Technology.

[6] Global Sustainability Systems Research.

[7] Global Positioning Satellites.

[8] Vehicle Occupancy Characteristic Enumerators.

The study was however not exhaustive on how these findings could be used to estimate the total level of pollutant emissions from motor vehicle sources so as to ascertain the true level of vehicle emission's contribution to the air quality of the city of Nairobi. Nonetheless, as a pioneering study, its findings are important for analyzing the operating characteristics of vehicles as shown in figure 3 below. This paper therefore seeks to employ most of the factors taken into consideration, in coming up with these findings towards estimating the level of motor vehicle emissions in the ATMA since residents of both Accra and Nairobi cities share similar socio-economic and geographic conditions as well as similar fleet composition.

2.6.2 South African study

The main objective of this study was to quantify the amount of evaporative emissions released by gasoline powered motor vehicle subjected to a variety of conditions typical of South Africa (Van der Westhuisen *et al.,* 2004). This stems from the fact that most previous research studies on evaporative emissions of in-service vehicles have been performed in US cities (Lyons & Heirigs, 2000; Delaney *et al.,* 2000) in (Van der Westhuisena *et al.,* 2004), where legislation is of the strictest in the world. South Africa also has no legislation controlling vehicular emissions at the moment. This, coupled with other factors such as South Africa's fleet composition difference in terms of emission control devices compared with other developed countries, the high vapour pressure fuel in South Africa compared with international levels (Van der Westhuisen, 1998), and also the general low turnover rate of new vehicles compared with international standards, imply that the level of HC evaporative emissions from South African vehicles is very high, hence the need for this study.

This study focuses on diurnal emissions and running losses. Because ambient temperatures are generally very high during the summer period in South Africa and fuel temperature inside the fuel tank may rise above 45ºC during driving, this therefore called for a specific test (road tests) required to simulate fuel loss in an average South African gasoline powered motor vehicle, operated under various conditions. The test therefore required higher temperatures for longer periods of time than is prescribed in the standardized test procedures. This was achieved before the normal laboratory emission test (Horiba SHED) designed by USEPA and CONCAVE (US EPA, 1994; CONCAWE, 1987) were conducted. The distances covered for the road test were Cape Town to Graaff-Reinette, Durbanville to Stellenbosch, Durbanville to Saldanha Bay, and urban driving conditions, of distances ranging from about 30 km to 120 km in all.

Road tests under both urban and highway driving conditions in South Africa indicate that fuel temperatures can far exceed the maximum fuel temperature of 30 ºC specified for the prescribed evaporative emissions test. The mixed urban and highway driving tests indicated that temperatures can reach as high as 47 ºC, while the open road testing indicated temperatures reaching 52 ºC.

Evaporative diurnal emissions of vehicles without evaporative emission control systems increase with increasing temperature. South African vehicles without evaporation control can emit ten times the amount allowed by the EPA. The vehicle fitted with evaporation control was well within the EPA limits. An extended-time diurnal test at higher temperatures was conducted. The results indicate that the amount of unburned HC emitted during the average life span of a South African gasoline powered vehicle without evaporative emission control systems and driven volatility on vehicle evaporative emissions under conditions typical of South Africa, is about 291 litres.

To reduce fuel consumption and improve air quality, gasoline powered motor vehicles should be equipped with evaporative control equipment. Regulations to reduce the allowable limit of unburned HCs emitted from the entire vehicle should also be implemented. Fuel circulation test shows that a very small amount of fuel is emitted, which proves that evaporative emissions depend mainly on the temperature of the fuel.

The major limitation of this study lies in the fact that its scope is narrowed to just evaporative emissions (diurnal and running losses), which make it difficult to draw experiences from, in the estimation of emission levels in the ATMA. South Africa's geographic and topographic conditions are slightly different from those pertaining in the Accra area.

2.6.3 Accra study

This study sought to estimate the release of PGE[9] (Pt) and Pb from catalytic converters during vehicle operation in Accra. It focuses on Pb and Pt levels in collected road dust and soils, and also includes an inventory of a number of catalytic converters in Accra.

To get a better idea of PGE emissions in Accra, data on vehicle fleet including manufacturers' home location or known years of production of a particular vehicle and the possible age range of the vehicle fleet was gathered. Sampling of sites for road dust collection was done in five locations in and around Accra. The sites were selected based on their traffic intensity and ease of sampling. The samples later went through different processes and then analyzed for results.

Nearly all vehicles in Ghana come from Europe through private sales or commercial operations. Platinum and lead concentrations in road dust increased with increasing traffic density as shown in the figures below. The highest traffic density in the study was found at Kotoka International Airport area with approximately 5,000 vehicles a day and an average Pt value of 55.0 ng g^{-1}, as shown in table 2.3 below.

Table 2.3: Sampling site description

Site No.	Site Name	Cars per day	Location
1	Background	0	Remote Village
2	Village	200	Remote Village
3	Residential	500	Residential
4	Highway	4000	Two lane coastal highway
5	Airport	5000	Kotoka international airport

Source: Kylander *et al*., 2003.

Although this study, like the previous ones, was limitation to Pt and Pb, as a pioneering study in the field of pollutant emissions in Ghana, it has been helpful to the analysis of this study.

[9] Petroleum group elements, which in this case refers to platinum.

3. TRANSPORT AND SUSTAINABLE DEVELOPMENT IN GHANA

3.1 Transport, Environment and Development

Transportation plays a vital role in the socio-economic development of regions, and the lives of people irrespective of where they live. Without mobility, vital societal functions cannot take place. Different groups have different demands on and requirements for the mobility system. Mobility possibilities also determine society's level of development, and vice versa. However, in most cases, transport in an attempt to facilitate development ends up inflicting irreversible damaging consequences on the physical environment, which at the end undermines the whole purpose of development. There are no doubts about the role of a cleaner environment to development. This ranges from the reduced health impacts on resident, a vital component of human capital development (Lvovsky *et al.,* 2000; Kojima & Lovei, 2001; EEA, 2002, p.149), the reduced impact on the ecosystem and the urban physical damage to materials (U.S. EPA, 1996), as illustrated in figure 2.1, also vital for especially agricultural productivity.

The pressures on transport systems are increasing in most developing countries, as part of the process of growth. It is even worst in urban areas where population densities are higher Motor vehicle ownership and use are growing even faster than population, with vehicle ownership growth rates of 15 to 20 % per year common in some developing countries (World Bank, 1995). The average distance traveled per vehicle is also increasing in all but the largest, most-congested cities. This growth exceeds the ability to increase road space, and the major impediment to the efficient working of the urban economies in large-size cities, is the level of road traffic congestion (UNCHS, 1998). Travel speeds are decreasing and the travel environment for pedestrians and people-powered vehicles is deteriorating. Downtown weekday traffic speed is below 10 km/h in Accra for instance (Kwakye *et al.,* 1997 p. 11).

Countries do not have to suffer worsening air quality as they industrialize, motorize, and become richer. Many technologies and behaviors for curbing urban air pollution are cost-effective even at low levels of economic development and limited institutional capacity, as long as there is political commitment and public understanding (World Bank, 2000). For instance, while action by industrial countries to eliminate leaded gasoline took a decade to implement, sharing knowledge and demonstrating workable solutions have permitted developing countries to phase out this fuel much more rapidly (World Bank, 1995). Curbing stationary sources of urban air pollutants (concentrated interests) is institutionally easier than curbing mobile sources (dispersed interests) because there are fewer polluters (industries) as compared with mobile sources where there are many polluters (car owners). Curtailing mobile sources of pollution and large gas guzzling vehicles is most challenging because the middle and upper-income groups are the beneficiaries of increased motor vehicle travel, and the main source of growing emissions with global and regional impact. These stakeholders are a more influential interest group than the rest of the general public, suffering from the resulting pollution. Collective action to reduce transport-based pollutant emissions is further complicated by the non-local and longer-term nature of the damages.

3.2 Sustainable Transport

To be effective, urban transport must satisfy the three main requirements of economic, social, and environmental sustainabilities (Munasinghe, 1993). First, it must ensure that a continuing capability exists to support an improved material standard of living. This corresponds to the concept of economic and financial sustainability. Second, it must generate the greatest possible improvement in the general quality of life, not merely an increase in traded goods. This relates to the concept of environmental and ecological sustainability. Third, the benefits that transport produces must be shared equitably by all sections of the community. This is termed social sustainability. Economic, environmental, and social sustainability are often mutually reinforcing (Munasinghe, 1993).

Road transport systems that fall into disrepair because they are economically unsustainable fail to serve the needs of the poor and often have environmentally damaging consequences. Hence, policy instruments should aim at incorporating all the dimensions of sustainability in a synergistic way, to generating win-win solutions. These instruments include measures to improve asset maintenance, technical efficiency of supply, safety, contract design, and public administration, as well as charges for environmental externalities, measures to improve asset maintenance, technical efficiency of supply, safety, contract design, and public administration, as well as charges for external effects. However, that convenient synergy does not always hold. Increased mobility, particularly private motorized mobility, typically increases measured GDP[10] but damages the environment. Although global sourcing of manufacturing industry and "just-in-time" logistics reduce the costs of products, expenditures on transport tend to increase as many more goods are transported over longer distances. These shifts to movement by faster modes (air) or in smaller batches with greater flexibility in frequency of schedule and variety of routes (road) also have potentially adverse environmental implications (particularly noise and air pollution).

Improvements of transport infrastructure may involve involuntary resettlement. More efficient provision of transport services in a competitive framework may involve loss of jobs, imposing social costs and restructuring of prices and services that may hurt some users[11] Public transport provided cheaply by the informal sector may meet the transport needs of the poor but be environmentally damaging. All these phenomena involve trade-offs that governments must face. A policy for sustainable transport is one that both identify and implements the win-win policy instruments and explicitly confronts the trade-offs so that the balance is chosen rather than accidentally arrived at. It is a policy of informed, conscious choices.

[10] Gross Domestic Product.

[11] Economic efficiency is not synonymous with technical efficiency. A technically superior infrastructure is only economically superior if the extra benefits accruing from its technical superiority outweigh the extra costs of its construction.

3.3 Vehicle emission in the ATMA

The form of urban growth in most developing countries has tended to increase the use of motorized transport, particularly road transport, which leads to increased environmental impacts. Densely populated cities resulting from rural-urban migration are growing faster than the financial capabilities to provide adequate services (Hilling, 1996, p. 197).

