UNIVERSITY OF NAIROBI

ASSESSING THE CONTRIBUTION OF TRAFFIC CONGESTION TO GREENHOUSE GAS (GHG) EMISSIONS IN THE CENTRAL BUSINESS DISTRICT (CBD) OF NAIROBI CITY, KENYA

BY

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DEDICATION

To Aggrey and Damaris, my beloved parents and source of encouragement

To my siblings, who believed in me and saw a better tomorrow for me, and

To the Almighty God who is my continuous source of strength

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ABSTRACT

Traffic congestion significantly contributes to climate change due to the emissions of Greenhouse Gases (GHGs) such as Carbon Dioxide (CO_2), Nitrous Oxide (N_2O) and Ozone (O_3). Rapid urbanization and poor planning coupled with increased motorization and fragmented public transport system in cities such as Nairobi has led to increased vehicular emissions along the various roads and within the Central Business District (CBD). To reduce GHG emissions in the urban transport sector, institutional coordination and relevant policy tools must be considered. The aim of this study was to estimate CO_2 emissions from different vehicle categories during congestion, using Uhuru Highway as a case study. The relationship between traffic congestion and CO_2 emissions was analysed using qualitative and quantitative methods, through a bottom-up approach. Both primary and secondary data were used in this study. Questionnaires were administered to get individual vehicle characteristics and opinions on the best actions for reduction of CO_2 emissions along Uhuru Highway in Nairobi. The Average Annual Daily Traffic (AADT) for different vehicle categories from 2014 to 2019 formed the basis for estimation of CO_2 emissions. Results showed that private cars predominate over other vehicle types, contributing 73% of the total CO_2 emissions in Nairobi Central Business District (CBD). Private cars are the highest contributors of CO_2 emissions with a total of 25.3 million of Carbon dioxide equivalent (gCO_2e), between 2014 and 2019. In comparison, Public Service Vehicles, commonly referred to as *Matatus* emitted 6.89 million gCO_2e, Light Commercial Vehicles (1.82 million gCO_2e), Heavy Goods Vehicles (251,683 gCO_2e) and motorcycles (181,054 gCO_2e). To minimize CO_2 emissions, the study recommended enforcement of strong mobility policies to control the high motorization rate. One of these policies is the prioritization of the development of mass public transport system to achieve the potential health, economic and environmental gains within the CBD.

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LIST OF ABBREVIATIONS AND SYMBOLS

AADT	-	Average Annual Daily Traffic
ADT	-	Average Daily Traffic
ANN	-	Artificial Neural Networks
ARAI	-	Automotive Research Association of India
AR4 WG-I	-	IPCC 4th Assessment Report, Working Group I
ArcGIS	-	Aeronautical Reconnaissance Coverage Geographic Information System.
BRT	-	Bus Rapid Transit
CBD	-	Central Business District
CDT	-	Centre for Doctoral Training
CMEM	-	Comprehensive Modal Emissions Model
CO_2	-	Carbon Dioxide
CO	-	Carbon Monoxide
CH_4	-	Methane
CHF_3	-	Hydrofluorocarbon-23
DPSIR	-	Drivers, Pressures, State, Impact and Response
IEA	-	International Energy Agency
EEA	-	European Environment Agency
EI	-	Emissions Inventories
EMEP	-	European Monitoring and Evaluation Programme
EPA	-	Environmental Protection Agency
4WD	-	Four-wheeled Drive
GHG	-	Greenhouse Gases
GLM	-	General Linear Modelling
gCO_2e/km	-	Grams of Carbon Dioxide equivalent per Kilometre
$GtCO_2$	-	Gigaton of Caron Dioxide
HC	-	Hydrocarbon
HGV	-	Heavy Goods Vehicle
INFRAS	-	A Research Consulting Company
IPCC	-	Intergovernmental Panel on Climate Change
IR	-	Infrared Radiation

ITS	-	Intelligent Transportation Systems
JICA	-	Japan International Cooperation Agency
JKIA	-	Jomo Kenyatta International Airport
KeNHA	-	Kenya National Highway Authority
KNBS	-	Kenya National Bureau of Statistics
KRB	-	Kenya Roads Board
KS 1515	-	Kenya Standard Code of practice for inspection of road vehicles
KURA	-	Kenya Urban Roads Authority
LCS	-	Low-Cost Sensors
LRT	-	Light Rail Transit
MATLAB:	-	Matrix Laboratory
$MtCO_2e$	-	Million Tonnes of Carbon Dioxide Equivalent
NACOSTI	-	National Commission for Science and Technology
NAMATA	-	Nairobi Metropolitan Area Transport Authority
NCCG:	-	Nairobi City County Government
NDC:	-	Nationally Determined Contributions
NDIR	-	Non-dispersive Infrared Radiation
NCCAP	-	National Climate Change Action Plan
NEMA	-	National Environment Management Authority
NMT	-	Non-Motorized Transport
NO_2	-	Nitrogen Dioxide
N_2O	-	Nitrous Oxide
NO_x	-	Nitrogen Oxide
NTSA	-	National Transport and Safety Authority
ORSEEM	-	On-Road Simulation Emissions Estimation Model
O_3	-	Ozone
$P.M_{2.5}$	-	Particulate Matter with a diameter of 2.5mm
PM_{10}	-	Particulate Matter with a diameter of 10mm
ppb	-	Parts Per Billion
ppm	-	Parts Per Million
RSIP	-	Road Sector Investment Program

SATURN:	-	Simulation and Assignment of Traffic to Urban Road Networks
SDGs	-	Sustainable Development Goals
SLoCaT	-	Sustainable Low Carbon Transport
SO_x	-	Sulphur Oxide
SO_2	-	Sulphur Dioxide
SPSS	-	Statistical Package for the Social Sciences
SSA	-	Sub-Saharan Africa
TROPOMI:	-	Tropospheric Monitoring Instrument
TTI	-	Travel Time Index
UN-HABITAT:		United Nations Human Settlements Programme
UNFCCC	-	United Nations Framework Conference for Climate Change
VKT	-	Vehicle Kilometer Travelled
VOC	-	Volatile Organic Compounds

CHAPTER ONE: INTRODUCTION

1.0 Introduction

This Chapter presents a detailed background of the study outlining the relevance and approaches used in this study. The problem statement, research questions, the objectives, significance of the study and the scope of the study have been discussed.

