UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY

# "Inventory of Short Lived Climate Pollutants (SLCPS) and PM2.5 from road transport in Rwanda"

**BY:**

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A dissertation submitted in partial fulfillment of the requirements for a degree of **MASTER OF SCIENCE IN ATMOSPHERIC AND CLIMATE SCIENCE** at University of Rwanda, College of Science and Technology.

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**NOVEMBER, 2024**

# Declaration

I, NIYIBIZI Pascal (221027774), declare that this dissertation "Inventory of Short Lived Climate Pollutants (SLCPS) and PM2.5 from road transport in Rwanda" for the award of Master of Science in Atmospheric and Climate Science is my original work.

**Names**: NIYIBIZI Pascal

**Signature: ………………………………………**

**Date: ……..../…………../……………….**

# DEDICATION

This project is dedicated to my beloved wife, who continually provide her moral, spiritual, emotional and financial support. To my brother, sisters, relatives, mentors, friends and classmates who shared their words of advices and encouragement to finish this study. I dedicated this work to the Almighty God, for strong guidance, Strength, power of mind, protection and skills.

Thank you very much

# CERTIFICATION

This is to certify the work entitled **“Inventory of Short Lived Climate Pollutants (SLCPS) and PM2.5 from road transport in Rwanda”** is a record of the original work done by NIYIBIZI Pascal with Registration Number **221027774** in partial fulfillment of the requirement for the award of master’s degree of science in atmospheric and climate Science in Department of physics at the University of Rwanda College of science and Technology.

| | |
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## Abstract

This study has focused on the Inventory of SLCPS from the transport and their effect on the environment and human health in Rwanda and the data used were collected from the Rwanda Statistical Yearbook by taking the year of 2006 as baseline and the year of 2022 as end year in this inventory. The vehicles of different categories in Rwanda were recoded and analyzed under the model called:" Low Emissions Analysis Platform (LEAP)". From the results analyzed and given by LEAP model, all my objectives were full-filled and it becomes easier to evaluate and characterize the emissions from different vehicles. In addition, by using the results from the model, the study of the effect of emission types and concentrations on human health and environment were achieved. The results show that fuels consumed and the emissions of SLCPs in the atmosphere were increased as well as the vehicles increased from 2006 till 2022. This study investigates from different sources the serious problems on the environment and also on the human health caused by Short lived climate pollutants from the road transport. These pollutants are known as the black carbon, Particulates of matter of diameter shorter than 2.5µm, Methane, and Nitrogen Oxide formed from the stratospheric ozone and ground –level or tropospheric ozone. Therefore, it was found that if left uncontrolled, the emission will continue to grow as the number of vehicles using roads is increased. This study shows some proposed mitigations methods facilitating in reduction of short lived climate pollutants which is introduction of hybrid electric vehicles.

# Abbreviations and notations

SLCPs: Short lived Climate Pollutants

PM: Particulate Matter

LEAP: Low Emission Analysis Platform

VOC: Volatile Organic Compounds

REMA: Rwanda environmental Management Authority

RURA: Rwanda utilities Regulatory Authority

BC: Black Carbon

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# CHAPTER 1: INTRODUCTION

## 1.1. Background

Road transport in Rwanda is taken as one of the key strategic pillars of economic growth of the country and increases the prosperity for the Rwandan population in this sector the road network was improved and sustain in maintenance [1]. Today the road transport is taken as the main way based public transport where this sector is dominated by internal combustion of fuels which produce the emissions in the atmosphere and emissions become dangerous to the environment and the human health where the exposure in area of poor air quality can cause several health problems such as a respiratory injury, Cardiovascular disease, strokes and lung cancer [2]. To limit the risk of health impacts taking source from the poor air quality, the World Health Organization has created air quality guidelines for key air pollutants. Unfortunately, many people are facing the presence of pollutant concentrations which don't meet these guidelines where approximately 92% of the world's population live the regions where the annual Particulates matter (PM2.5) guideline is exceeded [3]. The Scientist developed and clarified the understanding of air quality in Rwanda by specifying the main sources of pollution through The Rwanda environmental Management Authority (REMA). The different research shows that the air pollutants come from a variety of anthropogenic and natural sources. In Rwanda the main sources of man -made air pollution are based on the road transport through the burning of the fuels consumed by the vehicles. This study focus on the emissions from the transport as the biggest contributor to air pollution by taking account to pollutants of the too short lifespan it means that they don't resist in atmosphere for long period. In addition, even though these pollutants have short time they cause the serious impacts on the environment and also on the human health [2]. These pollutants of short lifespan are called Short lived climate pollutants where some of them taking source from out of the transport sector and the remains are: Black carbon, methane, Particulates of matter of diameter shorter than 2.5µm, Stratospheric Ozone (O3) and the Nitrogen oxides (NOx) reacting chemically with the volatile organic compounds (VOC) to form Tropospheric or Ground Level Ozone [4]. Therefore, each pollutant has its own impacts on both environment and human health and these impacts will be the focus of this dissertation by evaluating the gas emissions from different vehicle category and their impacts on public health and environment.

## 1.2. Statement of the problem

The fact that in Rwanda the population growth is significant with 9,000,000 Population in 2006 and 13,246394 in 2022, this justify the increase of vehicles as well as the sufficient emissions of SLCPS from the transport and these Pollutants create the strong impact on the environment and human health. This is the main reason of my study which will improve understanding of climate effects due to the short lived climate pollutants emitted from the road transport and also to highlight suitable mitigation methods in the transport sector in order to reduce the poor air quality in the country. [5]

## 1.3. The objectives of the study

The main objective of this study is to carry out the inventory of the short-lived climate pollutants from transport, by taking account on their strong impacts on climate and human health in Rwanda. This objective is accomplished from the specific objectives shown below:

(i) To Evaluate the currently vehicles emissions levels and characterize the emissions from different automobile types

(ii) To Study the impacts of the different emission types and their concentrations on public health and environment.

## 1.4. Justification of the study

The strong consideration of the roles of SLCPs in the past and present-day atmosphere is crucial to accurately assess their role in historical climate change and potential for future mitigation of climate change. Therefore, it is necessary to have a sufficient knowledge of the inventory of SLCPs in the atmosphere, their variability and the extent to which they affect the radioactive balance of the Earth's atmosphere. The purpose of this study is to assess the inventory of Short Lived Climate Pollutants (SLCPS) from transport and their impacts on climate and human health in Rwanda by providing proposed solutions which will help the Rwandan Society to know how the short lived climate pollutants are harmful on both environment and their own health and hence the measures they can take to avoid the increase of poor air quality. [6]

# CHAPTER 2: LITERATURE REVIEW OF SLCPS FROM TRANSPORT

## 2.1. Introduction

The gas emissions is one of the biggest challenge we face in front of us every day. These gases are categorized into two categories, where some of them have the long lifespan and the others have the short lifespan living in the air we breathe in our everyday lives and these gases of short life span are known as short lived climate pollutants and this part of my dissertation shows the main and specific aim for the Inventory of SLCPs from the transport and their impacts on climate and human health in Rwanda.