Ghana, as a developing country is not exempted from this problem. Although some people may disagree with the fact that vehicular emission in Ghana, or the ATMA for that matter, is problematic because Ghana's vehicular population is no where near what exist in many other big cities in developing countries. This also stems from the fact that Ghana is among the few countries in Sub-Saharan Africa which opted to phase-out the addition of lead (Pb) to gasoline[12] (Government of Ghana, 2003), as vehicle fuel.

Nonetheless, according to Whitelegg *et al.,* (2003), "Air pollution from motor vehicles continues to rise in spite of technological improvements on vehicles.… Technology cannot deliver significant improvements in air quality against a background of steep rise in car ownership and use" This is the situation in the ATMA now. Car ownership growth rate in 1993 was 4.1%, higher than population growth rate of 2.5% in the same period (Kwakye *et al.,* 1997; Ghana Statistical Service, 2000), with relatively older vehicles dominating the fleet, most of which have no catalytic converters or any other form of emission control devices in them. The fact that the vehicle population in ATMA is not as large as can be found in other major developing cities does not guarantee ATMA's immunity from the adverse impacts of vehicular emissions on its residents, majority of who are more exposed to emissions than other regions in Ghana due to high population densities.

Increased exposure to these emissions can impart enormous consequences to the health conditions of individuals such as adverse neuro-developmental effects on children, headaches, cough, phlegm, wheezing, chest illness, bronchitis, and cancer chronic (Needleman *et al.,* 1979; World Bank, 1995; U.S. EPA, 1996).

3.4 Ghana's Transportation Sector

The transportation sector is assuming enormous prominence in recent times due to a rise in domestic productivity, trade and regional transit cargo. Ghana is taking advantage of its central geographical location, political and economic stability within the West African sub-region to market herself as the gateway to especially her landlocked neighbours by lunching the gateway project. This project among other things is to develop and maintain transport services and infrastructure, reorganize and rationalize port services and custom procedures to facilitate transit cargo traffic, particularly to the landlocked countries of Burkina Faso, Niger, Mali and others.

This project has already started achieving encouraging results as transit freight traffic to and trade with the neighbouring countries is increasing rapidly, as can be seen from figure 3.1 below. Although the government of Ghana is trying to improve rail and inland water transport infrastructure through the Volta Lake Transport Project to cater for this among other reasons. The current rail and lake transport infrastructure is not up to date to be able to handle the rising transit cargo, hence the reliance on road transport.

[12] The government of Ghana phased out the use of leaded gasoline as a motor vehicular fuel since 2003.

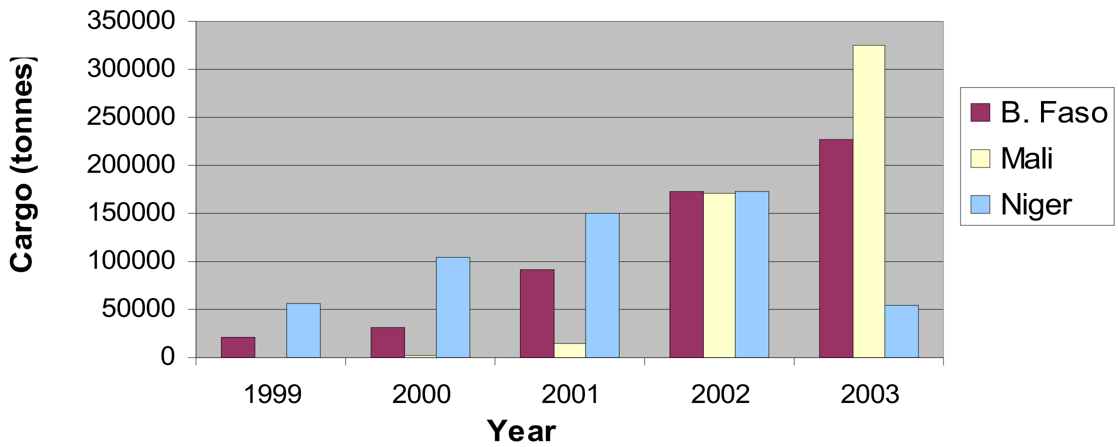

Figure 3.1: Total transit cargo received through the port of Tema

Source: Adapted from Ghana Shippers' Council, 2003.

However, the about this trend is that, all this transit cargo is presently solely handled by road transport, which further compounds the already high pollutant emissions in ATMA, as the Tema port is within this metropolitan area. It also increases traffic congestion and road accidents, particularly on the major highways in the country as cargo trucks move between the Tema port and their various destinations with Cargo.

3.5 Conceptual Framework

The figure below summarizes the concept of pollutant emissions from vehicles with particular reference to the ATMA, using Causal Loop Diagrams (CLDs) as an analytical tool. CLDs are relevant tools for representing the feedback structure of a system. According to Sterman (2000), CLDs can be used to capture hypotheses about the causes of dynamics, elicit and capture mental models of individuals or teams and to communicate important feedback that one believes are responsible for a problem.

The variables under consideration here are connected by arrows to denote the causal influences among them. Each of these causal links is assigned a positive (+) or negative (-) polarity to show how the dependent variable changes when there is a change in the independent variable. Important loops are shown with loop identifiers which can be a positive (reinforcing) or negative (balancing) feedback. A positive link means an increase or decrease in cause will result in a more than proportionate increase or decrease in effect. On the other hand, a negative links means that an increase or decrease in cause will result in more than proportionate decrease or increase in effect (Sterman, 2000).

The conceptual framework is presented in three parts, the first part shows the cause and dynamics of vehicle emissions, the second part shows the effects of the emissions on the health and economy, and the third part shows ways of mitigating the problem.

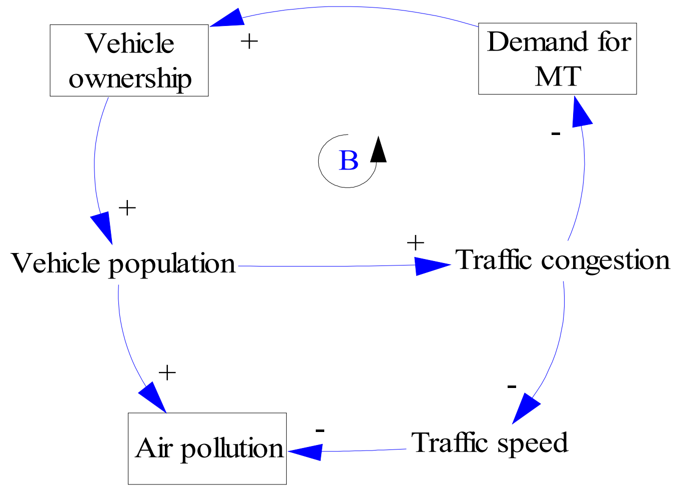

Figure 3.2: CLD showing the cause and dynamics of vehicle emissions.

From the above figure, the high demand for motorized transportation (MT) leads to a high desire by many residents of the ATMA to own cars. This leads to a higher vehicle population which increases traffic congestion. Higher traffic congestion decreases traffic speed within the city and acts as a disincentive to the use of MT and vehicle ownership, which balances the first loop. On the other hand, increased traffic congestion leads to a decrease in traffic speed which increases air pollution. A high vehicle population also directly increases air pollution, decreasing the urban air quality. This is environmentally unsustainable and hence the need for that cycle to be broken.

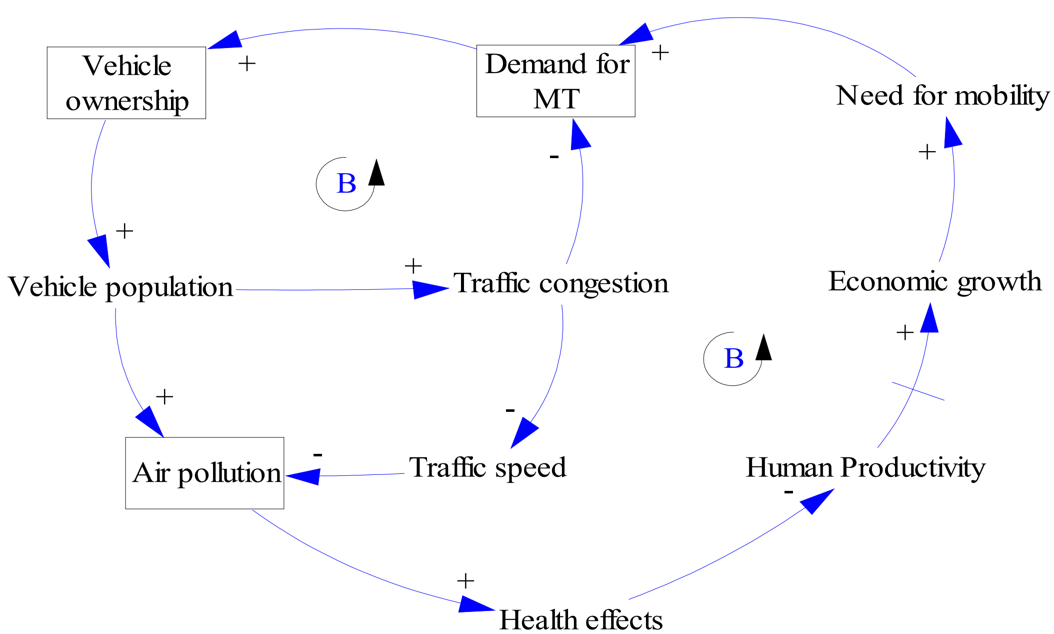

Figure 3.3: CLD showing the effects of vehicle emissions.

From the above figure as in figure 3.4, higher air pollution negatively affects the health of city residents which reduces human productivity. A lower human productivity in the long run leads to a decrease economic growth of the ATMA. Decrease in economic growth intern leads to a decrease in the need for mobility, which results in a low demand in the demand for MT.