1.1 Background of study

The transport sector plays a vital role in contributing to the successful implementation of all the Sustainable Development Goals (SDGs). According to the Partnership on Sustainable Low Carbon Transport (SLoCaT), the sector is considered as the engine of the global economy that helps in accelerating human development (SLoCaT, 2019). However, as the global economy grows, transport Greenhouse Gas (GHG) emissions continue to rise, impacting on the successful implementation of the SDGs. The increase in emission of GHGs is as a result of burning of fossil fuels (IPCC, 2014) which ultimately alter the climate causing adverse effects such as floods, droughts, and heatwaves, especially in cities (La Notte *et al*, , 2018).

The International Energy Agency (IEA) estimates that the transport sector is responsible for 24% of the total CO_2 emissions (IEA, 2020). Road transportation accounts for nearly three quarter of these emissions. This includes emissions from traffic congestion which has become a common occurrence in cities and urban areas around the world. Traffic congestion is a serious problem in the urban road networks, especially in developing cities. It contributes to the increase in travel time and fuel consumption, causes environmental pollution, decreases productivity and thereby, imposing huge economic, social and environmental costs on the economy (Bharadwaj *et al*., 2017).

Traffic congestion results in emissions of harmful substances such as particulate matter, Volatile Organic Compounds (VOCs) and also greenhouse gases (GHGs) such as carbon dioxide (CO_2), nitrogen oxides (NOx), methane (CH_4) and ozone (O_3). Among the greenhouse gases, carbon dioxide is the most significant because of its long-term impact on global warming (having a lifespan of hundreds of years) as compared to other gases. It occupies the biggest proportion of all the greenhouse gases, with a Global Warming Potential of 1 (IPCC, 2007), having a lifetime of 50-200 years in the atmosphere (Lisa, 2008). It traps heat, making the planet warmer. Carbon dioxide has the capacity to absorb excess heat from the sun and redirecting it back to the surface of the earth, making the planet habitable. However, too much of CO_2 in the atmosphere may be fatal as it may directly cause respiratory problems (Lakouari *et al*., 2020). Too much of CO_2 may also create a surplus of greenhouse gases that trap heat, thereby causing enhanced warming hence climate change.

Previous studies have shown that CO_2 emissions from traffic congestion are influenced by different factors. Pandian *et al* (2009) investigated the effects of traffic on vehicular emissions and revealed that traffic conditions, driving speed and pattern, vehicle and road characteristics, and vehicle composition greatly influence emissions especially near road intersections. Other factors such as the slope, density and length of the road, travel time, distance and speed of each vehicle on the road and, class of the road which determines the traffic conditions and driving patterns, have also been reported to influence carbon dioxide emissions (Li *et al*., 2014; Zhang and Zhu, 2017; Zhu, 2013)

According to Raje *et al* (2018) traffic congestion poses a huge threat to the social, economic and environmental development in many cities of both developed and developing countries. Chang *et al* (2017) reported that larger cities in the USA, while others such as the United Kingdom, Poland, Slovakia and Spain experience more congestion which results to increased CO_2 emissions. Another study conducted in Chennai, India, showed that transportation sector was one of the largest emitters contributing 29.7% of the total CO_2 emissions (Kumar and Nagendra, 2016). China being one of the world's biggest emitters of carbon dioxide (Zheng *et al*., 2020) accounts for 9.3 % of the country's total emissions from the transportation sector, while more than 8% of the total carbon emissions are from traffic congestion (Zhang *et al*., 2019), in which private vehicles constitute to majority of the traffic especially in metropolitan areas such as Beijing (Li and Jones, 2015; Zheng *et al*., 2020). Other cities such as Mexico City, Bangkok, Singapore, Jakarta, Manila, Delhi and Mumbai have reported drops in their average speed during peak hours, an indication of heavy traffic congestion (Chang *et al*., 2017). Sao Paulo, Brazil, has been widely known to experience worse traffic congestion of a daily basis, that lasts for 2-3 hours (Chang *et al*., 2017).

In the past decades, majority of the African countries have experienced traffic congestion which has resulted in massive delays as well as decrease in productivity (Agyapong and Ojo, 2018).

This could be attributed to the rapid increase in vehicle ownership coupled with rapid urbanization in many African countries. Research has shown that the African continent has always had the lowest amount of greenhouse gas emissions. However, these emissions have increased over the years especially from the transportation sector which has recorded a sharp increase in motorization. Moreover, the increase in CO_2 emissions have been attributed to buying of second-hand vehicles from the developed nations and inefficiency of public transport vehicles (Wojuade, 2018).

South Africa is one of African countries with the highest emissions of greenhouse gases with the transportation sector accounting for 30.82% (Rhikhotso *et al*., 2016). The city of Tshwane in South Africa has experienced heavy traffic congestion, contributing 7.2% of South Africa's total CO_2 emissions (Rhikhotso *et al*, 2016). In Ivory Coast, Abidjan has also experienced intense traffic congestion which has significantly contributed to the increase in the city's emission levels (Doumbia *et al*., 2018).

Kenya, one of the Sub-Saharan African countries has experienced traffic congestion in its major cities of Nairobi, Kisumu and Mombasa (Salon and Gulyani, 2019). This has caused a rise in emission levels within the transportation sector which is responsible for about 11% of the country's total greenhouse gases (Government of Kenya, 2018). Due to the rapid increase in vehicle ownership, the emission levels have been projected to increase to about 14.7 % by 2030 (Government of Kenya, 2018). It is estimated that the road transport sector accounts for 99% of GHG emissions from non-aviation transport sector in Kenya (Cameron *et al*., 2012).

Nairobi is the most populated city in Kenya with a population of about 4.4 million people (Kenya National Bureau of Statistics (KNBS), 2019). It has the highest concentration of sources of industrial air pollutants and vehicles in Kenya (Gaita *et al*., 2014; Maroa, 2019). As the city's population continues to increase, the air quality continues to deteriorate, exposing both the citizens and visitors to health risks especially from motor vehicle emissions (Kinney *et al*., 2011; Odhiambo *et al.*, 2010; Rajé *et al*., 2018a). Heavy traffic congestion experienced within the city of Nairobi is mainly attributed to the high rates of motorization (Gachanja, 2015), as 60% of the total registered vehicles in Kenya operate in Nairobi (Madara *et al*., 2018).