## 2.2. Road transport and SLCPs

The Rwanda is one of the landlocked country and use the road transport for carrying goods, personal movements and service trades as the one way for economic country success [1]. Unfortunately, this method of road transport becomes the hostile for the environment and the human due to the emission of SLPs produced by the fuel combustion used in vehicle engines [5]. The SLCPs are called short-lived from the periodic time living in the atmosphere where they last the few days to a decade. But even they take a short time in the air they have a serious effect in warming the air, and they are considered as the powerful agents [5]. The group of SLCPs taking source from the road transport is composed of black carbon, Particulates matter of diameter shorter than 2.5µm, methane($CH_4$), particulates of mater and nitrogen Oxide ($NO_x$) formed by the stratospheric ozone and tropospheric or ground-level ozone and each of them has the specific effects on the environment and human health [4].

## 2.3. Impacts of SLCPs on the environment

The black carbon is formed from the incomplete combustion of fuels consumed by the vehicles in rod transportation [7]. This type of pollutants is a black particle small sized and a major component of PM2.5. Incase this BC particle suspended in the air, they create a negative impact on the environment, where it raises the temperature of any location due to the absorption of incoming solar radiations and reradiate as heat energy [8]. In addition, the BC particles contribute in formation of cloud and hence the regional weather and the rainfall are changed due to the presence of black carbon.

The ground-level ozone ($O_3$) is harmful to the nature and affect the ecosystems, it affects more the plants by reducing the photosynthesis, the plant reproduction and this $O_3$ is considered as most responsible for reducing the crops and hence affecting the global food security [4]. The tropospheric Ozone is one of the reacting gas and it has the harmful to the human health and the ecosystems. The formation of this ozone on the lower level of the layer's atmosphere the O3 reduces the ability of plants to make their own food, the plant's capacity to absorb the CO2 emitted in the atmosphere [9].

## 2.4. Impacts of SLCPs on the human health

The black carbon is composed with PM2.5 with the diameter less than 2.5µm and PM10 of diameter less than 10 µm. The impacts of these pollutants increases with the decrease in in size [10]. Therefore, this PM2.5 has a serious injury on the cardiovascular and respiratory system of humans. According to the World Health Organization, the BC and Carbon come up with a part of group of thin PM in air pollution which cause a major environmental effect of illness and premature deaths globally(WHO,2029).[10] The particulate matter of 2.5µm has the small diameter which is too small to be entered inside the human body where they enter through the respiratory system and also thought the human Skin and is responsible for causing asthma, attacks, bronchitis, sinus infections and the reduction of general life expectancy. The emissions of methane don't cause direct effects to human health, agriculture or the ecosystems. But the methane is considered as one of the most prominent precursor gases to the ground level ozone, which has the strong impacts on both human health and particular on the crop. Like other greenhouse gases the methane also traps the infrared radiations that enters the atmosphere and after are reradiated into the space in the form of heat. [11] Methane is produced from both natural like wetlands and anthropogenic sources, the main source of the methane from the human activities is the road transport using the fossil fuels. On the high levels of this methane can reduce the amount of oxygen breathed from the atmospheric air. This can result in mood changes, slurred speech, vision problems/ memory loss, vomiting, facial flushing and headache. In the serious cases of presence of methane there may be changes in breathing and heart rate balance problems and unconsciousness. [11].

## 2.5. Conclusion

The SLCPs take a significant contribution in both the environment and the human health. The serious measures must be applied to reduce the emission of air Pollutants both solid and gas

# CHAPTER 3: DATA AND METHODOLOGY

## 3.1. Data and method

The data to be used were collected from NISR, the Rwanda statistical Yearbook (2006-2022) and Rwanda utilities Regulatory Authority (RURA) [12]. This study takes all vehicles using road as one of different ways of transport in Rwanda and applies model called LEAP to analyze inventory of short lived Climate Pollutants during the period of 2006-2022. Emissions are calculated all SLCPs, black carbon, methane, NOx and PM2.5. Where the emission factor of these SLCPs from use of gasoline and Diesel have already been integrated in the LEAP Model

## 3.2. Methodology

This study used the LEAP for estimation of consumption of energy and emitted pollutants from all categories of vehicles This LEAP model was developed by the Stockholm Environment Institute. From the applications of this LEAP model I analyzed emissions from the Whole country and regional air pollutants. In this dissertation the base year was taken as 2006 and the inventory of energy consumption and emission of SLCPs it means a Black Carbon, a Methane, a Nitrogen Oxide (NOx) and the Particulate of Matter are carried up to 2022. Where the fuel consumed will be found from product of the number of all vehicles (N) and the intensity of energy (Ei) while emitted amount of pollutants is captured from the product of fuel demand, annual vehicle kilometer travelled, the Net Calorific (NCV) and the emission factor

## 3.3. Calculations

In this study the fuel consumed from the transport in Rwanda is found as follow:

The total travel distance and the intensity of energy are calculated while the travel demand is evaluated in function of vehicle-km, the intensity of energy is calculated in terms of liters per vehicle kilometer.

**Formulas used:**

(a) Fuel consumption (FC) = $\sum Ni$ x Ei

Where N represents the whole number of vehicles for category i, and Ei represents the energy intensity

(b) Energy demand (ED)= NEi x VKT x NCV

With ED is the energy demand, VKT is the average annual vehicle kilometer travelled and NCV is the Net calorific value