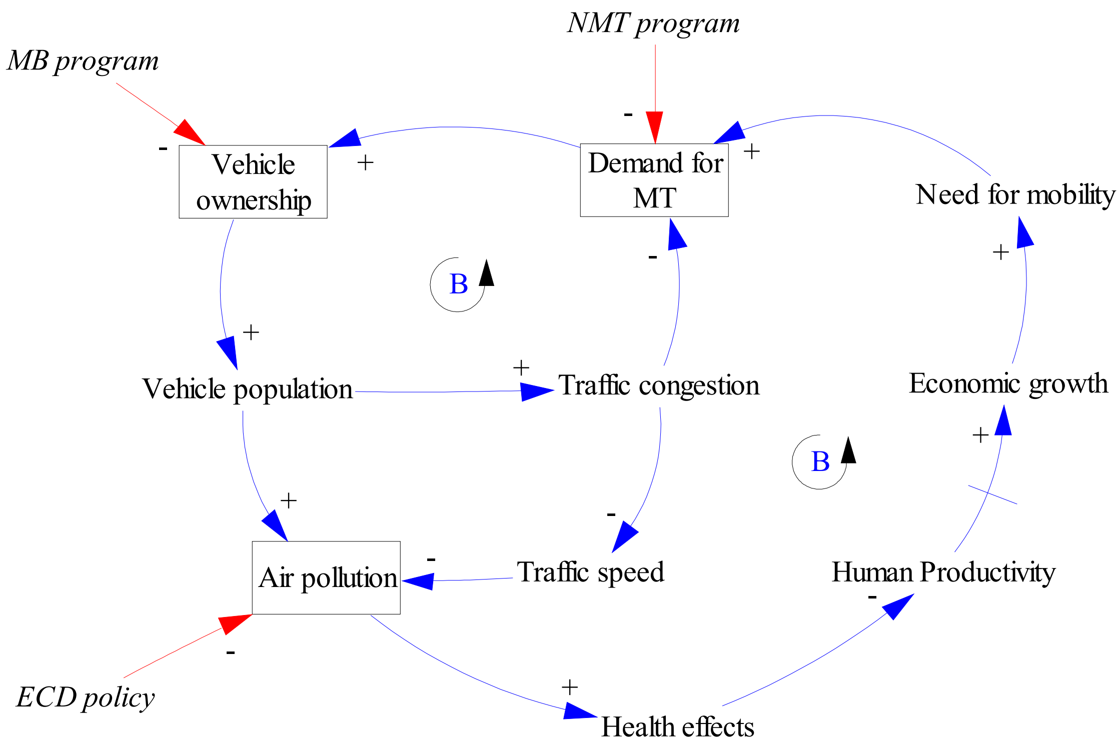

Figure 3.4: CLD showing approaches towards solving the problem of vehicle emissions in the ATMA.

The above figure presents the general dynamics of vehicle emissions in the ATMA and emphasizes on the different approaches towards addressing the problem. From the figure, there are three options towards addressing the problem. First is the promotion of the use of NMT in the form of walking and cycling. This will reduce the demand for MT especially PCs. A MB program on the other hand will lead to reduction in vehicle ownership which will eventually reduce air pollution. Finally, the introduction of an ECD policy would also directly lead to a reduction in air pollution. The effect of all these mitigation measures working together would be magnificent towards reducing emissions in the ATMA.

4. METHODOLOGY

4.1 Materials

Methods used in gathering data for this study include interviews and field surveys. Primary data was collected through interviews and personal interaction with relevant government agencies such as the EPA which is responsible for monitoring air quality issues, DVLA responsible for vehicle registration and driver licensing, CEPS[13] which oversees the importation of vehicles and the ministries of Energy and Roads and Transport which is also responsible for transport and fuel issues. Primary data was also collected from some second hand car dealers in Accra. Secondary data was collected from other public sector organizations such as MTTU[14] and Ghana Shippers' Council, working in the same light. Apart from these two sources, information was also gotten from books, peer-reviewed articles, international and government publications, as well as information from the internet.

4.2 Methods

The target respondent group was the heads of government ministries, departments, agencies and other groups working in the domain of transport and energy. The choice of this category of respondents was based on the fact that these institutions are the implementing agencies of government policies, and as such they have a good knowledge of the problem. Other organizations would have been contacted but it was not possible due to time and other constraints. In most of the agencies visited also, either the right respondents were unavailable or the required data was not available, as most of the agencies are yet to computerize their database.

During the study, open interview schedule was designed for each government agency, to suit the different data required for the study. A set of questions were then posed to the various respondents and their responses noted. In all, eleven organizations responded to various set of questions. It is worth mentioning that the information collected was broader than the questions posed. Interviews were equally conducted on other aspects, which were considered necessary for the study. The analysis done in this study is based on both the information obtained from interviews and personal observation during the survey and data from government publications.

The tools employed for analysis of the problem are; the concept of system dynamics with the use of CLDs to show the various interacting factors and how they related to vehicle emissions in the ATMA; and the Methodology for Estimating air pollutant Emissions from Transport (MEET), which is a vehicle pollutant emissions estimation model as explained earlier.

43. The MEET Model

With this methodology, the total level of vehicular emissions is estimated by the combination of hot, start, and evaporative emissions (Hickman *et al.,* 1999; EC, 2003), as given by (Eq. 1) below. Before this estimation is done, the total fleets of vehicles under consideration are grouped in four main categories namely:

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[13] Customs Excise and Preventive Service, responsible for taxes on imported vehicles and implementing governments' policy on the importation of over-aged vehicles.
[14] Motor Traffic and Transport Unit of the Ghana Police Service.

- Two Wheel Vehicles (2-W)
- Passenger cars (PC)
- Light Duty Vehicles (LDV) and
- Heavy Duty Vehicles (HDV), excluding heavy equipments.

$$E = E_{hot} + E_{start} + E_{evap} \qquad \text{(Eq. 1)}$$

Where; (E_{hot}*,* E_{star} *and* E_{evap}) are hot emissions, start-up emissions and evaporative emission respectively.

But each of these forms of vehicular emissions is a product of an activity related emission factor (*ex*) and the amount of traffic activity (*a*), usually the distance. This therefore gives the equation of each emission form as,

$$E_x = ex * a \qquad \text{(Eq. 2)}$$

The equation for estimating the hot emission of one vehicle is therefore given as,

$$E_{hot} = e * m \qquad \text{(Eq. 3)}$$

Where,
e = the hot emission factor (g/kg), and m = the activity (km/a), distance/time.

But the activity $m = n * l$

Where,
n = Number of vehicles in each vehicle category, and l = the average distance traveled by vehicles of a particular category over time (km/a) usually a year.

To apply (Eq. 3) *therefore, the data needed are:*

- The number of vehicles in each vehicle category
- The total annual distance traveled by each vehicle category
- The percentage of this distance driven on urban, rural or highways (but in the case of ATMA, only urban roads would be used since it is only city traffic)
- The average speed on each type of road (in this case, only urban roads)
- The emission factor, average speed correlation

Therefore,
taking into account the different vehicle categories and combining all the above equations, the final equation for hot emission estimation is derived by,

$$E_K = \sum_{i=1}^{i=categories} n_i \times l_i \times \overrightarrow{\sum_{j=1}^{j=roadtype} p_{i,j} \times e_{i,j,k}}$$

Where,

k = Pollutant

i = Vehicle category

j = type of road (urban roads only)

n_i = Number of vehicles in category (i)

l_i = Average annual distance traveled by vehicles of category (i)

$p_{i,j}$ = Percentage of annual distance traveled on road (j) by vehicle type (i)

$e_{i,j,k}$ = Emission factors of pollutant (k) corresponding to average speed on urban road

Besides,
Hot emission factors for HDVs (because of the additional parameters of road gradient and load state of vehicle), is given by;

$$E = K + av + bv^2 + cv^3 + d/v + e/v^2 + f/v^3$$

Where,
E = Rate of emissions in (g/km) for an unloaded (HDV, bus and coach) carrying a mean load, on a road with no gradient (0%), K = Constant, a-f = Coefficients, and v = Mean velocity of the vehicle.

The general equation for estimating start emissions is given as,

$$E_{start} = w * [f(v) + g(T) - 1] * h(d) \qquad \text{(Eq. 4)}$$

Where,

E_{start} = start emissions expressed in (g), V = Mean speed in km/h during the cold period, T = temperature in ^oC (ambient temperature for cold start, engine start temperature for starts at an intermediate temperature), d = distance traveled, w = preference excess emissions (at 20 ^oC and 20km/h).

However,
Correction to excess emissions $h\ (d)$ in above equation is also given as,

$$h\ (d) = 1\text{-}e^{-ab}/1\text{-}e^{-a}$$

Where,
a = constant, and b = ratio of trip distribution to cold distance.

Lastly, the general equations for evaporative emissions is also given as,

$$E_{evap\ voc,\ j} = 365 * a_j * (e^d + s^c + s^{fi}) + R \qquad \text{(Eq. 5)}$$

But

$$S^c = (1\text{-}q) * (pxe^{s,\ hot} + wxe^{s,\ warm})$$

$$S^{fi} = q * e^{fi} * x$$

$$R = m_j * (pe^{r,\ hot} + we^{r,\ warm})$$

Where,

$E_{evap,\ voc,\ j}$ = VOC emissions due to evaporative losses caused by vehicle category *j*.

a_j = Number of gasoline vehicles of category *j*.

e^d = Mean emissions factor for diurnal losses of gasoline powered vehicles equipped with metal tanks, depending on average monthly ambient temperature, temperature variations, and fuel volatility (RVP).

S^c = Average hot and warm soak emission factor of gasoline powered vehicles equipped with carburetor.

S^{fi} = Average hot and warm soak emission factor of gasoline powered vehicles equipped with fuel injection.

R = Hot and warm running losses.

q = The fraction of gasoline powered vehicles equipped with fuel injection.

p = Fraction of trips finished with a hot engine.

w = Fraction of trips finished with a cold or warm engine (shorter trips).

x = Mean number of trips per vehicle per day.

$e^{s,\ hot}$= Mean emission factor for hot soak emissions (dependent on RVP).

$e^{s,warm}$ = Mean emission factor for cold and warm soak emissions (dependent on RVP).

e^{fi} = Mean emission factor for hot and warm soak emissions for gasoline vehicles with fuel injectors.

$e^{r,hot}$ = Average emission factor for hot running losses of gasoline powered vehicles (dependent on RVP and temperature).

$e^{r,warm}$= Average emission factor for warm running losses of gasoline powered vehicles (dependent on RVP and temperature).

mj = Total annual mileage of gasoline powered vehicles of category *j*

4.3 Critique of Methods and Data Sources

The major limitation of this study is that, the MEET model as developed by the European Commission (Hickman *et al.,* 1999; EC, 2003) was designed for use in Europe countries where weather conditions vary in relation to what pertains in Ghana. However, some adjustments such as (temperature, load and road gradient) based on local conditions, as explained in parameters 5, and 6 below, were made to make the estimated emissions more realistic and representative of what pertains in the ATMA so as to avoid over estimation or underestimation.

Besides, some discrepancies have been identified with the different data collected from various sources. For example, data collected from different government ministries, departments and agencies differed in some cases, because of the absence of a good database management system in the country.