As of 2013, the total person trip generation by persons living inside Nairobi City was 6.8-million-person trips in a day with the biggest mode of transport being walking (over 40%), 28% being the use of public transport while 14% was the use of private vehicles (JICA, 2014). In 2015, the city generated 7.8 million trips per day with an increase in the different modes of transports (JICA, 2015). The public transport, mainly dominated by matatus and private cars have been reported to be the major contributors to traffic congestion, especially in the CBD of Nairobi (Mitullah, 2020). This is attributed to inefficiencies such as not operating on schedules within the public transport thus making Nairobi residents opt for private means of transport. As a result, private vehicles become more dominant on the roads. Traffic congestion has imposed heavy economic burden on the Kenyan economy. In a recent report by the Nairobi Metropolitan Area Transport Authority, traffic congestion costs Kenya almost $ 1 billion per year, with an average travel time of about 57 minutes in Nairobi city, making Nairobi the fourth most congested city in the world (Mwakaneno, 2019). This implies that the economic and environmental costs of traffic congestion in Nairobi are at an acute stage and therefore need to be explored further to reduce these costs

Therefore, Nairobi residents need to be safeguarded from the effects of traffic congestion and its resultant emissions. This can be done by adopting some of the keys strategies to reduce the effects of traffic congestion as suggested by Chavez-Baeza and Sheinbaum-Pardo (2014), Hogarth *et al* (2015), Li and Jones (2015), Xu and Lin (2015), Song *et al* (2018), Campbell and Casas (2018) and Ayetor (2020) which include fiscal policies, technology through adoption of electric vehicles, decongestion through investing in Mass Rapid Transit systems and implementation of initiatives such as car-free days. However, in order to address these issues, an assessment of the effects of traffic congestion on CO_2 emissions first needs to be done to reveal the role that traffic plays in the emissions of GHGs at an urban scale.

1.2 Problem Statement

Traffic congestion in Nairobi is mainly caused by inadequate infrastructure which ends up weakening the economy (Lall *et al.*, 2017), indicated by the Level of Service (LoS) (Attri, 2016). Nairobi City has one of the longest average trips to work compared to other African cities which is attributed to heavy traffic congestion (Rajé *et al*., 2018). In 2013, the total person trip generation by persons living inside Nairobi City was 6.8 million-person trips in a day JICA,

2014) and 7.8 million trips per day in 2015 with an increase in the different modes of transports (JICA, 2015). In Nairobi, vehicle emissions contribute about 39% of fine particulate matter thus exposing its inhabitants to challenges related to air pollution impacts (Gaita *et al*., 2014). Heavy traffic congestion do worsen the situation as it consumes much fuel, increases travel time and also leads to environmental pollution (Bharadwaj *et al*., 2017). The pedestrians walking along the busy streets of Nairobi stand a greater risk of exposure to pollution being emitted from the stationary vehicles during traffic congestion. Moreover, the street vendors, as well as the traffic police who spend much of their day along these congested streets are also affected by the emissions from motor vehicles (Kinney *et al*., 2011).

Regulatory guidelines such as the Kenya Standard Code of Practice for inspection of road vehicles (KS 1515 of 2000) (governs motor vehicle inspection and hence vehicle emissions in Kenya) have been put in place to control vehicular emissions. However, Nairobi lacks a regular air quality management system, which includes management of GHG emissions such as CO_2 (Japan International Cooperation Agency (JICA), 2018). So far, CO_2 emission measurements, have been done only on a need-basis and the present state of CO_2 emissions profile from road traffic congestion is not fully understood, because no assessment of ambient air quality has been done (Gaita *et al*., 2014; Haq and Schwela, 2012). Therefore, there is need to assess the city's CO_2 emissions which contribute to the overall ambient air quality.

1.3 Research Questions

The specific research questions were;

- What role does traffic congestion play towards the contribution of CO_2 emissions within Nairobi's CBD?
- Do the CO_2 emissions contribution from the different vehicle categories vary?
- What are some of the interventions that can be put in place to reduce CO_2 from vehicular emissions?

1.4 Research Objectives

The overall objective of this study is to assess the contribution of traffic congestion to greenhouse gas emissions in the CBD of the city of Nairobi. However, the study did not take into consideration the baseline emissions for no congestion as it only focused on emissions during congestion. The specific research objectives are to:

i. Examine the factors that contribute to traffic congestion and increase in CO_2 emissions
ii. Analyse the variance of CO_2 emission levels according to the different vehicle categories
iii. Develop strategies and measures on how CO_2 emissions from traffic congestion can be reduced

1.5 Justification of the Research and Significance

Kinney *et al.* (2011) examined the effect of congestion on air pollution in Nairobi. However, the effects of transport and its contribution to greenhouse gas emissions was not taken into account. This study therefore will make an attempt to bridge this gap since it will address the effect of traffic congestion on the emissions of greenhouse gases within the CBD of Nairobi City. It will provide some information on how emissions from traffic congestion can be mitigated. The results from this study will also provide useful information for policy-makers and transport practitioners to formulate low-carbon transport strategies. This may inform change in integrating GHG emissions in the guidelines for the management of greenhouse gas emissions in Kenya and create a deeper understanding of the impact of these emissions on the climate system.

Climate change is a major threat to sustainable development, especially, urban transport which is a significant contributor of urban air pollution and greenhouse gas emissions. The effects of air pollution in Sub-Saharan cities have tremendously affected the health of urban dwellers. Therefore, finding solutions on how to mitigate urban air pollution is a major achievement towards achieving a sustainable and inclusive city. It is anticipated that the lessons learned will provide a clear understanding of the origin of emissions in the urban transport system in Nairobi which may be applied to other transport systems. This will also help in achieving of the Sustainable Development Goals and promote a sustainable city. Nairobi City County Government is also in the process of formulating the GHG emission inventory for all sectors, including the transport sector. Hence, this study's methodology and data collected and analysed could inform the city's top-down emission inventories and the impact traffic congestion has on GHG emissions. To my knowledge this is the first study to quantify traffic congestion emissions at microscale/street level in Nairobi

The purpose of this study was to determine the emissions from different vehicle categories, including private and public service vehicles in the city's CBD. Uhuru Highway was the preferred chosen study site because it is one of the busiest and congestion-prone highways in Nairobi (Jimbo *et al*., 2020). It offers a good mix of land uses (education, recreation, commercial, administrative, public purpose and transportation) thus making it an interesting area for this study as it draws major traffic to the CBD. It is also a major transport link that serves as an important commuter route into and out of the CBD. Ultimately, the road segment connects major highways in the country (Mombasa Road, Thika Road and Nairobi-Nakuru highway), thus portraying a good mix of vehicles during traffic congestion. Additionally, the strategic location of the Jomo Kenyatta International Airport (JKIA) along Mombasa Road gives an indication of major traffic flow into and out of the CBD using Uhuru Highway. The major cities (Nairobi, Mombasa and Kisumu) and towns (Nakuru, Eldoret and Malindi) in the country are also connected through the aforementioned highway, an indication that the highway harbours huge traffic volume.