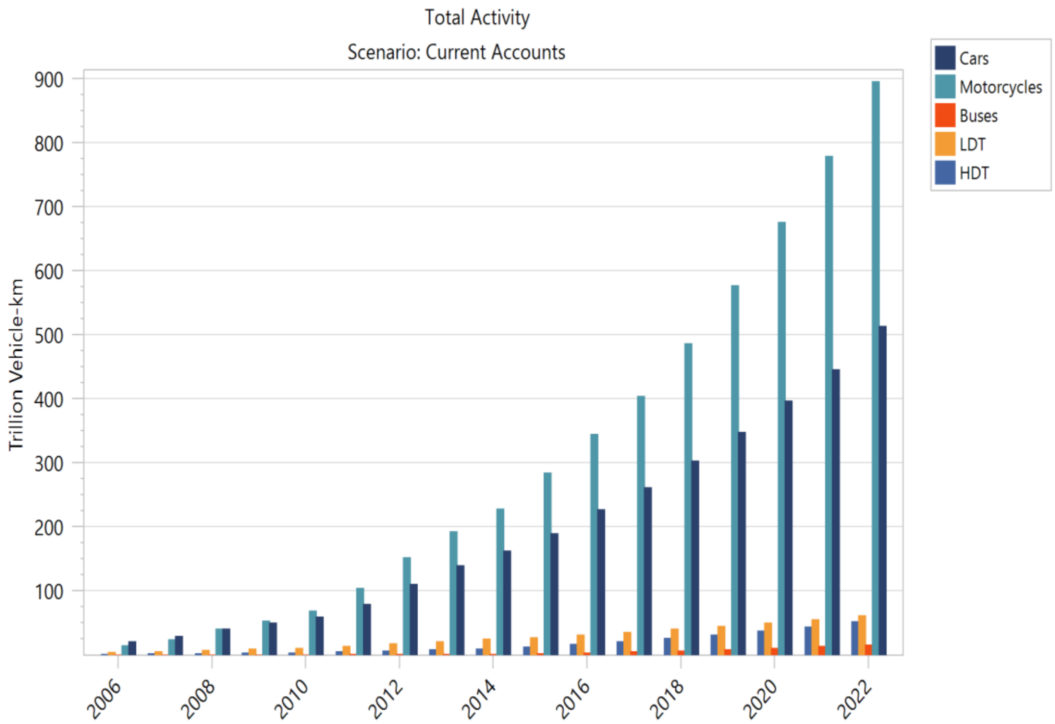
(c) Emissions(E) = ED x EF

Where EF is the emission factor

# CHAPTER FOUR: RESULTS

## 4.1. Simulation

Results shows that energy consumption and emissions from gasoline and Diesel consumed by each category of vehicle in road transport sector increase as well as the vehicles increased in the country. The analysis of emitted SLCPs from different vehicles showed that black carbon, methane, stratospheric ozone, PM2.5 and O3 are emitted due to the fuel combustion and increases in the atmosphere due to the significant increase of vehicles from 2006 up to 2022.

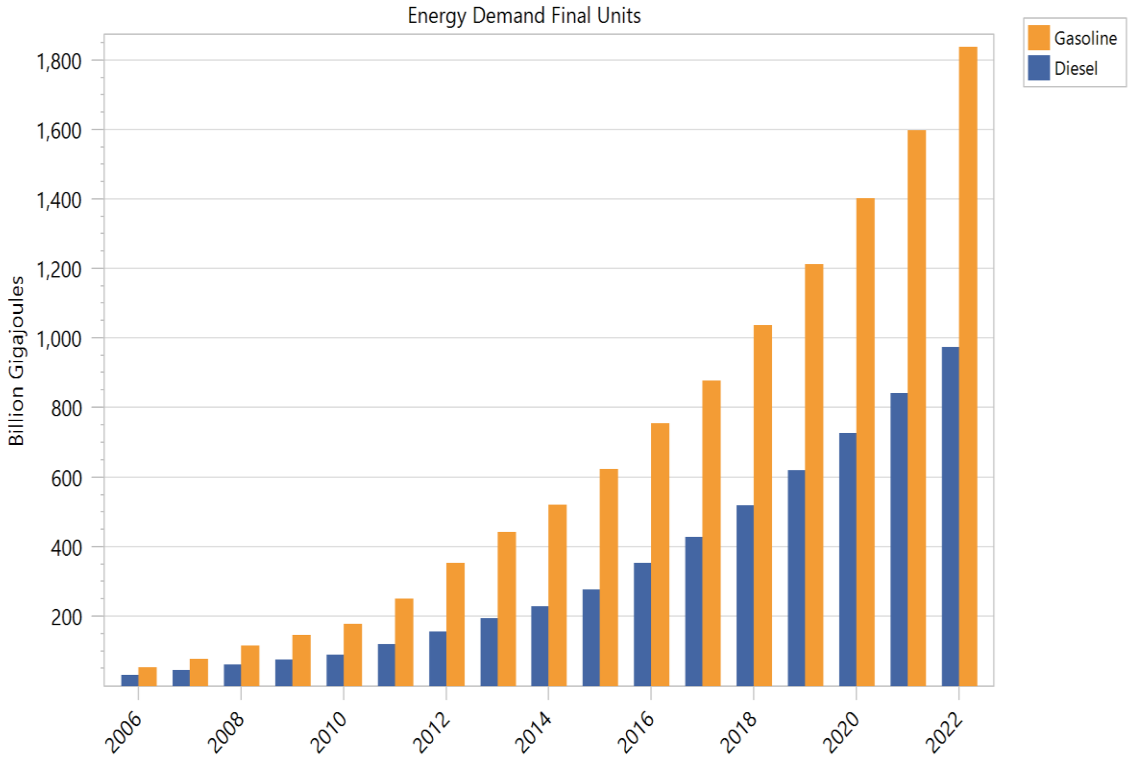



**(Figure 1: Increase of each vehicle category from 2006 to 2022)**

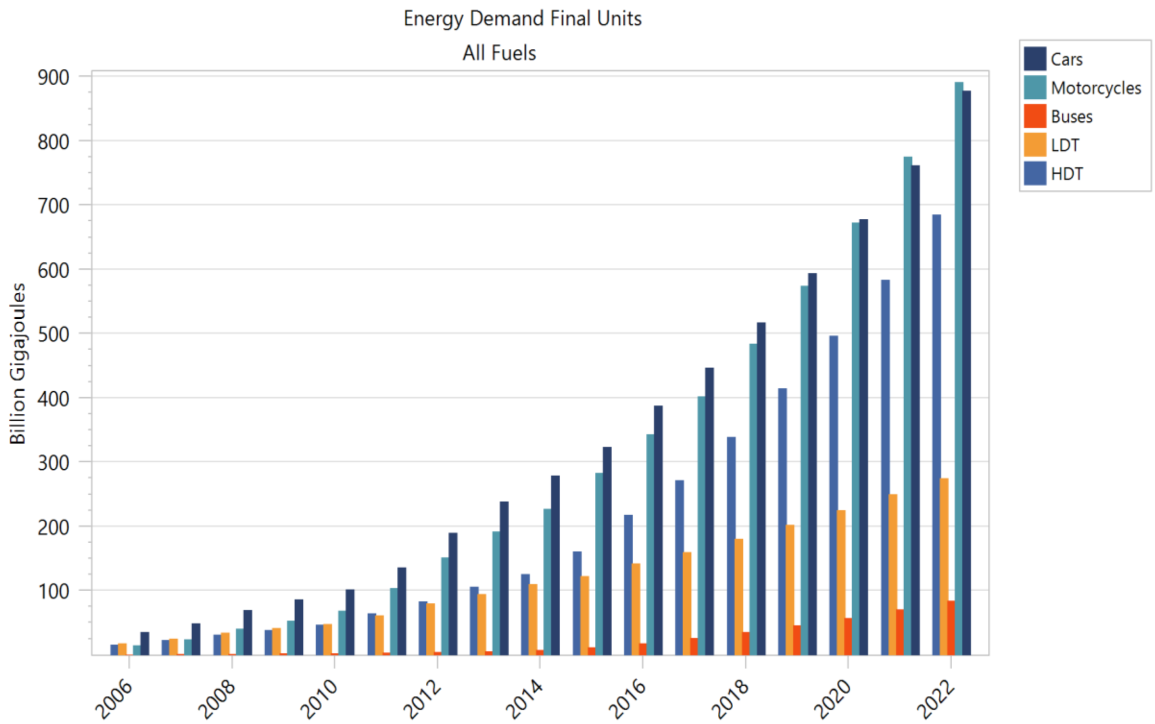
From the graph above,the vehicles inside the country have been increasing I different ways due to the development of the country and the rate of increase in the population. Therefore the motocycles are taken as the ones which are often used by many people due to the fact that they facilitate many people to make short trips in their daily work and this is the reason why the motocycles come in the first place in the growth of vehicles.