5. RESULTS AND DISCUSSION

This chapter presents the various forms of data that was collected from the field and how the information was processed using the MEET methodology together with Microsoft Excel in running both the Business- as- usual (BAU) and alternative scenarios of the study.

5.1 Vehicle Population

Vehicle population data from 1995 to 2003 for both regional and the national level was collected from the DVLA. Only the national data was grouped into categories as shown in figure 5.1 below. Apart from this, all other estimations were either based on personal observations or from information from the relevant quarters as explained in the section under parameters.

In the early 1980s, the government of Ghana adoption structural adjustment policies (SAP) including liberalization of the economy, following the virtual collapse of the economy, this led to significant improvements in infrastructure (including transport) (Pedersen, 2001), and further promoted the importation of more vehicles both new and slightly used ones by mostly private individuals. This period is considered to be the inertia of the rising vehicular population in the country as it stimulated the desire for more people to own cars.

Even though the government of Ghana in 1998 completely banned the importation of vehicles older than 10 years into the country (Kylander *et al.,* 2003), and later changed this ban to higher taxes in the form of import duties depending on the age of the imported used vehicle in question, the policy has not been fully effective as the Accra's traffic density is still high with a huge number of vehicles still registered every year, as shown in figure 3.2 above. Nearly all vehicles in Ghana are imported from Europe, North America and Japan through private sales, commercial operations or through second-hand car dealers,[15] majority of these vehicles are imported as used vehicles (second-hand condition) (Kylander *et al.,* 2003).

[15] Car dealers who import second- hand vehicles from mostly Europe, North America and Japan for sale in Ghana.

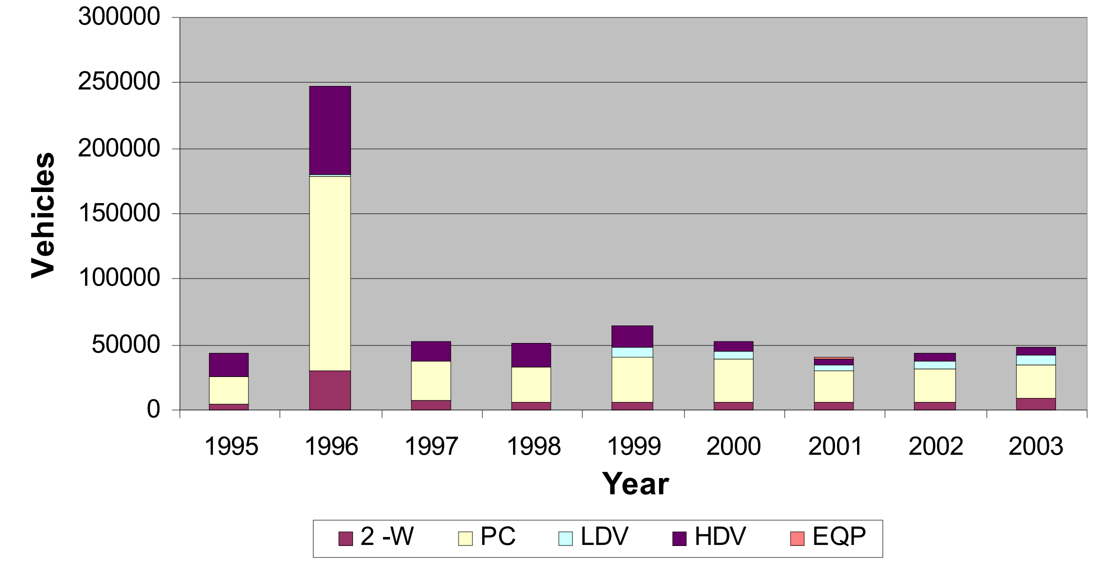

Figure 5.1: Vehicles registered in Ghana

Source: Adapted from DVLA, 2004.

The high number of vehicle registered in 1996 (figures 5.1 and 5.2) was because of the new registration system adopted in 1995, under which it was mandatory for all old vehicles to be re-registered under the new system before the end of 1997 (DVLA, 2004).

The tendency of African governments to adopt more liberal policies during election years may have accounted for the slightly higher figures recorded between 1999 and 2000. Similarly, the assumption of power of the new government in 2001 and more stringent application of rules and regulations governing imports may account for the drop in numbers in 2001.

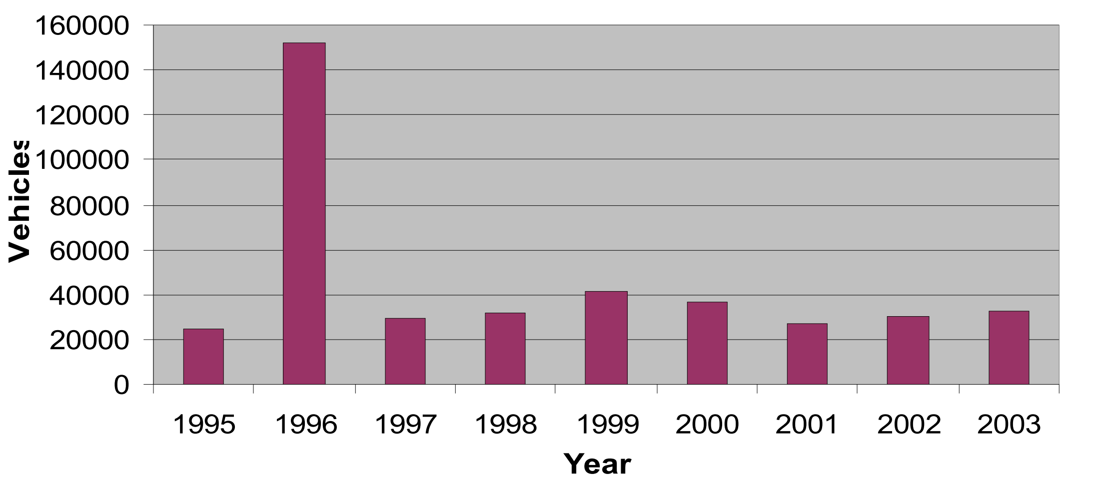

Figure 5.2: Vehicles registered in the ATMA

Source: Adapted from DVLA, 2004.

5.2 Parameters

All scenarios discussed below use the following parameters:

1. The vehicle categorization was based on the MEET and UN-ECE[16] classifications, into four categories (2-W, PC, LDV, and HDV). This excludes earth moving equipments used in construction, agricultural, and mining activities, as are excluded in the MEET model (EC, 2003; Hickman *et al.,* 1999; Emissions inventory guidebook, 2003).
2. All vehicles registered in the ATMA are assumed to operate only in this metropolitan area and no where else within the country, although in reality, some vehicles operate in other parts of the country even though they may be registered in Accra or Tema, this leads to over-estimatation of emissions. However, this is offset by vehicles registered elsewhere but occasionally operate within the ATMA, especially transit cargo trucks from the neighbouring countries.
3. The ATMA vehicle population by categories was extrapolated from the national data. This was done because the ATMA data was not categorized by the DVLA. This has the effect of either under-estimating or over-estimating emissions.
4. Vehicles in Ghana run on gasoline, diesel and liquefied petroleum gas (LPG) fuels according to the proportions listed in table 5.2 below, as was used in the model.

Table 5.1: Vehicle categories and type of fuel consumed in ATMA.

Category	**Type of fuel used (%)**		
	Gasoline	**Diesel**	**LPG**
2-W	100	-	-
PC	70	29.95	0.05
LDV	70	29.95	0.05
HDV	100	-	-
EQP	100	-	-

Source: Adapted from DVLA, 2004.

5. Vehicle load, road gradient and altitude is not taken into account since data on the average load of HDVs in ATMA was not available, and the topography of the ATMA is generally flat, as it is located within the Accra plains relief belt (Benneh G, & Dickson K, 1988; EC, 2003). This has the effect of under-estimating emissions.
6. The ambient temperatures of the ATMA used in the model are: 26.5 ^oC average annual temperature; 23.6 ^oC average annual minimum temperature; and 30 ^oC average maximum temperature (Climate-zone, 2004; Benneh & Dickson, 1988).
7. Air conditioning has the effect of increasing the load imposed on the engine. This increases both fuel consumption and emissions (Samaras and

[16] United Nations Economic Commission for Europe

Ntziachristos, 1998). This factor is not taken into account due to lack of data, even though more vehicles are believed to use air conditioning due to higher ambient temperatures in Ghana, which therefore under-estimates emissions.

8. All vehicles are considered not to have catalytic converters or any other form of emission control device fettered in them, apart from fuel injection systems for the whole period up until 2003. This stems from the fact that the use of leaded gasoline was phased-out only in late 2003 by the government (Government of Ghana, 2003; Kylander *et al.,* 2003), and the efficient operation of catalytic converters is not compatible with the use of leaded gasoline. This has an over-estimating effect on emissions, from year 2003 till now.
9. The average annual mileage of vehicles in the ATMA is assumed to be a maximum of 23000 km/year and a minimum of 18000 km/year for PC, LDVs and HDVs, and 10000 km/year for 2-Ws (Based on information communicated orally by taxi, trotro[17] and commercial truck drivers, and figures from the Nairobi study). However, apart from the Nairobi study, both the maximum annual average (23000km/year) and 1000km/year for 2-W were arrived at without taking into account the ages of the vehicles, as fleet age increases with decreasing annual driving distances covered, hence decreased pollutant emissions (EC, 2003; Zachariadis *et al.,* 2001; Van Wee *et al.,* 2000). This has the effect of over-estimating emissions but the effect is offset by the fact also that older vehicles emit more than new ones.
10. The fraction of gasoline powered vehicles equipped with fuel injectors was considered to be 20% based on information communicated orally by used-car market dealers (K. Fosu, personal communication, September 2, 2004). This could lead to an under-estimation of emissions due to unreliability of the source.
11. The fraction of trips finished with hot engines is considered to be 80%, and the fraction of trips finished with cold or warm engines (shorter trips/cold distance), 20%, because the ATMA has a relatively slower driving speeds due to traffic congestion and even shorter trips that can normally be made in shorter periods end up taking too much time hence, ending such trips with hot engines.
12. The number of trips made by each vehicle per day is also assumed to be a minimum of 2, and a maximum of 3. This is because no data on the average number of trips made per day existed both from drivers, and the DVLA. This could also lead to under-estimation of emissions, as a lot of factors come in to play when it comes to number of trips made in a day.
13. The fuel volatility (RVP) of gasoline in Ghana is 0.40, according to the Tema Oil Refinery, (2004), which supplies fuel to the entire country.
14. Vehicles which no longer operate due to old age, fatal accidents and serious mechanical conditions were not factored into the model. The DVLA, which is responsibility for the registration of new vehicles into the country, currently does not register old vehicles (off-road). This therefore leads to a gross over-estimation of emissions.