1.6 Scope of the Research

This section outlines the extent of the research undertaken for this study. The research focuses on traffic congestion and its contribution to greenhouse gas emissions from motor vehicles. It is limited to CO_2 emissions from mobile sources on a section of Uhuru Highway between University Way roundabout and Bunyala Road roundabout. The aim of the study was to quantify carbon dioxide emissions from various vehicle categories, enabling decision-makers to control GHG emissions at a local scale.

1.7 Overview of the Methodological Approach

The overview of the the methodological approach has been illustrated in Figure 1-1. The study employed an exploratory case study approach to explore the relationship between traffic congestion and greenhouse gas emissions, focusing on a road segment (Uhuru Highway) in the capital city of Nairobi. Both quantitative and qualitative research methods were used. The study further adopted a multiple-case design by exploring the characteristics of the different vehicle categories operating along Uhuru Highway, including the behaviours of the vehicle operators. Primary and secondary data were collected. Data was analysed with the help of Statistical Packages for Social Sciences (SPSS) software and Microsoft Excel spreadsheet.

1.7.1 Questionnaire Survey

A questionnaire survey was an important tool for this study to achieve its objectives and also help in answering the key research questions being investigated. The data collected using a questionnaire included the following variables, traffic congestion, ease of movement along the highway, connectivity, causes of emissions from vehicles, vehicle fleet characteristics (odometer readings, engine capacity, fuel type, fuel consumption). These data were obtained from passengers, pedestrians and vehicle owners/driers operating along Uhuru Highway.

1.7.2 Key Informant Interviews

Additional information was obtained from the key informants representing the main government agencies responsible for road transport issues in Nairobi. This group of people provided specific data on control, management and possible solutions to reduce CO_2 emissions from traffic congestion. This data was important particularly in achieving objective two and three of the study as well as answer question three of the research question.

1.7.3 Traffic Count

A visual count of the number of vehicles formed the basis of estimating the amount of CO_2 emissions from different vehicle categories within the study area to achieve objective two of the study.

1.7.4 Observation

Observation method of data collection involved observing the behaviours of drivers, pedestrians and passengers using Uhuru Highway by taking notes and also use of camera to capture the situation on the ground. This method was useful in providing more information that may have not been captured in the questionnaire.

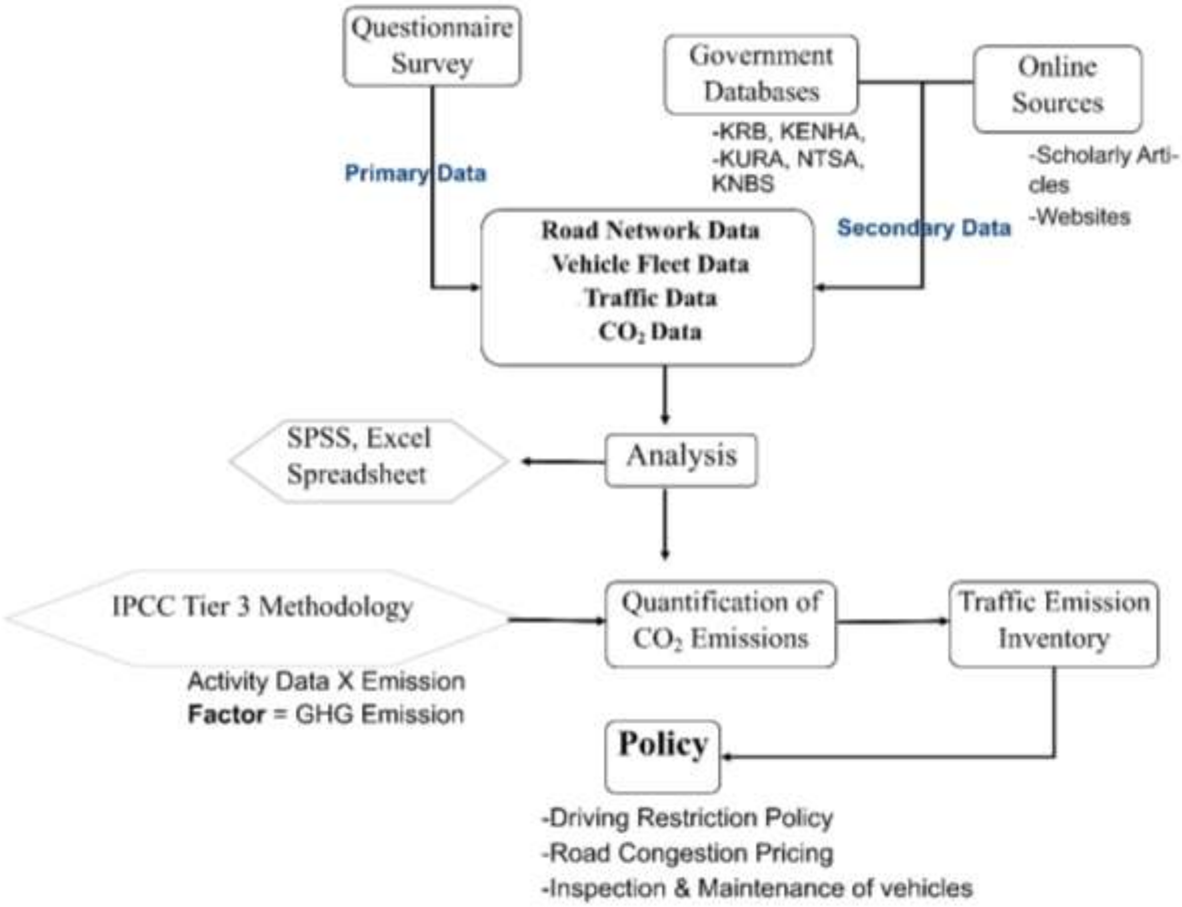

Figure 1-1: Graphical overview of the methodological approach

1.8 Study limitations and Uncertainties

This section discusses some of the limitations experienced when conducting this study. The uncertainties have also been discussed, explaining how the researcher overcame the sources of error and uncertainty during the study.