### 4.1.1. Estimation of energy consumption:

In Rwanda one of the ways that many people use for business and daily trips is the road, where different types of vehicles are used to accomplish these tasks. The fuels used for road transport are gasoline and Diesel. Where the gasoline is more consumed due to the great number of vehicles using the gasoline as fuel and the more details are shown on the graphs.




(Figure2: Energy consumption by fuel)



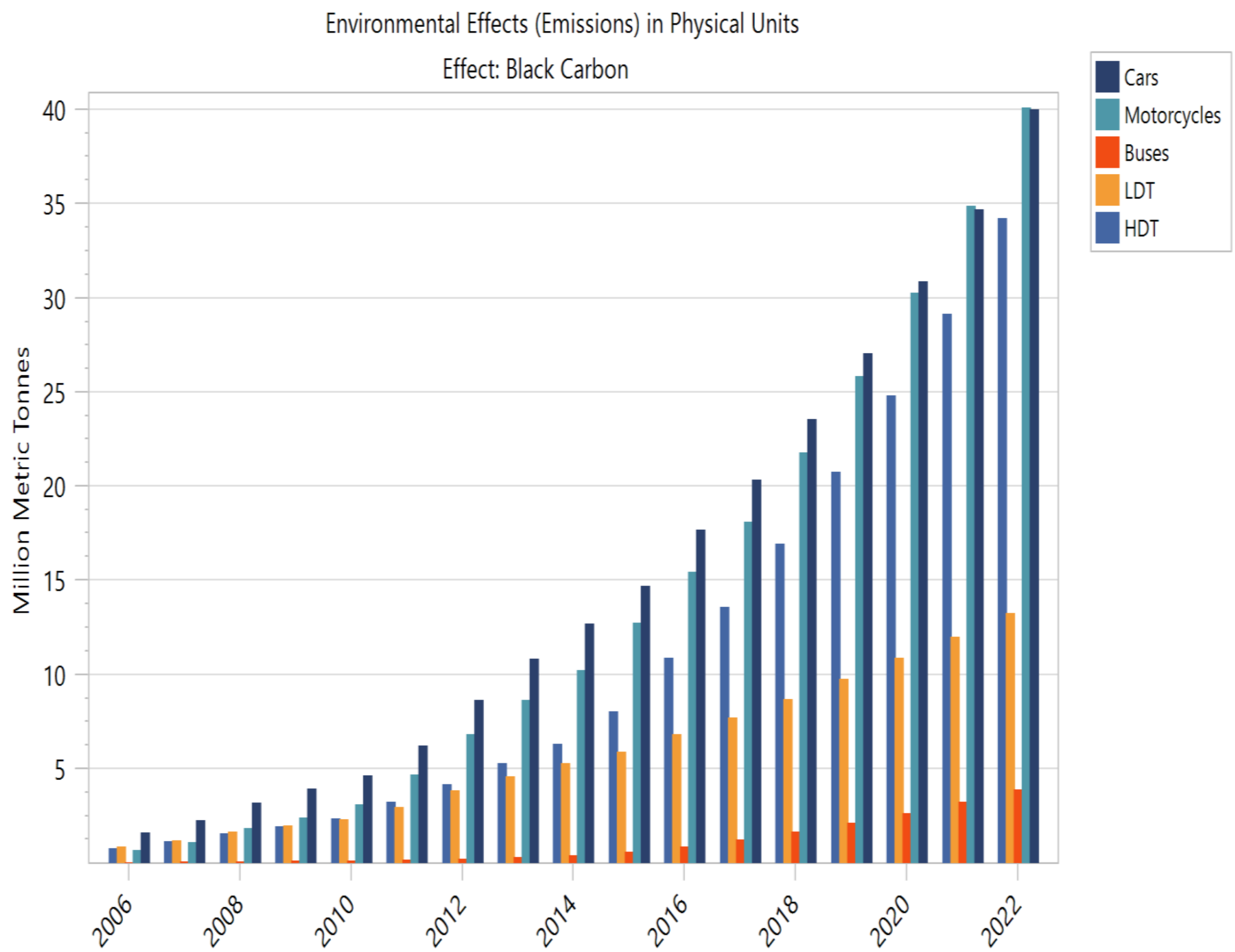

**(Figure 3: Energy consumption per vehicle category)**

### 4.1.2. Estimations of emitted SLCPs pollutants

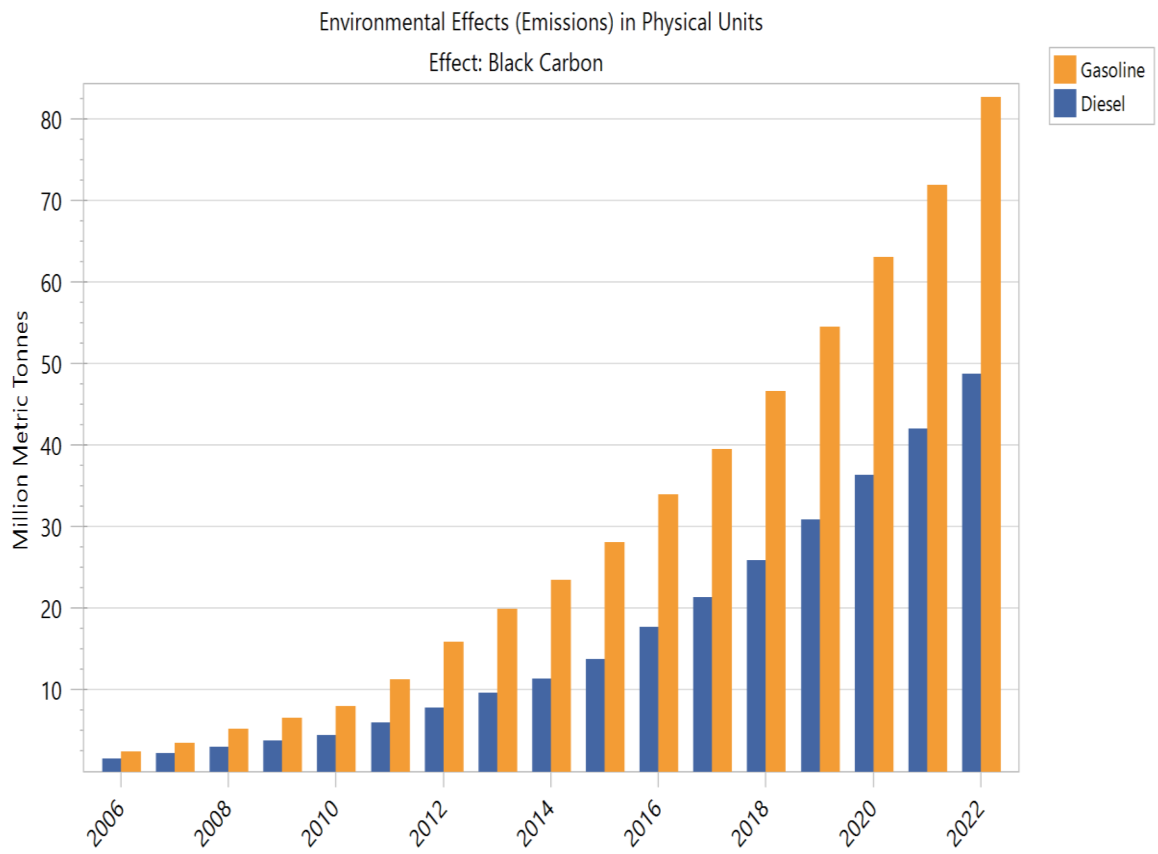
This part of estimations of emissions of the short lived climate pollutants shows the different gases emission analyzed by the LEAP model and the level of emissions are presented on the graphs shown below.

### 4.1.2.1. Black carbon (BC) emission.

A BC is taken as the contributor to the global climate change where it takes a second place after CO2 as the global main driver of change [13]. BC is composed by small particles which absorb the radiations from the sun. Therefore, the emissions of black carbon from different vehicles are shown below.