[17] Commercial mini buses operating in Ghanaian cities, with an average seating capacity of 15 passengers.

5.3 Analysis

This part depicts the business- as -usual (BAU) situation in the ATMA, as shown in figure 5.1 below. In the early 1980s, the government of Ghana adopted Structural Adjustment Programme (SAP) prescribed by the World Bank and IMF, part of which brought tremendous improvements of transport infrastructure in the country, particularly road transport (Pedersen, 2001). The SAP also changed the structure of the Ghanaian economy, expanding the production and tertiary sectors. This trend has expanded the base of the Ghanaian middle income class. Most of these people live and work in the country's cities. Meanwhile, there are no adequate transport facilities (non- motorized and public transport) to cater for this expansion, which therefore creates the desire by many residents, especially in the ATMA to want to own their own cars. This accounts for the BAU situation. Kwakye *et al.,* (2003) showed car ownership ratio of the ATMA in 1993 to be 35.7 per 1000 people, with a growth rate of 4.1% between 1987 and 1993. This is greater than the city's population growth rate of 3.5% (Ghana Statistical Service, 2002). Although, the government banned the importation of vehicles older than 10 years of age between 1998 and 2002, this policy was later reviewed to a mere heavy import tax on older vehicles, all of which have accounted for the rising vehicle population, with the resultant increasing pollutant emissions in the ATMA coupled with the non existence of any formal environmental policy for vehicle emissions and air quality in Ghana (Kylander *et al.,* 2003).

Figure 5.1: below shows the rising trend of the five pollutants considered under this study between 1995 and 2003, taking into account the upper and lower estimates as discussed under parameters 9, 10, 11, and 12 above. The lower emission levels for 1995, 1999 and 2003 for instance were 3 million, 7 million, and 17 million tonnes respectively.

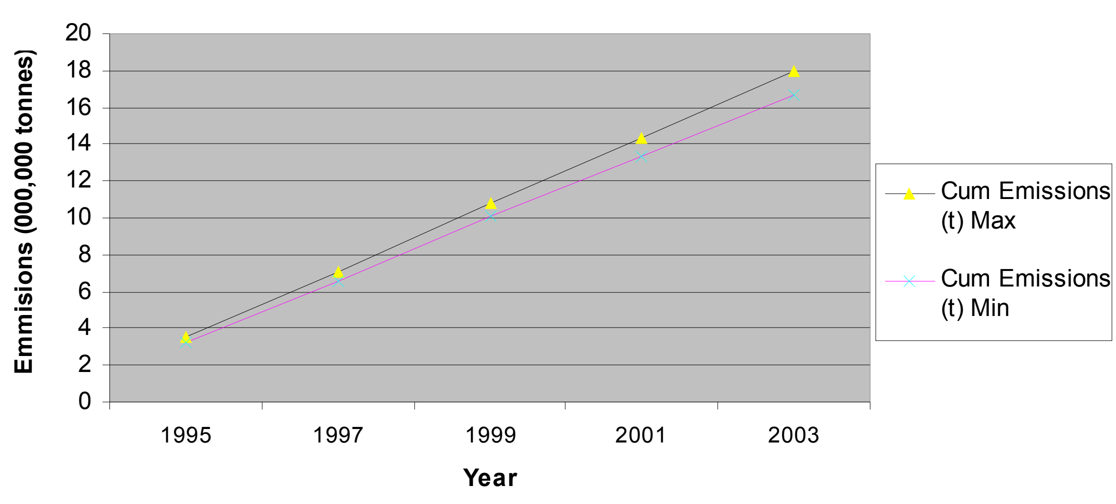

Figure 5.3: Pollutant emissions from vehicles in the ATMA

It should also be noted that unlike in both figures 5.1 and 5.2 where 1996 registered vehicles were far above the other years due to the new registration exercise, as explained earlier, the number of vehicles with the old registration system were estimated and their emissions calculated. These emissions were now added to the subsequent year's emissions, referred to in figure 5.3 above as cumulative emissions. It can be observed from figure 5.3 above that there is a rising trend of emissions from 1995 to 2003.

Figure 5.4 is a continuation of figure 5.3, showing future projections of emissions. This was estimated using basic linear best-fit analysis, which gives projections up till 2011, taking into consideration the maximum and minimum emissions levels as explained earlier. This gives the projected emissions in exponential curves format due to the high emission levels anticipated.

If this trend continues without any action to redress the situation, as shown in figure 5.4 below, where emissions from vehicle operation within the metropolitan area is projected to be 29 million, 63 million, and 94 million tonnes by years 2005, 2009, and 2011 respectively, Ghana could be heading for trouble.

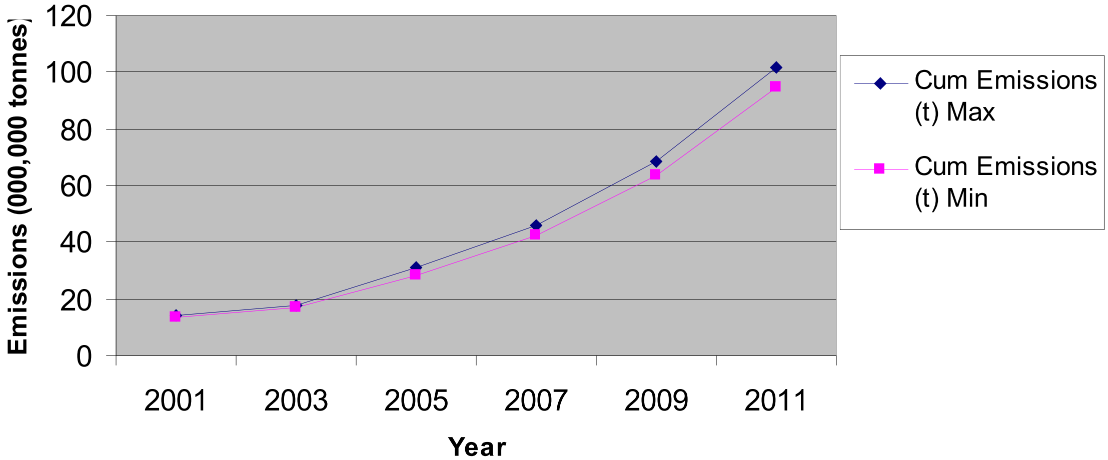

Figure 5.4: Projected pollutant emissions from vehicles in the ATMA

The government's vision of making the country a gateway to the West African sub-region and transforming the economy into middle income status by 2020 as enshrined in the "Ghana- Vision 2020"[18] document (Government of Ghana, 1995) will be seriously jeopardized since such high levels of emissions could undermine the country's human productivity through health problems as illustrated in figure 3.3 above. The future therefore depends on what programmes and policies we put in place now to achieve a sustainable transportation system that can withstand this challenge.

5.4 Alternative Scenarios

The programmes and policies of a future sustainable transport system are considered here as alternative scenarios. These include the following:

A- The use of emission control devices in vehicles (ECD[19] - scenario).
B- The use of metro buses (MB – scenario).

[18] Ghana's Development blueprint of becoming a middle income country by 2020.
[19] The devices here include; Catalytic converters; Fuel injection systems; Electronic engine control systems; Turbo charging systems; and Change air cooling systems.

C- The use of non- motorized transport (NMT– scenario).

5.4.1 Scenario A - The use of emission control devices in vehicles. (ECD)

Scenario A is the first option to cutting down on the current level of pollutant emission from vehicles and depicts the use of emission control technology (ECD) in all vehicles in the ATMA. The ECD here are: catalytic converters; fuel injection systems; electronic engine control systems; turbo charging systems; and air cooling systems.

However, only the first two would be considered in view of how feasible they can be used based on socio-economic and technological conditions pertaining in Ghana. It should be noted that there are a few vehicles in Ghana already operating on engines fitted with catalyst and fuel injection systems, and data on the actual number of these vehicles is not available since the DVLA as at now does not record such information during vehicle registration and inspection. Ghana also phased- out leaded gasoline only in 2003 (Government of Ghana, 2003), which means that prior to this period, the effect of catalytic converters as ECDs was ineffective, even though a good number of vehicles have catalyst in them (Kylander *et al.,* 2003).

According to Faiz *et al.,* (1996), the use of emission control devices in vehicles reduces pollutant emissions (including CO, CO_2, HC, NOx, and PM) by more than 50%. The percentage reduced is actually higher depending on the emission device or the pollutant in question. However, for purposes of analysis, a baseline of 50% is used to run this scenario. First, we assume that a law is passed by the government in 2003 which makes it mandatory for every vehicle to be fitted with a catalytic converter or fuel injection system, instead of the normal carburetors, just as the law that phased out the sale and use of leaded gasoline in 2003. Unlike in parameter 8, it is further assumed that 25% of vehicles change to the use of ECD every two years, which is reasonable and practicable.

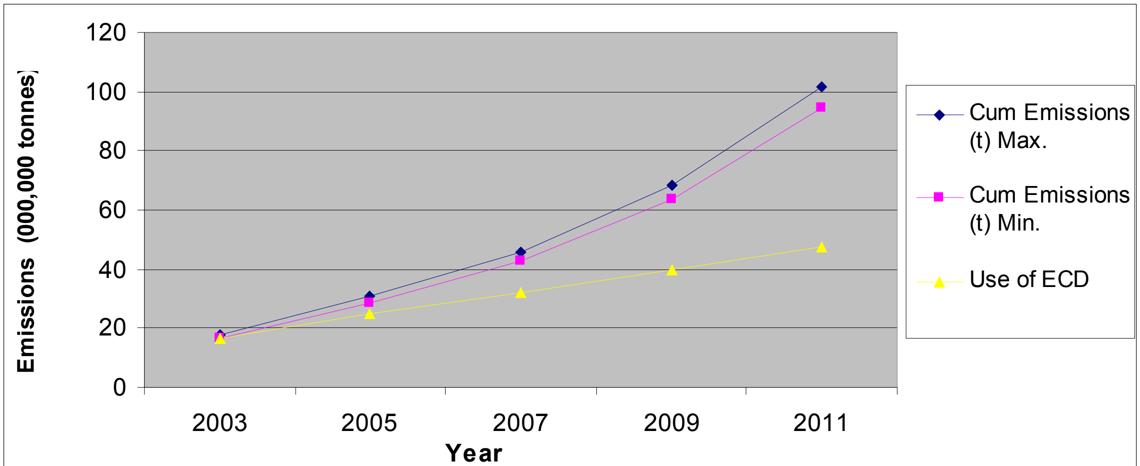

Figure 5.5: Level of pollutant emissions with the introduction of ECD policy

The result of such a policy would be a cut on the level of emissions by half the BAU levels, as shown on figure 5.5 above (with the use of ECD), compared with the minimum cumulative emission figures, which were used as the baseline for estimating the ECD values for the projected period. This policy can make the air in the ATMA cleaner and residents healthier than they would be by 2011 by cutting emissions. For instance, emissions is expected to be 25 million and 47 million tonnes by 2005 and 2011 respectively, instead of BAU levels of 29 million and 94 million tonnes for the same period, as shown in figure 5.5 above. This would perhaps make them healthier than they would have been, putting them in a better position towards contributing to development without wasting scarce time and financial resources on treating respiratory related illnesses. The ecosystem and materials of the built environment would also been in a better shape than they are now.