1.8.1 Data limitations

The researcher experienced limitations during the data collection phase on traffic count. Obtaining permissions from multiple authorities to collect traffic survey data was a challenge as some of these permissions successfully obtained were rescinded without notice by traffic authorities during the first 6 days of the campaign (see Appendix 1). Follow up permissions could not be obtained and the researcher faced resource and time limitations. This primary data was limited and therefore was supported with some secondary data that was obtained from the relevant institutions as can be seen used in the subsequent chapters

Quantifying CO_2 ambient levels was going to be ascertained through direct measurements using low-cost sensors for inventory validation. These sensors were not locally available, furthermore to acquire them through importation was prohibitive in cost and time constraints. Since the direct measurement method using sensors was not possible given these constraints, the researcher proceeded with a method of estimation which involved the use of simple mathematical model to obtain the CO_2 emission levels.

1.8.2 Uncertainties

Uncertainties associated with Emission Inventories (EI) which are widely known to be fundamental tools to quantify the amount of GHGs and monitor their compliance and emission reduction commitments (Oda *et al*., 2019) were considered. According to Lanotte (2018), all emission estimates contain uncertainties which should be dealt with by a reliable methodology. Emission inventories may have various sources of error and uncertainties that stem from what the inventory guidelines can define depending on the scale (Oda *et al*., 2019). Given that this study aimed at developing a traffic emission inventory limited to a local scale (street level), there were no specific guidelines at this scale which are necessary in achieving spatial emission estimates. However, the emission factors used in this study could be a potential source of uncertainty. Therefore, according to the EMEP/EEA guidelines (2019), it is good practice to estimate the associated uncertainties from the original research, which in this case is the country specific data

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter highlights the importance and relevance of the work previously done. It establishes the gaps in previous literature which identifies the importance of the study by focusing on the key literature on the relationship between traffic congestion and carbon dioxide emissions. In addition, it provides a critical assessment of the different methodologies used in quantifying traffic GHG emissions thus making it easier to identify some of the appropriate methods for undertaking this study.

2.1 Overview of the Literature Review

Globally, traffic emissions are a leading source of air pollutants, GHGs and SLCPs(Zhang and Batterman, 2013; Kelly and Zhu, 2016).The major cities around the world are increasingly becoming subject to major crises such as climate change which are attributable to rapid urbanization processes (Shindell *et al*., 2011; Bharadwaj *et al*, 2017). Megacities such as Mexico City, Beijing, Bangkok and Jakarta are at the forefront of tackling such crises by enforcing appropriate measures such as enforcing driving restriction policies that work to reduce congestion, as well as emissions (Li and Jones, 2015). Cities and urban centers consume the largest amount of energy (Chavez-Baeza *et al* , 2014), which amounts to 65% of the world's total energy and emit 70% of the greenhouse gases (IEA, 2019; Solecki *et al*, 2013) with motor vehicles being the main sources of GHG emissions (UNHABITAT, 2013). Traffic congestion is a key problem in these cities since it increases GHG emissions(Zhang and Batterman, 2013) hence causing economic, social, economic and climate impacts (Bulkeley, 2010) that finally results in elevated levels of illnesses and deaths for drivers, commuters and residents living near major roads (Zhang and Batterman, 2013). Vehicles are also a major source of outdoor air pollution in most African cities (Li, 2011; Haq and Schwela, 2012; Akumu, 2014;). As of 2013, Kenya reported 3,952 premature deaths resulting from ambient particulate matter pollution whose cost was USD 2,244 million in which vehicular emissions most likely contributed significantly (Roy, 2016).

Most of the emissions in urban areas come from road traffic congestion and the aging vehicle fleet that are commonly found in sub-Saharan African cities (Haq and Schwela, 2012). Lack of emission controls on vehicles as well as poor monitoring and enforcing systems in African cities also exacerbate pollution problems (Doumbia *et al*., 2018). Moreover, inadequate policies and low institutional capacities have also resulted in low maintenance of highways as well as rural roads in many African countries (Haq and Schwela, 2012). Doumbia *et al* (2018) also noted that majority of the African governments do not adequately invest in sustainable infrastructure, thus having huge impacts on both air quality and greenhouse gas emissions. However, the lack of emission monitoring gives the impression that this is not a serious problem.

The transport sector is a key contributor to greenhouse gas emission in most Kenyan cities. This is highly attributed to the growing number of motor vehicles within the urban areas and cities that are rapidly urbanizing. It is estimated that the road sector is accounts for 99% of GHG emissions from non-aviation transport sector in Kenya (Cameron *et al*., 2012). This makes it a key sector of focus especially assessing mitigation options to develop a low-carbon transport system. Moreover, the increasing demand for petroleum products in the country translates to an increase in transport emissions which are also expected to increase by 2030 depending on different business as usual demand scenarios. Nevertheless, this provides a great opportunity for the government and other interested parties including researchers to find alternatives to low-carbon transport systems. Most of the individual trips in Kenyan cities, especially Nairobi are on foot (Cameron *et al.*, 2012). As a result, private cars have taken centre stage contributing to massive traffic volumes in the cities such as Nairobi. Hence, private car ownership may be responsible for the rising levels of traffic congestion in the city roads.

2.2 Current GHG Emission Trends

The transport sector accounts for 23% of total CO_2 emissions (8 Gigatons of CO_2 ($GtCO_2$)) of fuel combustion worldwide, with 73% of these emissions from transport by highway vehicles (IEA, 2016). These emissions have continued to increase worldwide in developing countries such as China and India, while emissions from developed countries such as European countries are decreasing (IEA, 2016). As of 2016, the global CO_2 emissions from fossil fuel combustion were 32.31 $GtCO_2$ (IEA, 2019). These emissions have increased by around 40% since 2000. By

2017, they had increased by 1.5%, with the leading countries being China, India and the European Union. Developing countries such as Kenya attribute most of its outdoor emissions to urban transport activities, which directly accounts for about 11% of the country's total GHG emission as of 2015 (Government of Kenya, 2018b). The Report further projects the emissions to grow to about 14.7% by 2030 due to a rapid growth of vehicles experienced within the sector. A recent study by Madara *et al* (2018) indicates that the current vehicle registration in the country stands at 2.9 million. With the current urbanization trends, this number is projected by the NCCP 2018-2022 to increase to 4.1 million and 5 million by 2020 and 2030 respectively.