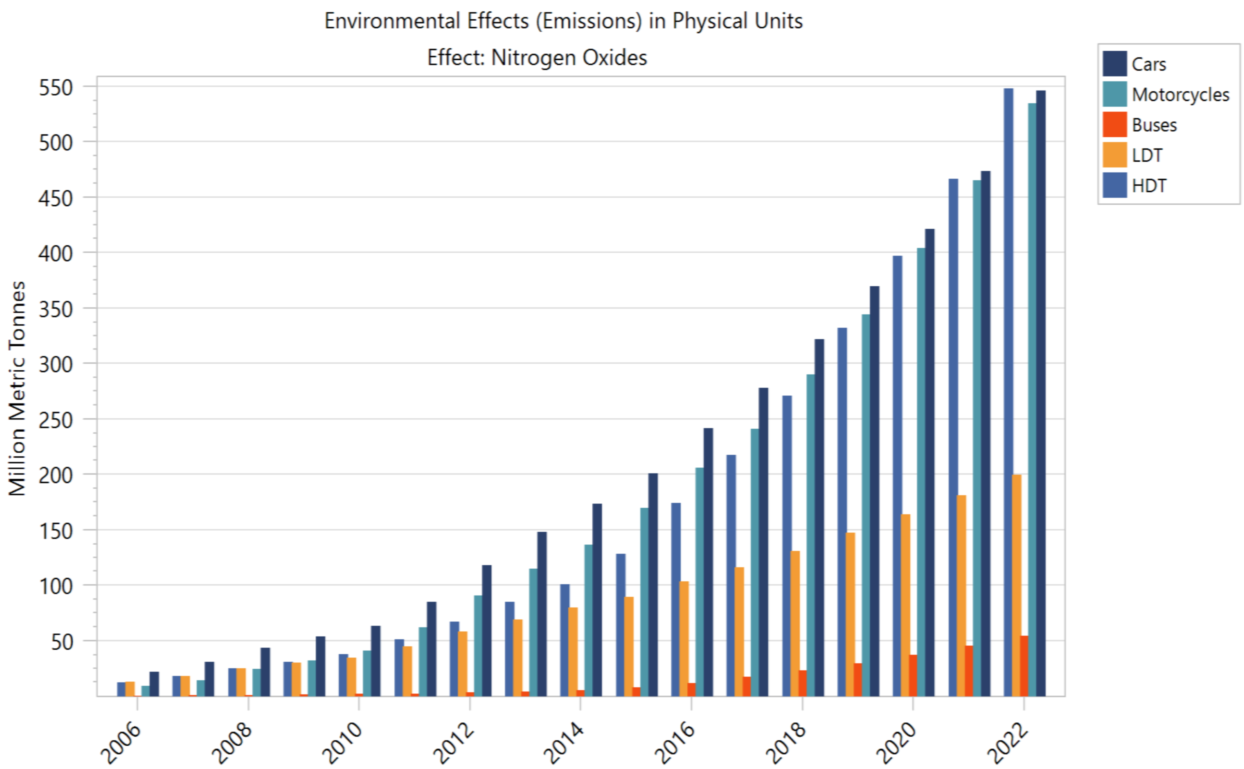

**(Figure 4: Black carbon emissions per vehicle category)**



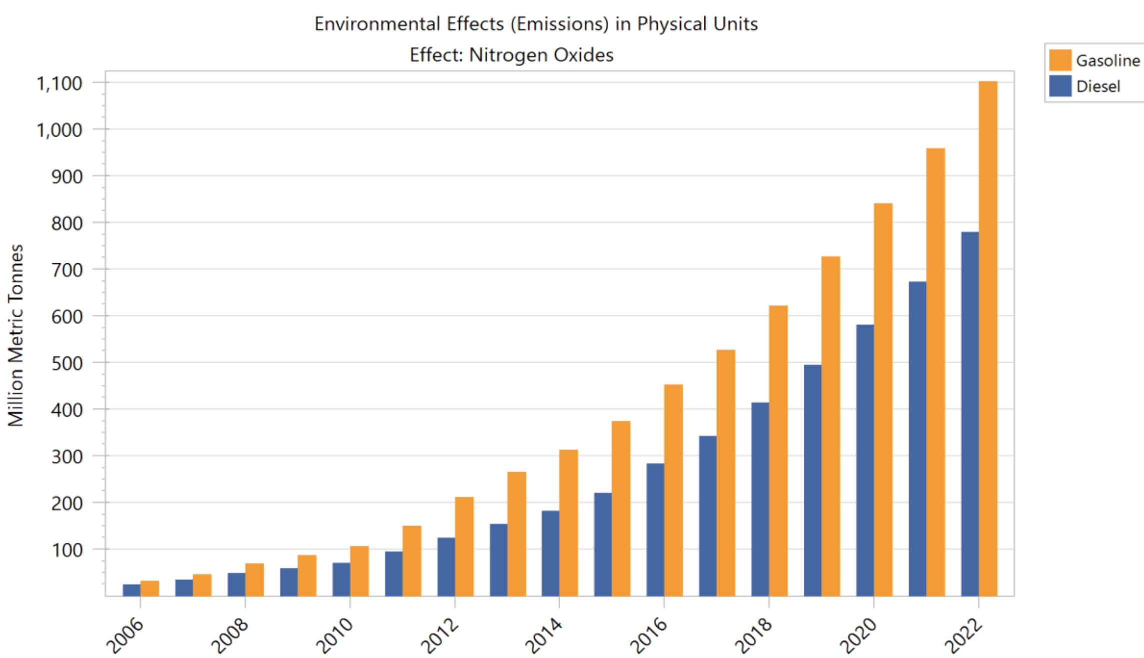

**(Figure 5: Black carbon emissions per fuel category)**

### 4.1.2. Emission of Nitrogen Oxides (NOx)

The nitrogen Oxides is produced from the chemical reactions and it has significant impact on both environment and human health [14]. Therefore the emissions of nitrogen oxides from different vehicles are shown below