To achieve this target however, vehicle owners and passengers would have to bear the extra cost of fitting these vehicles with ECD, which Faiz *et al.,* (1996) estimates to be within the range of US $ 130 per vehicle for catalytic converters. All new and most second-hand vehicles imported from Europe, North America and Japan usually have these devices fettered in them. The vehicles that will be affected by such a policy are the ones operating prior to the phase-out of leaded gasoline in late 2003, but exclude 2-Ws.

This has the effect of increasing travel cost since transport operators would shift that extra cost to their passengers in the form of increased fares. The policy on the other hand is also an effective way of internalizing the externalities of vehicle operation through vehicle owners paying for the cost of their emissions through fitting their vehicles with ECDs rather than allowing such externalities (emissions) to be born by ATMA residents at large.

5.4.2 Scenario B- The use of metro buses (MB)

Scenario B depicts the use of MB mass transport system, as a second option to solving the pollutant emission problem in the ATMA. It should be noted that there is already a metro mass transport company (MMTC) in Ghana that operates metro buses in the four major cities, including the ATMA. It started operation in October 2001, with a fleet size of 183 buses by August 2003 (Garblah, 2003). However, the current fleet size is too small to cater for the whole of the ATMA. This vacuum has however been complemented by the services of private commercial minibuses (trotro), with average seating capacity of 15 seats (Kwakye *et al.,* 1997).

According to personal observation, the MMTC buses operating in the ATMA have an average seating capacity of 35 seats (excluding double-decker buses which have more than 35 seats), whereas a normal car has an average of 5 seats, and 18 seats for minibus. This means therefore that 1 metro bus can replace 7 cars (PC). Assuming therefore that we replace half the number of cars in the ATMA with the number of buses that can cater for the same number of passengers between 2003 and 2011, the results would be as shown in figure 5.6 below, where there would be significant cuts in pollutant emissions.

From the above figure, pollutant emission levels in 2007 is 43 million tonnes whereas if half the current fleet of cars in the ATMA were replaced with the number of MBs that can handle same number of PCs passenger, the emission levels would have been 21 million tonnes, which is 22 million less the 2007 BAU levels, and the same sequence for the subsequent years as shown in figure 5.6 below.

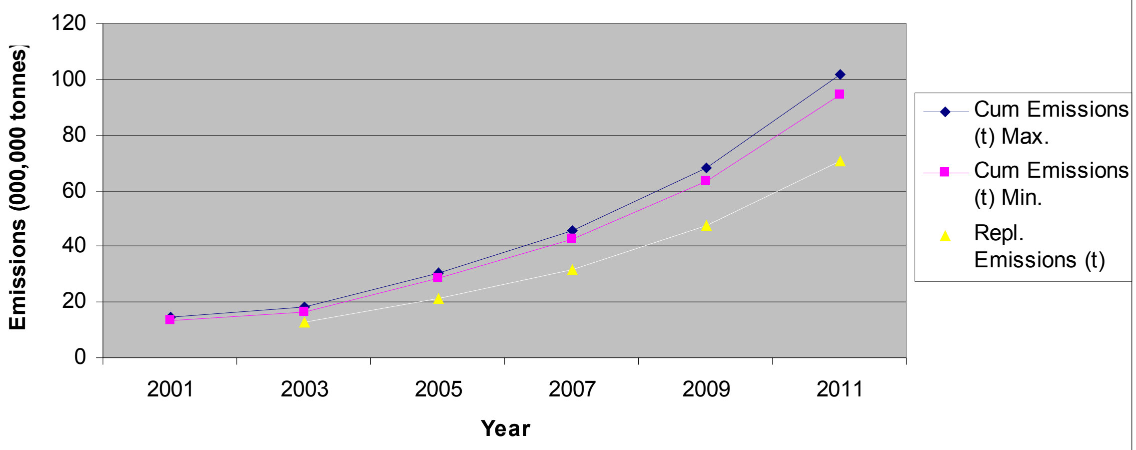

Figure 5.6: Effects of replacing car use with MB on the level of pollutant emissions in the ATMA

Besides cutting down emissions, the MB programme can also be effective towards reducing traffic congestion on urban roads, which would intern ultimately improve traffic speed, as illustrated in figure 3.4 above. It is obvious that public transportation in the country is not yet developed to the extent of being as efficient and convenient enough to attract most ATMA commuters, and therefore achieving this scenario is something that would take some time to come to reality.

5.4.3 Scenario C- The use of non- motorized transport (NMT)

Scenario C depicts the use of non-motorized transport mainly in the form of walking and cycling. This particular mode of transport is suitable for shorter trips. Kwakye *et al.,* (1997), in their analysis of trip characteristics in Accra showed that 40% of trips by all modes are less than 5 km, while 75 % are less than 10 km.

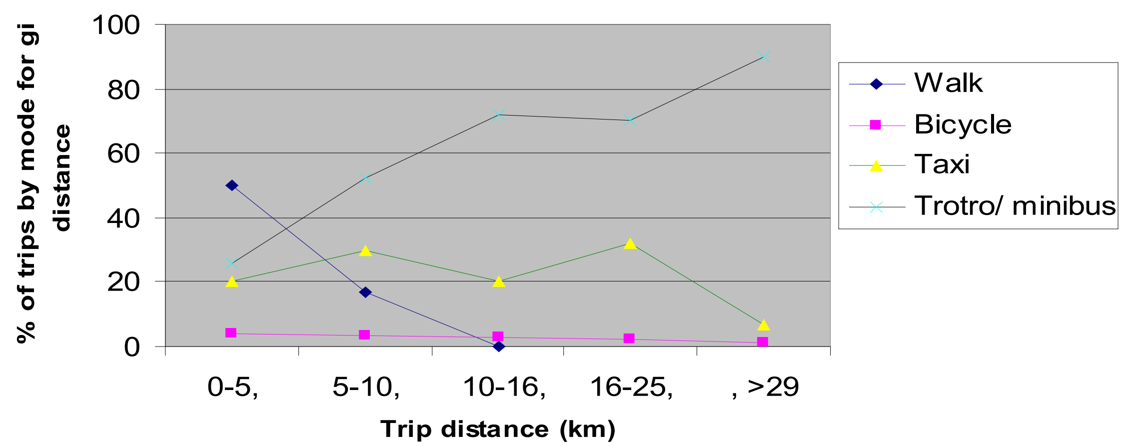

Figure 5.7: Mode choice by trip distance

Source: Adapted from Kwakye *et al.,* 1997.

Modal choice is strongly associated with trip distance, as is shown in Figure 5.7 above.

Present travel conditions in the ATMA makes walking and cycling unattractive for most passengers who make short trips. They therefore have to rely on cars, taxis or trotro to meet their mobility needs, when such trips could have been made by walking or cycling. With about 75% of all trips made in the ATMA falling below 10 km, and more people willing to switch to cycling or walking instead of trotros or taxis, if there are adequate facilities that make this mode more convenient (Kwakye *et al.,* 1997). Efforts should therefore be made towards making MB system more attractive so as encouraging commuters to patronize it thereby reducing vehicle traffic density in the ATMA.

Assuming therefore that 60% all current trips below 10 km were made by cycling and walking, instead of the use of motorized transport. This means therefore that 45% of all passenger vehicles (2-Ws, PCs, and LDVs) operating between now and 2011 would be grounded, and emissions would also be reduced by the same amount in the coming years as depicted in figure 5.8 below.

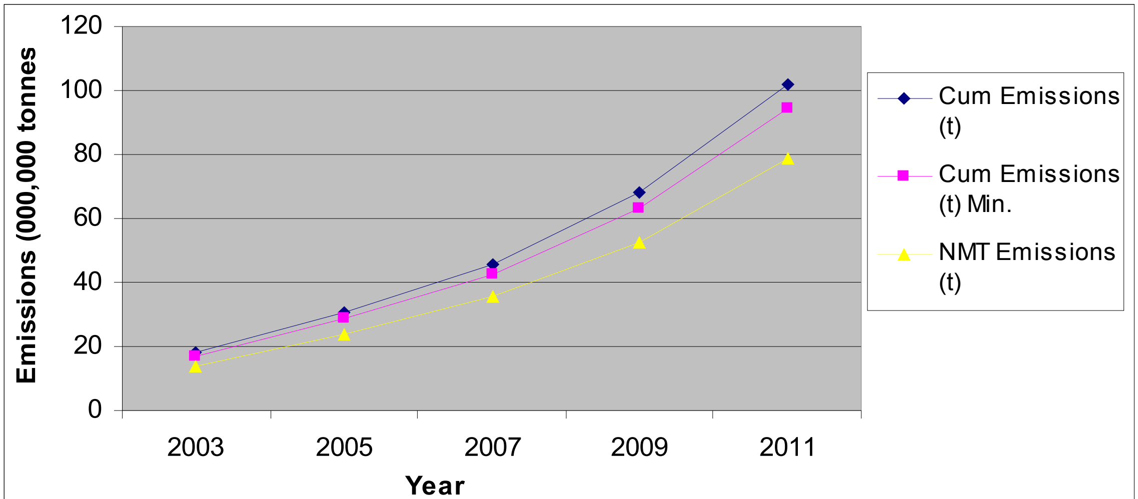

Figure 5.8: Introduction of NMT and cuts in pollutant emissions in the ATMA

As can be seen from the above figure, a NMT programme in the ATMA would reduce future emissions tremendously comparing with the BAU projected trends. For instance, emissions would be 79 million tonnes by 2011, instead of 94 million tonnes according to the BAU trend. This can only happened if non-motorized transport is made more convenient and attractive to residents. It would make the atmosphere in the ATMA cleaner than it would have been under normal circumstances.