2.3 Traffic Congestion and Greenhouse Gas Emissions

Although there are many definitions of congestion, often, it is defined as a period during which the vehicles on a specific road are more than the road capacity. Rahane and Saharkar (2014) claim that there is no widely accepted explanation of traffic congestion, based on the fact that congestion is both a physical phenomenon that affects the way vehicles operate in traffic, interfering, with each other, as well as an obstacle; relative phenomenon related to user expectations. In this regard, this study will examine congestion as a physical state in which there is an excess of vehicles on a given road at a given time, resulting in acceleration and deceleration. According to Zhang and Batterman (2011) congestion mainly occurs as a result of increase in vehicle ownership and use. This happens mostly in cities and urban areas when the level of demand for movement from one place to another, increases, and this is indicated by the presence of long queues on the roads.

Congestion results in increased emissions, among them, the greenhouse gases such as CO_2, CH_4, and N_2O. Of these greenhouse gases, CO_2 is the most dominant and significant gas mainly due to its long-life span in the atmosphere and its impact on warming as shown in Table 2-1. Further research has revealed that CO_2 could last up to 50-200 years in the atmosphere (Lisa, 2008). However, no single lifetime for CO_2 can be defined because of the different rates of uptake by different removal processes (Lisa, 2008).

Table 2-1: Greenhouse gases, their global warming potential (GWP), and their lifetimes

Greenhouse gas (GHG)	100-Year Global Warming Potential (GWP)	Lifetime (Years)
Carbon Dioxide (CO_2)	1	Hundreds
Methane (CH_4)	25	12
Nitrous Oxide (N_2O)	298	114
Hydrofluorocarbon-23 (CHF_3)	14,800	264

Source: IPCC, 2007

CO_2 emissions from road transport vary depending on the vehicle type and speed patterns. Congestion affects CO_2 emissions negatively, such that when there is heavy congestion, CO_2 emissions increase (Barth and Boriboonsomsin, 2008). Heavy congestion tends to result in higher CO_2 emissions due to greater speed fluctuations as compared to zero congestion which can lower the CO_2 emission. In case of congestion, a large amount of energy is used, resulting in large amounts of carbon monoxide produced during the burning of fossil fuels. Carbon monoxide then burns in oxygen and releases carbon dioxide, an important greenhouse gas that has severe impacts that are linked to climate change on earth due to warming (Rikhotso *et al*, 2016).

There are limited studies on direct field measurement of emissions in existing literature. For instance, Barth and Borisboonsomsin (2008) did an analysis of traffic congestion and how it influences CO_2 emissions by using comprehensive energy and emission models. The results showed that there is a variation in CO_2 emissions which depend on the speed and type of vehicle. Additionally, heavy congestion resulted in higher CO_2 emissions, acknowledging the significant effects of congestion on CO_2 emissions.

Nejadkoorki *et al* (2008) demonstrated how useful modelling was in measuring greenhouse gas emissions from road traffic in urban areas. In their study, three different tools, MATLAB, ArcGIS and SATURN were used to model and estimate CO_2 emissions. These tools were combined in a manner that each produced independent output. SATURN enabled the identification of the road traffic features. The output was then analyzed using MATLAB to estimate CO_2 emissions while ArcGIS mapped out the model output. The study identified the need to look into how to effectively manage CO_2 emissions to reduce their impact as a greenhouse gas and identify future scenarios.

Zhang *et al* (2011) used Comprehensive Modal Emissions Model (CMEM) to produce emissions from light and heavy duty vehicles in work regions and rush hour congestion. These emissions were compared to those under free-flow traffic situations. The work zones were reported to experience high CO_2 emissions due to high fuel consumption rates in congestion during rush hour. These differences show the significance of accounting for traffic congestion in CO_2 emissions, exposure and health risk evaluation. This study also presented the following argument; (a) Overloading reduces average speed, which increases travel time, (b) Congestion reduces the distribution of vehicle-induced pollutants, as vehicle-induced turbulence is dependent on vehicle speed and (c) Congestion can change driving patterns, resulting in an increase in the number of accelerations, decelerations, starts, stops, which increase emissions.

Zhang and Batterman (2013) used simulation models to estimate the NO_2 concentrations on and near the road, as well as the health risks for expressways and arterial roads, where there is heavy traffic during rush hour. The results show that the risks increase in the arterial road for both road and road proximity with increase in traffic. This suggests that health risks from traffic congestion near roads can be significant depending on the type of road and other factors. According to Zhang and Batterman (2013), traffic-related health effects can be reduced by congestion pricing.

Avetisyan *et al* (2014) used an emission estimating tool (ORSEEM-On-Road Simulation Emissions Estimation Model) to approximate CO_2, CO, CH_4, HC, NO_x, SO_x, PM_{10} and $PM_{2.5}$ emissions from on-road traffic. The results showed that the traffic volume strongly influences the amount of emissions. Therefore, they suggested that emissions reduction can be achieved through improvements in the efficiency of the different vehicles in traffic jam.

In an attempt to reduce greenhouse gases and their effects on the climate, Rikhotso, *et al*. (2016) suggest that park and ride facilities could be an ideal means of amending congestion and traffic situations. In their study, a traffic count was conducted on heavily congested roads into the CBD and also a questionnaire survey was administered. The goal was to enable estimation of CO_2 emitted by traffic within the CBD of Tshwane in South Africa and the quantity of CO_2 to be reduced by using park and ride facilities. From the findings, it is clear that the Bus Rapid Transit has the potential to reduce CO_2 emission of up to 96.2% when using park and ride transport system (Rikhotso *et al*., 2016).

Bharadwaj, *et al* (2017) demonstrated that Fuel Consumption and Vehicle Kilometer Travelled (VKT) methods could be used to estimate the amount of greenhouse gases emitted from road transport. The study highlighted that traffic congestion plays a key role in increasing the fuel used and CO_2 emission levels. In addition, it increases the exposure time of passengers. The study established Travel Time Index (TTI) as a congestion factor to be used when accounting for greenhouse gasas from traffic congestion. (Bharadwaj *et al*., 2017).

Doumbia *et al,* (2018) used data on the type and age of vehicles, travel time, and, type of fuel to estimate the amount of fuel consumed from different vehicles. These types of data were useful in estimation of emissions at either national or regional levels, thus, support implementation of policies on how emissions can be reduces in African cities

Mbandi *et al* (2019) demonstrated that a vehicle fleet questionnaire survey can be used to collect primary data relevant for the estimation of fuel economy in sub-Saharan cities such as Nairobi with limited data on air quality. As such, fuel economy was analysed using General Linear Modelling (GLM) and Artificial Neural Network (ANN) models. The findings indicated that a questionnaire survey is an important tool that can be used to determine fuel economy, which may be useful for emissions inventories.