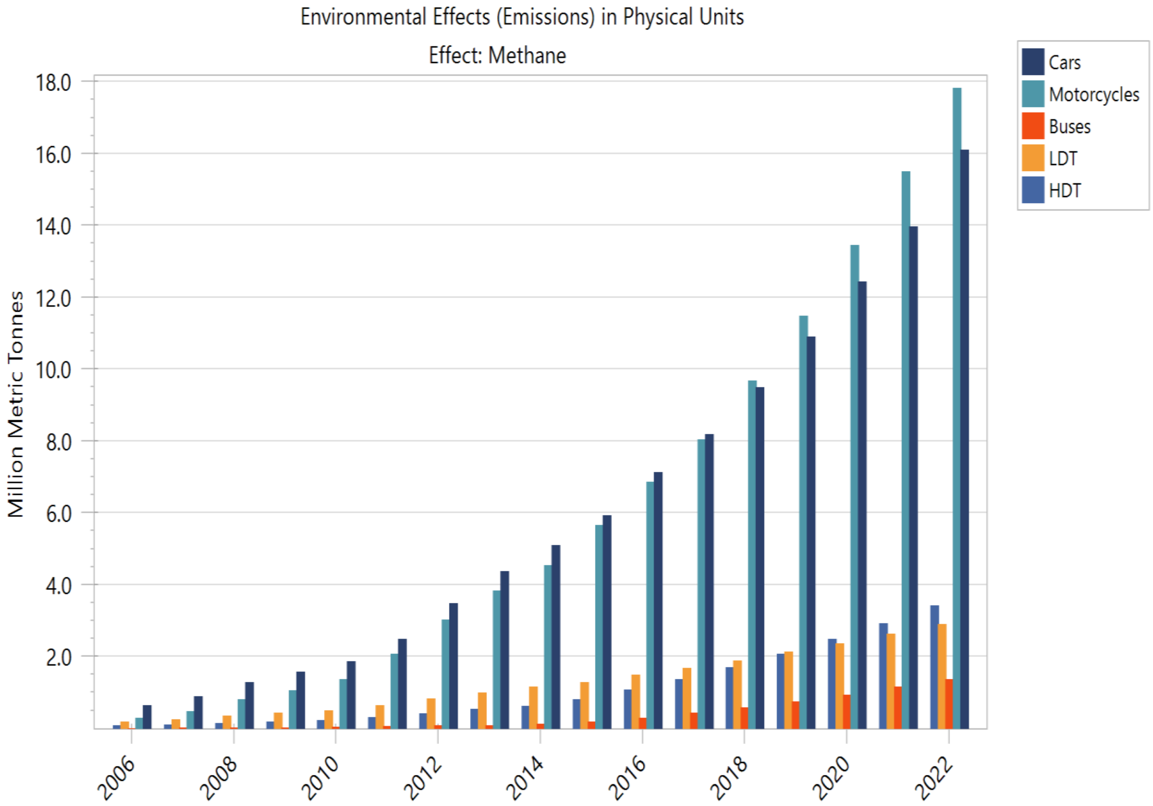

**(Figure 6: Nitrogen oxides emissions per vehicle category)**



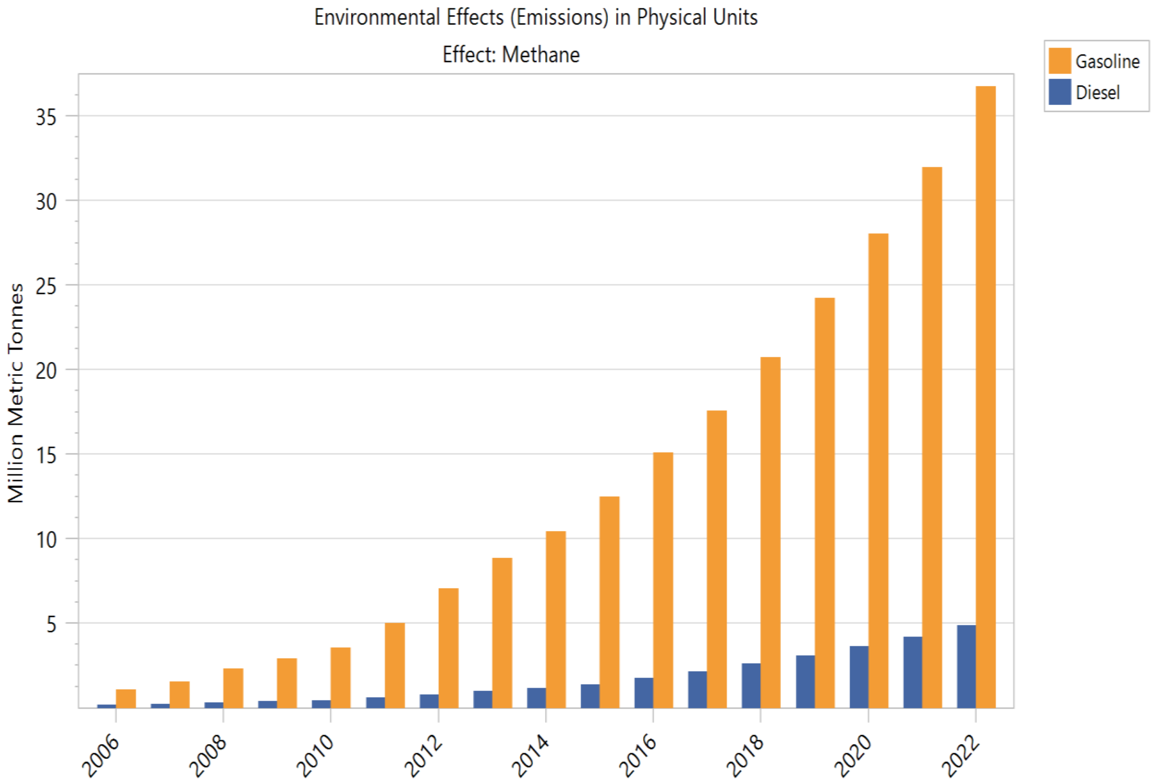

**(Figure 7: Nitrogen oxides emissions per fuel category)**

### 4.1.3. Emission of Methane (CH4)

CH4 is one the SLCPs emitted by human activities. This SLCP gas has more ability of absorbing radiations from the sun. Methane has a number of indirect effects. This gas has short lifetime comparatively to the carbon dioxide where the methane takes few years in the atmosphere but it cause the increase in temperature [15].



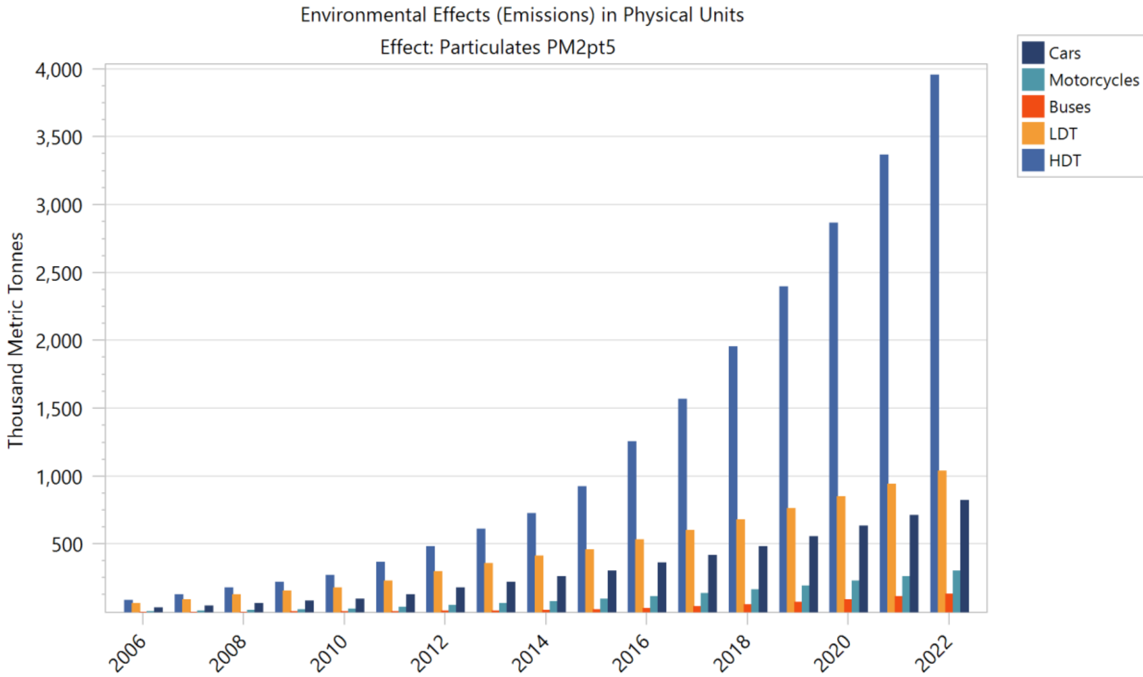

**(Figure 8: Methane emissions per vehicle category)**



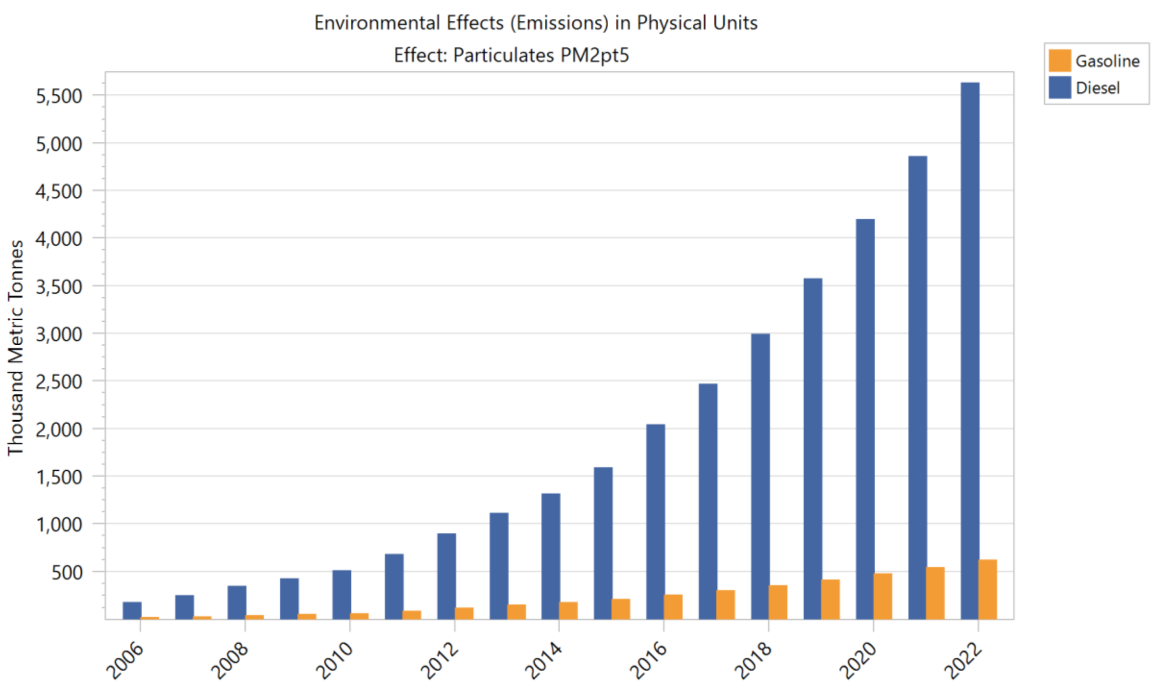

**(Figure 9: Methane emissions per fuel category)**

### 4.1.4. Emission of particulates matter(PM2.5)

Particulate matter (PM) is subdivided into two types due their size. One is the PM2.5, whose the diameter less than 2.5micrometrs and the second one has the diameter less than 10micrometers as these particles differ from their size they have also the different impacts on the human health and on the climate. In this study the particulate matter considered is one of 2.5 micrometers formed from incomplete combustion of the fuels in the vehicle. So, the exposure from these particulates of matter can cause serious health problems [16].