Besides, it also has the effect of reducing traffic congestion as both figure 3.4 above the MB scenario discussed earlier illustrates, since fewer vehicles would remain on roads, especially taxis and trotros, which intern would have improved travel speed especially in the CBD areas where travel speeds are below 10 km/h. (Kwakye *et al,* 1997). However, inspite of the flexibility and health advantages associated with this mode of transport, it should also be emphasized that it is slow and this makes it not too attractive to many commuters.

In 1993, the government of Ghana in collaboration with the World Bank initiated an Urban Transport Project (UTP) (Kwakye *et al.,* 1997), part of which was to expand the existing non-motorized transport facilities such as pedestrian walk ways, especially along streets, and incorporating bicycle lanes and tracks into road rehabilitation designs in the ATMA and three other major cities in the country. Even though some progress has been made in terms of the pedestrian walkways, not much has been done with respect to the bicycle lanes, which makes cycling in the ATMA not only unattractive but also dangerous. More efforts therefore has to be made towards making walking and cycling more attractive if these gains in reducing pollutant emissions would actually see the light of day.

5.5 Policy Orientation

For both public and non-motorized transportation to truly make any meaningful contribution towards reducing pollutant emissions in the ATMA as shown by scenarios B and C, the government, in collaboration with the Metropolitan and Municipal Assemblies of Accra and Tema respectively, should find strategies of making both forms of transport convenient, safer and comfortable. To achieve this, strategies should aim at providing adequate facilities and also ensure their effective operation to enable a high quality service to be provided to effect the needed change.

In the case of the MB system, their operations should be made more flexible to cover all suburbs of the two cities, and reliable with good bus-route planning and on-road management. There should also be improved route frequency and speed. The on-street operating environment should also be improved with bus-lanes, bus-stops and bus-routes neatly outlined. It is also important to avoid overloading the buses as this makes them uncomfortable to passengers and could deter them from patronizing buses.

With pedal cycling, a good cycling network should be developed connecting the various residential areas to important centres like lorry parks, bus terminals, markets, CBDs etc. The network should be coherent with cycle lanes that are continues and consistent in quality. The cycle lanes should be direct as possible, as detours deter use. It should also be aesthetically attractive and comfortable with good lighting, smooth and gentle gradients. It is also important to make cycling safer through minimizing the incidence of casualties and perceived danger from other road users, mainly motor vehicles. Bicycle storage facilities should also be provided to encourage people to cycle to and from terminals in the manner of a '*park and ride system*'.

With regards to walking, good pedestrian networks, in the form of pavements and walkways should also be developed along major streets and also connecting residential areas to important places like lorry parks, bus terminals, commercial and business centres. These walkways together with cycle lanes should be incorporated in the future road design rehabilitation in the ATMA, as contained in the UTP of 1993 (Kwakye *et al.,* 1997). The pedestrian network should be a comprehensive, safe, well-signed and well-lit network of walkways providing easy access to major attractions. Like the cycle lanes, they should be short and as direct as possible with adequate facilities to cater for disabled people. It is also equally important to take into consideration the vulnerability of pedestrians to risks posed by other road users such as cyclist and motorist and put in place facilities to protect pedestrians from such dangers.

6. CONCLUSION

It should be emphasized that the pollutant emissions under analysis were all based on the minimum (lower limit) emission levels to avoid any incidence of over-estimation in view of the parameters taken into consideration. The results of this study gives a clear indication that the implementation of the mitigation strategies analyzed are not only necessary now, but also very urgent if Ghana is to truly make any progress towards achieving a sustainable transportation system and sustaining any future gains anticipated under the vision 2020 development plan.

It must be admitted that this study has some limitations, given the tentative nature of the analytical tools used, and the scanty nature of data sources. There is no doubt however that this piece of empirical work is in it self a novelty, and an important contribution to the country, given the economic difficulty many developing countries such as Ghana find them selves in. Any hope for the implementation of such mitigation strategies could only be based on a quantitative cost and benefit analysis, which requires the results of this study.

Future research relating to pollutant emissions in the ATMA and Ghana as a whole could be directed at such areas as correcting the limitations identified in this study such as revising the methods and using other models. It would also be interesting to relate the current levels of emissions against economic growth, and then comparing the two indicators with other developed countries some years back when they were in similar stages of development.

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Mr. Amoah, Ministry of Energy, Accra, Ghana, 2004-09-16.

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Appendix

Appendix 1. *HOT EMISSIONS FOR HDVs 1995-2003.*

	Pollutant	k	a	b	c	d	e	f	v (km/h)	National total	ATMA-total(ni)	E/ vehicle (g/km)	Emissions (g)
HDVs (7.5t-16)	CO	3,08	0,01350	0,00	0,00	-37,70	1560,00	-5736,00	15,00	32941,00	21082,24	6,00294	2910776856
	CO_2	871,00	-16,00	0,143	0,00	0,00	32031,00	0,00	15,00	32941,00	21082,24	805,53500	3,90597E+11
	VOC	1,37	0,00	-8,10E-05	0,00	0,00	870,00	-3282,00	15,00	32941,00	21082,24	4,24600	2058848047
	NOx	2,59	0,000	-0,000665	8,56E-06	140,00	0,00	0,00	15,00	32941,00	21082,24	11,80260	5722979846
	PM	0,0541	0,00151	0,00	0,00	17,10	0,00	0,00	15,00	32941,00	21082,24	1,21675	589991757
HDVs (16t-32t)	CO	1,530	0,0000	0,00	0,00	60,60	117,00	0,00	15,00	7890,00	5049,60	6,09000	707297472
	CO_2	765,00	-7,04	0,00	0,0006320	8334,00	0,00	0,00	15,00	7890,00	5049,60	1217,13300	1,41359E+11
	VOC	0,207	0,00	0,00	0,00	58,30	0,00	0,00	15,00	7890,00	5049,60	4,09367	475441721,6
	NOx	9,45	-0,107	0,00	7,55E-06	132,00	0,00	0,00	15,00	7890,00	5049,60	16,6705	1936123029
	PM	0,184	0,00	0,00	1,72E-07	15,20	0,00	0,00	15,00	7890,00	5049,60	1,28026	148690865,8
HDVs> 32t	CO	0,349	0,0101	0,00	0,00	79,60	0,00	0,00	15,00	2697,00	1726,08	5,80717	230543587,5
	CO_2	1576,00	-17,60	0,00	0,00117	0,00	36067,00	0,00	15,00	2697,00	1726,08	1476,24653	58606750953
	VOC	0,254	0,00	0,00	0,00	53,90	0,00	0,00	15,00	2697,00	1726,08	3,84733	152738517,8
	NOx	5,27	0,00	0,00	0,00	343,00	-552,00	0,00	15,00	2697,00	1726,08	25,6833	1019624224
	PM	0,246	0,00	0,00	0,00	18,20	0,00	0,00	15,00	2697,00	1726,08	1,54168	61204581,66
Urban buses	CO	1,64	0,00	0,00	0,00	132,00	0,00	0,00	15,00	96950,00	62048,00	10,44000	14898965760
	CO_2	679,00	0,00	0,00	-0,00268	9635,00	0,00	0,00	15,00	96950,00	62048,00	1312,28833	1,87277E+12
	VOC	0,08	0,00	0,00	0,00	41,20	0,00	184,00	15,00	96950,00	62048,00	2,87899	4108611274
	NOx	16,30	-0,173	0,00	0,00	111,00	0,00	0,00	15,00	96950,00	62048,00	21,10500	30119029920
	PM	0,0694	0,00	0,000366	-8,71E-06	13,90	0,00	0,00	15,00	96950,00	62048,00	1,04902	1497061233

Appendix 2. *HOT EMISSIONS FOR 2-Ws, PCs & LDVs 1995-2003.*

(A) **(Gasoline)**

Pollutant	Category (i)	n,i	l,i	n,i*l,i	P,i,j	v	e,i,j,k	Emissions (g)
CO	2W	14510	10000	145100000	1	15	17,305	2 510 955 500,00
	PC	22265	23000	512095000	1	15	51,0233332	26 128 793 836,40
	LDV	4682	23000	107686000	1	15	37,575	4 046 301 450,00
CO_2	2W	22265	10000	222650000	1	15	44,0023333	9 797 119 516,67
	PC	44533	23000	1024259000	1	15	267,961667	274 462 148 738,33
	LDV	4682	23000	107686000	1	15	400,1835	43 094 160 381,00
VOC	2W	14510	10000	145100000	1	15	14,7525	2 140 587 750,00
	PC	22265	23000	512095000	1	15	4,64498519	2 378 673 692,47
	LDV	4682	23000	107686000	1	15	3,870725	416 822 892,35
NOx	2W	14510	10000	145100000	1	15	0,04075	5 912 825,00
	PC	22265	23000	512095000	1	15	1,479	757 388 505,00
	LDV	4682	23000	107686000	1	15	2,2232	239 407 515,20

(B) Diesel

Pollutant	Category(i)	n,i	l,i	n,i*l,i	P,i,j	v	e,l,j,k	Emissions (g)
CO	PC	9528	23000	219144000	1	15	1,14383043	250663574,7
	LDV	2006	23000	46138000	1	15	1,4891	68704095,8
CO_2	PC	9528	23000	219144000	1	15	283,225	62067059400
	LDV	2006	23000	46138000	1	15	355,116	16384342008
VOC	PC	9528	23000	219144000	1	15	0,36450494	79879070,04
	LDV	2006	23000	46138000	1	15	0,44775	20658289,5
NOx	PC	9528	23000	219144000	1	15	0,730725	160133999,4
	LDV	2006	23000	46138000	1	15	3,5235	162567243
PM	PC	9528	23000	219144000	1	15	0,33405	73205053,2
	LDV	2006	23000	46138000	1	15	0,2821575	13018182,74

(C) (LPG)

Pollutant	Category (i)	n,i	l,i	n,i*l,i	P,i,j	v	e,i,j,k	Emissions
CO	PC	117	18000	2106000	1	15	7,1305	15 016 833,00
	LDV	10	18000	180000	1	15	7,1305	1 283 490,00
CO_2	PC	117	18000	2106000	1	15	227,2975	478 688 535,00
	LDV	10	18000	180000	1	15	227,2975	40 913 550,00
VOC	PC	117	18000	2106000	1	15	2,527183686	5 322 248,84
	LDV	10	18000	180000	1	15	2,527183686	454 893,06
NOx	PC	117	18000	2106000	1	15	1,666006663	3 508 610,03
	LDV	10	18000	180000	1	15	1,666006663	299 881,20