2.4 Measurements of Air Pollutants from Traffic Congestion

Motor vehicles release different types of emissions such as: particulate matter, carbon monoxide (CO), nitrous oxide (NO), Nitrogen dioxide (NO_2), sulphur oxides (SO_2), methane (CH_4), carbon dioxide (CO_2) and volatile organic compounds (VOCs) that form ozone (O_3). Each of these gases is known to have various health, as well as environmental effects, either directly, or indirectly as described in Table 2-2

Table 2-2: Pollutants from Vehicular Emissions (UNEP, 2011)

Pollutant	Brief description/ Effects
Particulate matter (PM)	-Comprises mainly of suspended particles, dust, and smoke -Tends to remain in the atmosphere quite longer, thus affecting a larger area. -Motor vehicles appear to be among the main sources of particulate matter.
Nitrous oxides (NOX)	-released during fuel combustion and is formed during complex photochemical reactions in the air -Exposure to the NO has also been linked to a wide range of respiratory symptoms such as airway inflammation, increased bronchial reactivity and decreased immune defence
Carbon Monoxide (CO)	-Is produced in the incomplete combustion of fuels containing carbon such as natural gas, coal, coal and gasoline.
Carbon dioxide (CO_2)	- Responsible for half of the annual increase in global average temperatures. -Accounts for about 21% of total CO_2 emissions worldwide. (IEA, 2016)
Methane (CH_4)	-Found in small quantities in gasoline, diesel and jet fuel. -Natural gas mostly consists of methane and its use is growing within the transport sector.
Ozone (O_3	- Not a primary pollutant from motor vehicle emissions - Formed in the lower atmosphere through a complex reaction that involves VOC, CO and NO_x in the presence of sunlight -Exposure to ozone has negative effects on health as it is likely to enhance cardiovascular diseases.
Short-lived climate pollutants (SLCP);	- Substances that have a short lifespan in the atmosphere and have a warming effect on the climate close to time - Include methane, black carbon and tropospheric ozone, which contribute the most to global warming after carbon dioxide. - Black carbon is also a SLCP, a component of particulate soot in the form of particulate matter resulting from incomplete combustion of fossil fuels, wood and wood other biomasses. (UNEP, 2011).

2.5 Theoretical Underpinnings

This section provides a detailed analysis of the importance of policies, society and technology towards the reduction of greenhouse gases from the transport sector.

2.5.1 The Role of Policy

Policies play a crucial role towards the reduction of CO_2 emissions from road transport. Studies done by Li and Jones (2015) have demonstrated this by revealing that the policy launched by the Beijing Government on restricting vehicle ownership is indeed effective in regulating the faster motorisation hence, reduction of carbon emissions. Woodcock (2009) also points out that without a strong policy to increase public acceptance and safety, it will be difficult to achieve the potential health and environmental benefits. Therefore, developing countries should not overlook the role of policies in trying to tackle the challenges of climate change.

Globally, there are efforts made to address congestion-related impacts. For instance, in the developed nations, measures such as congestion pricing have been implemented in cities of Stockholm and London to ease congestion as well as emissions (Hickman, Ashiru, and Banister, 2010) Transport policies have also been put in place to deal with such issues hence reduce traffic-related pollution (Hickman *et al.*, 2011). Countries such as USA and India have developed vehicular emission standards through governing agencies like the United States Environmental Protection Agency (EPA) and Automotive Research Association of India (ARAI) whose function is to control vehicular emissions (Jaikumar *et al.*, 2017). In Africa, Cape Town, Kigali and Addis Ababa cities have implemented initiatives such as car-free days with the aim of reducing vehicular emissions within the city and also create awareness on health, wellbeing and air pollution (Campbell and Casas, 2018). Such initiatives tend to connect thousands of city dwellers by encouraging them to reclaim their streets and public spaces in a safe environment.

Over the last decade, Kenya has implemented a lot of infrastructural development programmes in the transport sector. Most of these programmes aim at addressing climate change through low-carbon development pathways. In its Nationally Determined Contribution (NDC), the sector main target is to reduce 3.46 MtCO2e emissions by 2030 against the Busines-as-Usual Scenario (Government of Kenya, 2018a, 2018b). In the road transport sector, a key target is to develop an efficient public transport system that is safe and affordable for Nairobi residents. This project is supported by various policy documents such as the Vison 2030 which identifies the transport infrastructure as an enabler. The Integrated National Transport Policy of 2009 emphasizes on an efficient transport system which is a key indicator in promoting economic development and also achieving the objectives of Vision 2030. Other policy documents, such as the National Action

Plan on Climate Change 2018-2022 (Volumes I and 3), have been prepared to guide the country in prioritizing and mitigating climate change policies (Government of Kenya, 2018a, 2018b). These policy documents recognize that operational inefficiency, congestion and consuming a lot of fuel, increases carbon dioxide emissions. As such the policy documents provide guidelines in defining the country's low-carbon development pathways that can result in the realization of the Nationally Determined Contributions (NDCs) goals. Institutional agencies such as KeNHA, NTSA, KURA, NAMATA and NEMA, in partnership with development agencies such as JICA, the World Bank, among others, are responsible for overseeing the operationalization of various projects oriented towards low-carbon development pathways according to each of their mandates.

2.5.2 *Socio-economic and Technological Implications*

Pongthanaisawan, (2010) notes that the country’s economy plays a significant role in vehicle ownership as well as fuel consumption. In developing countries, purchase of vehicles is strongly related to an individual’s income. As the income improves, there is more demand for the need to purchase a car or even more cars, particularly in developing countries where there are no restrictions to private car ownership. However, the operation of the car relies heavily on the countries economy since the fuel economy of a counry is governed by the government. Therefore, according to Pongthanaisawan (2010), governments should focus on improving the fuel economy and efficiency of vehicles to promote new environmental friendly and vehicle technologies. Such will ultimately help in the total emission reductions from the transport sector. In addition, Nakamura and Hayashi (2013) also note that economic and social benefits such as cost, mobility and quality of life should be vital when transitioning to a low-carbon city. The economic and social implications should be adequately evaluated in order to realise a desirable transport system in the long-term (Nakamura and Hayashi, 2013).