**(Figure 10: Particulates Matter emissions per vehicle category)**




**(Figure 11: Particulates Matter emissions per fuel category)**

# CHAPTER FIVE: CONCLUSION AND DISCUSSION

## 5.1 Discussion

The results show that in Rwanda the vehicles will continue to increase from 2006 till 2022 due to the population growth where the total population was 9,270,066 in 2006 and 13776698 in 2022 [12] and the graphs from the results shows the fuels consumed depends on the increase of vehicles and hence the emissions of SLCP become more concentrated in the atmosphere. The findings indicate that the motorcycles increased more than other vehicles this explain well the improvement for local movements. The follow is the personal car which increases for the sufficient rate and the fuels consumed increased relative to the increase of vehicles and hence the emissions of SLCPs affect the environment and the human health.

## 5.2. Conclusion

The road transport sector consumes the highest energy comparatively to the other economic sectors. Beyond of this, it is also one of the source of sort lived climate pollutants in the country and therefore creating the strong impacts on air quality and climate change. This study evaluate the Inventory of SLCPs from road transport sector of Rwanda from 2006 up to 2022, estimates the energy consumption, Analyze the emissions from the combustions of fuels used in vehicle's Engines and specify the serious impacts caused by these emissions for both human health and environment which will be the result of the climate chance and global warming.

The main objective of this study is to carry out the inventory of the short-lived climate pollutants from transport, by taking account on their strong impacts on climate and human health in Rwanda. The results show that the emissions of short lived climate pollutants will continue to increase as well as the number of vehicles increase these emissions cause the serious impacts on the human health like respiratory injury, Cardiovascular disease, strokes and lung cancer[2].

## 5.4 Recommendation

This study indicates that the emission of SLCPs from the transport will continue to grow due to the increase of vehicles in Rwanda. This problem of increase of poor air quality has the serious impact on the climate and the human health as shown in the previous chapters and I put forward for the future researchers and for my future studies to make the future projections and also to show the measures needed to be implemented by the government of Rwanda for the air pollution mitigations.

## 5.5 Suggestions for further study

This study has a great success of improving the understanding on the effects of SLCPs emitted from the road transport on the human health and environment. Therefore the further studies must focus on the future projections and discuss on different scenarios and suggest some mitigations for air pollutants reductions.

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## Appendices

| Variable: Vehicles: Activity Level (Thousand Vehicle-km per Vehicle-km) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Branch: Demand\Transport\Vehicles | | | | | | | | | | | | | |
| Branch | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 201 |
| Cars | 21.7 | 24.7 | 28.6 | 31.4 | 33.6 | 37.8 | 44.4 | 49.7 | 53.6 | 56.7 | 61.8 | 65.8 | 70.1 | 74.3 |
| Motorcycles | 15.2 | 20.6 | 28.4 | 33.1 | 38.5 | 49.4 | 60.7 | 68.6 | 75.1 | 85.1 | 93.9 | 101.8 | 112.5 | 123 |
| Buses | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 1.0 | 1.3 | 1.8 | 2.5 | 3.0 | 3.6 |
| LDT | 8.1 | 9.4 | 10.6 | 11.4 | 11.9 | 13.0 | 14.2 | 15.1 | 16.1 | 16.4 | 17.2 | 18.0 | 18.6 | 19.3 |
| HDT | 2.4 | 3.0 | 3.3 | 3.6 | 4.0 | 4.6 | 5.1 | 5.7 | 6.3 | 7.3 | 9.0 | 10.4 | 11.9 | 13.4 |
| Total | 47.6 | 57.9 | 71.3 | 80.0 | 88.6 | 105.3 | 125.0 | 139.9 | 152.0 | 166.8 | 183.8 | 198.4 | 216.1 | 234 |

Table 1: Vehicles

| Energy Demand Final Units | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Branch: Demand\Transport\Vehicles | | | | | | | | | | | | | |
| Units: Billion Gigajoules | | | | | | | | | | | | | |
| Branch | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| Cars | 35.3 | 48.9 | 69.8 | 85.9 | 101.8 | 135.9 | 189.4 | 237.9 | 278.2 | 322.9 | 388.0 | 446.0 | 517.2 |
| Motorcycles | 14.4 | 23.7 | 40.3 | 52.7 | 67.9 | 103.4 | 150.9 | 191.3 | 227.0 | 282.5 | 343.4 | 401.6 | 483.5 |
| Buses | 0.4 | 0.6 | 1.2 | 1.6 | 2.5 | 3.4 | 4.5 | 5.6 | 7.7 | 11.7 | 17.7 | 26.2 | 35.0 |
| LDT | 17.3 | 24.4 | 33.9 | 41.0 | 47.3 | 61.1 | 79.6 | 94.5 | 109.6 | 122.4 | 141.8 | 159.4 | 180.0 |
| HDT | 15.4 | 22.6 | 31.0 | 38.5 | 47.0 | 64.0 | 83.3 | 105.8 | 125.6 | 160.2 | 217.1 | 271.7 | 338.6 |
| Total | 82.8 | 120.3 | 176.2 | 219.7 | 266.5 | 367.9 | 507.7 | 635.1 | 748.2 | 899.7 | 1,108.0 | 1,305.0 | 1,554.3 |

Table 2: Energy demand

| Environmental Effects (Emissions) in Physical Units | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| All Fuels | | | | | | | | | | | | | | |
| Branch: Demand\Transport\Vehicles | | | | | | | | | | | | | | |
| Units: Million Metric Tonnes | | | | | | | | | | | | | | |
| Branch | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 20 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cars | 0.6 | 0.9 | 1.3 | 1.6 | 1.9 | 2.5 | 3.5 | 4.4 | 5.1 | 5.9 | 7.1 | 8.2 | 9.5 | 10.9 | 1 |
| Motorcycles | 0.3 | 0.5 | 0.8 | 1.1 | 1.4 | 2.1 | 3.0 | 3.8 | 4.5 | 5.7 | 6.9 | 8.0 | 9.7 | 11.5 | 1 |
| Buses | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.3 | 0.4 | 0.6 | 0.7 | 0. |
| LDT | 0.2 | 0.3 | 0.4 | 0.4 | 0.5 | 0.6 | 0.8 | 1.0 | 1.2 | 1.3 | 1.5 | 1.7 | 1.9 | 2.1 | 2. |
| HDT | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.8 | 1.1 | 1.4 | 1.7 | 2.1 | 2. |
| Total | 1.2 | 1.8 | 2.6 | 3.3 | 4.0 | 5.6 | 7.8 | 9.8 | 11.6 | 13.9 | 16.9 | 19.7 | 23.3 | 27.3 | 3 |

Table 3: Emissions