START EMISSIONS FOR HDVs, BUSES & COACHES

Pollutant	weight (tonnes)	ni	E	ni* E
CO	16 - 32	632	6	3792
	32 - 40	1791	6	10746
CO_2	16 - 32	632	500	316000
	32 - 40	1791	750	1343250
VOC	16 - 32	632	2	1264
	32 - 40	1791	2	3582
NOx	16 - 32	632	-5	-3160
	32 - 40	1791	-7	-12537
PM	16 - 32	632	0,6	379,2
	32 - 40	1791	0,6	1074,6
				1664391

Appendix 3. *START EMISSIONS FOR DIESEL EVHICLES, 1995-2003.*

(A) (Gasoline)

Pollutant	Category (i)	ni	w	v	f(v)	T	g (T)	d	dc	b	a	a*b	h(d)	Emissions	ni* Emissions
CO	PC	22267	63,51	15	0,8565	10	1,918	63	6,02	10,46512	6,7	70,12	1,001232429	112,8373879	2512550,116
	LDV	4688	63,51	15	0,8565	10	1,918	63	6,02	10,46512	6,7	70,12	1,001232429	112,8373879	528981,6744
CO_2	PC	22267	144,16	15	1,0509	10	1	63	4,93	12,7789	2,85	36,42	1,061395714	160,7990562	3580512,584
	LDV	4688	144,16	15	1,0509	10	1	63	4,93	12,7789	2,85	36,42	1,061395714	160,7990562	753825,9755
VOC	PC	22267	8,23	15	2,8454	10	2,3448	63	3,29	19,14894	10,96	209,9	1,000017384	34,48594548	767898,548
	LDV	4688	8,23	15	2,8454	10	2,3448	63	3,29	19,14894	10,96	209,9	1,000017384	34,48594548	161670,1124
NOx	PC	22267	-0,3	15	0,4313	10	1	63	3,13	20,1278	2,54	51,12	1,08561885	-0,140468223	3127,805922
	LDV	4688	-0,3	15	0,4313	10	1	63	3,13	20,1278	2,54	51,12	1,08561885	-0,140468223	658,5150296

E start = w* [f (v) + g (T) – 1] * h (d) But, h (d) = $(1 - e^{-ab} / 1- e^{-a})$; d = d/ dc

(B) (Diesel)

Pollutant	Category (i)	ni	w	v	f(v)	T	g (T)	d	dc	b	a	a*b	h(d)	Emissions	ni* Emissions
CO	PC	9528	2,18	15	1,0929	10	1,6028	63	6,03	10,44776	3,43	35,83582	1,033471	3,820356	36400,35
	LDV	2006	2,18	15	1,0929	10	1,6028	63	6,03	10,44776	3,43	35,83582	1,033471	3,820356	7663,633
CO_2	PC	9528	182,57	15	1	10	1,4583	63	3,69	17,07317	3,95	67,43902	1,019633	271,4689	2586556
	LDV	2006	182,57	15	1	10	1,4583	63	3,69	17,07317	3,95	67,43902	1,019633	271,4689	544566,6
VOC	PC	9528	0,82	15	1,0807	10	1,9752	63	6,03	10,44776	2,48	25,91045	1,091397	1,839919	17530,75
	LDV	2006	0,82	15	1,0807	10	1,9752	63	6,03	10,44776	2,48	25,91045	1,091397	1,839919	3690,877
NOx	PC	9528	0,06	15	1,114	10	1,8927	63	6,45	9,767442	0,89	8,693023	1,696517	0,204264	1946,227
	LDV	2006	0,06	15	1,114	10	1,8972	63	6,45	9,767442	0,89	8,693023	1,696517	0,204722	410,6724

Appendix 4. *EVAPORATIVE EMISSIONS FOR GASOLINE VEHICLE, 1995-2003.*

(A) **PC & LDV** **1995 - 2003**

Pollutant	Category	aj	e^d	$e^{s,hot}$	$e^{s,warm}$	e^{fi}	$e^{r,hot}$	$e^{r,warm}$	s^c	s^{fi}	R	E evap
VOC	PC	22267	11,40890754	3,02833	1,429089	0,7	0,038906	0,028607136	2,166785394	0,14	847,4578	306254,7924
	LDV	4688	11,40890754	3,02833	1,429089	0,7	0,038906	0,028607136	2,166785394	0,14	847,4578	65146,62626

(B) **2Ws** **1995 - 2003**

Pollutant	Category	ni	Diurnal (g/day)	E evap
VOC	2-W	14510	5,7	82707

Appendix 5. *TOTAL POLLUTANT EMISSIONS*

(A) **(Upper limit)**

YEAR	a (E hot- REST)	b (E hot - HDV)	d (E hot- LPG)	E hot (Total)	E start (Total)	E evap (Total)	Total Emission (g)	Total Emissions (kg)	Total Emissions (t)
1995	54 691 265 429,20	3,72503E+11	15367204,66	427 210 082 633,86	2481276,562	71028,8778	427 212 634 939,30	427 212 634,94	427212,6349
1997	64 624 354 688,04	4,40E+11	17288105,24	504 753 292 793,28	2929234,32	83814,6718	504 756 305 842,27	504 756 305,84	504756,3058
1999	91 770 788 403,47	625 020 000 000,00	24971707,57	716 815 760 111,04	4163320,623	118 761,14	716 820 042 192,80	716 820 042,19	716820,0422
2001	59 604 046 449,63	405 901 650 000,00	17288105,24	465 522 984 554,87	2 701 673,24	77 355,60	465 525 763 583,70	465 525 763,58	465525,7636
2003	72 135 285 351,36	491 302 350 000,00	19209005,82	563 456 844 357,18	3 272 519,31	93 485,88	563 460 210 362,37	563 460 210,36	563460,2104

(B) **(Lower limit)**

YEAR	a (E hot- REST)	b (E hot - HDV)	d (E hot- LPG)	E hot (Total)	E start (Total)	E evap (Total)	Total Emission (g)	Total Emissions (kg)	Total Emissions(t)
1995	24 064 156 788,85	3,72503E+11	12026507,99	396 579 633 296,84	2481276,562	68053,1306	396 582 182 626,54	396 582 182,63	396582,1826
1997	28 434 716 062,74	4,40E+11	13529821,49	468 559 895 884,23	2929234,32	80323,2556	468 562 905 441,81	468 562 905,44	468562,9054
1999	40 379 146 897,53	625 020 000 000,00	19543075,49	665 418 689 973,01	4163320,623	113 860,25	665 422 967 153,89	665 422 967,15	665422,9672
2001	26 225 780 437,84	405 901 650 000,00	13529821,49	432 140 960 259,33	2 701 673,24	74 124,74	432 143 736 057,30	432 143 736,06	432143,7361
2003	31 739 525 554,60	491 302 350 000,00	15033134,99	523 056 908 689,59	3 272 519,31	89 604,41	523 060 270 813,31	523 060 270,81	523060,2708

Appendix 6. *TOTAL POLLUTANT EMISSIONS*

(A) Business As Usual (BAU) Emissions

Year	Emission (t)	Emissions before 1995	Emissions (t) New vehicles	Cumulative Emissions (t) Max	Cumulative Emissions (t) Min
1995	427212,6349	3,06E+12	3,49	3,49	3,239656445
1997	504756,3058	3,06E+12	3,57	7,06	6,551273417
1999	716820,0422	3,06E+12	3,78	10,84	10,05968554
2001	465525,7636	3,06E+12	3,53	14,37	13,33489656
2003	563460,2104	3,06E+12	3,63	18,00	16,70099076

(B) Projected Emissions

Year	Emissions (t) New vehicles	Cumulative Emissions (t) Max.	Cumulative Emissions (t) Min.
1995	3,49	3,49	3,24
1997	3,57	7,06	6,55
1999	3,78	10,84	10,06
2001	3,53	14,37	13,33
2003	3,63	18,00	16,70
2005		30,75	28,53
2007		45,83	42,53
2009		68,31	63,39
2011		101,81	94,48

Appendix 7. *TOTAL POLLUTANT EMISSIONS*

(A) Scenario A- ECD policy

Year	ECD policy	Cumulative. Emissions (t) Max.	Cumulative. Emissions (t) Min.
1995		3,49	3,24
1997		7,06	6,55
1999		10,84	10,06
2001		14,37	13,33
2003	16,70	18,00	16,70
2005	24,97	30,75	28,53
2007	31,90	45,83	42,53
2009	39,62	68,31	63,39
2011	47,24	101,81	94,48

(B) Scenario B- Metro bus programme

Year	Cumulative Emissions (t) Max.	Cumulative Emissions (t) Min.	Replacement Emmissions
1995	3,49	3,24	
1997	7,06	6,55	
1999	10,84	10,06	
2001	14,37	13,33	
2003	18,00	16,70	8,35
2005	30,75	28,53	14,27
2007	45,83	42,53	21,26
2009	68,31	63,39	31,69
2011	101,81	94,48	47,24

(C) Scenario C- Non Motorized Transport Programme

Year	Cumulative Emissions (t) Max	Cumulative Emissions (t) Min	NMT Emissions
1995	3,49	3,24	
1997	7,06	6,55	
1999	10,84	10,06	
2001	14,37	13,33	
2003	18,00	16,70	14
2005	30,75	28,53	24
2007	45,83	42,53	35
2009	68,31	63,39	53
2011	101,81	94,48	79

Appendix 8. *POPULATION OF REGISTERED VEHICLES*

(A) NATIONAL

Year	Vehicle Category				
	2 -W	PC	LDV	HDV	EQP
1995	4908	20189	6	17873	0
1996	29551	149466	1067	67539	0
1997	7930	29624	26	14313	0
1998	6064	27562	71	17934	0
1999	6623	34438	6249	16928	513
2000	6440	32656	5196	8072	517
2001	6058	23521	5343	4647	445
2002	6430	24527	7143	4957	424
2003	8777	25674	7778	5521	324
2004	5348	11529	2484	3425	132
Total	**88129**	**379186**	**35363**	**161209**	**2355**

(B) ATMA

V category	Popultion	Gasoline	Diesel	LPG
2-W	52430	36701	15702,79	26,215
PC	234084	163858,8	70108,16	117,042
LDV	20835	14584,5	6240,083	10,4175
HDV	98521	68964,7	29507,04	49,2605
EQP	1415	990,5	423,7925	0,7075