Emission reduction tb in the road transport sector have the highest GHG abatement potential through innovations in infrastructure, fuel economy, traffic management, spatial planning, eco-driving among others (Shimada *et al*., 2007; Stanley*et al*, 2011). Such reductions could be achieved through use of electric vehicles, use of catalytic converters for heavy-duty vehicles and also incorporating plug-in hybrid and electrical vehicles. However, according to Suzuki (2016), transition to low fossil carbon societies requires more than the society, education and ethical and technological approaches. Although technological measures alone have a substantial influence on the total emission reduction potential, Shimada *et al* (2007) suggest that they are not sufficient to bring about large reduction, unless they are integrated with the socio-economic structure, including land use, , energy system and lifestyle.

CHAPTER THREE: DATA AND METHODOLOGY

3.0 Introduction

This chapter discusses the data and methods used to accomplish the objectives of the study. The main research question for this study was to assess the contribution of traffic congestion to carbon dioxide emissions in Nairobi, Kenya. This study, thus aims to estimate CO_2 emissions from different vehicles during traffic congestion, using Uhuru Highway as a case study. The overall goal is to inform policies meant to mitigate greenhouse gases from the transport sector in the city. The data and methodology to be applied in this study is briefly described under Sections 3.1, 3.4 and 3.5. First, the study area is delineated introducing the selected area. Second, the research methodology used in this study is a mixed approach that integrates both quantitative and qualitative approaches.

3.1 Case Study Approach Used

A case study approach in research enables one to comprehend the complex problems through previous study reports (Zainal, 2007). So, in most cases, it is generally considered a robust research method, especially when a thorough investigation is required. Through this method, a researcher goes beyond the quantifiable statistical outcomes to understand the social circumstances through the perspective of the participant. Tellis (1997) postulates that when quantifiable and qualitative data are used together, a researcher is able to explain the whole process of a phenomenon by observation and detailed analysis of the different cases being examined. Hence, by using the case study approach, this study has integrated both qualitative and quantitative research methods within the context of Uhuru Highway.

A case study technique picks a small area with few persons as the main subjects to study in details. To further understand this, Shan *et al* (2017) used a case study approach as a methodology to construct CO_2 emissions inventories for 24 Chinese cities. This explains that a case study approach can also be used for multiple cases to attain the objectives of the study. This study used a single case study approach which is a road segment (Uhuru Highway) within the city of Nairobi. The sources of emissions for the study were clustered within the single case study to help in the achievement of the study's objectives. The study also had multiple sources of data which came from various actor involved in the study such as pedestrians along the street, passengers using public vehicles, drivers/owners/vehicle operators and key informants from the relevant authorities within the study area's jurisdiction. By using the case study approach, the researcher considered it relevant because it does not only bring out the perspective of the actors involved, but also brings forth their relationship and their interaction which was necessary for the phenomenon under study. Additionally, it enhances validation of the results. Out of the three specific types of case studies identified by Yin (1993), the study adopted an exploratory case to explore the relationship between traffic congestion and greenhouse gas emissions.

3.1.1 Qualitative and Quantitative Approaches

Different approaches have been used to provide policymakers with the necessary information to direct their efforts towards mitigating greenhouse gases. Most of these approaches focus on producing quantifiable evidence on how emissions at different levels may change in the future based on a prognosis from current contexts. As such, quantitative approaches play an vital part in ranking actions and also provide the basis for decision making (Brett, 2020). However, in more complex systems quantitative approaches may become less effective at thoroughly capturing the effect of emissions pathways such as the influence of social and economic factors. Therefore, qualitative approaches can be used to provide a complementary role in providing information to support GHG emissions quantification and support long-term strategy development.

Qualitative approaches have previously been used to generate, analyse and present qualitative information that is richer, more ambitious and more creative than quantitative information (Brett, 2020). Those factors that cannot be readily quantified can be included so that they can easily be identified and understood. As such, rather than relying on one approach, the two approaches can be combined to offer a more comprehensive understanding of the research problem, which, according to Creswell (2014) in combining the two approaches allows a study to gain from the strengths of the two approaches.

Therefore, in this study the researcher chose to integrate the two approaches. Qualitative information was helpful in answering two key research questions with regards to social-economic factors that contributed to heavy congestion, their implications and the opinions on policy interventions that could be used to reduce emissions from traffic congestion. On the other hand, quantitative data was used to generate information useful in answering the research question on the quantification of emission levels from different vehicle fleet.

A questionnaire survey was used to generate both quantitative and qualitative information. This tool has proven useful in generating qualitative information for traffic congestion impacts, traffic patterns and behaviours of road users (Ye, Hui, and Yang, 2013). In addition, a traffic count was done to generate the Average Daily Traffic along the study area.

3.2 Study Area

The study was carried out in Nairobi City which serves as an economic, administrative, political and cultural centre. Nairobi is one of the largest and fastest-growing cities in Africa (Mastrota, 2019). The city has a dynamic economy, offering investment and development opportunities, accounting for about 50% of formal employment in Kenya and generating more than 50% of the country's GDP (Japan International Cooperation Agency (JICA), 2018). Located at 1.32^0S and 36.9^0E, it covers an area of approximately 696km^2, with an estimated population of 4.4 million (Kenya National Bureau of Statistics (KNBS), 2019). Thus, making it possibly the most affected city by vehicular emissions, primarily through traffic congestion in Kenya. There has been a steady increase of motor vehicle registration in Nairobi between 2008 and 2012 (Rajé *et al*., 2018) 2017 marked the highest number of registered vehicles (Madara *et al*., 2018). This can explain the traffic pattern in Nairobi as it among the African cities with the longest trips to work due to heavy traffic congestion (Lall *et al.*, 2017). The study confined itself to investigate how traffic congestion contributes to greenhouse gas emissions within the boundaries of the Central Business District of Nairobi City, along Uhuru highway.

3.2.1 A Case Study of Uhuru Highway

The major arterial road chosen for this study is Uhuru Highway which covers a total distance of approximately 2.80km. The highway is a major artery into and out of the Central Business District of Nairobi, hence experience heavy traffic volume compared to other roads. The road segment chosen for this study covers a distance of 2.17 km, starting at the Bunyala roundabout all the way to University way roundabout as shown in Figure 3-1.

Uhuru Highway is one of the busiest and congestion-prone highways in Nairobi (Jimbo et al., 2020). It offers a good mix of land uses (education, recreation, commercial, administrative, public purpose and transportation) thus making it an interesting area for this study as it draws major traffic to the CBD. It is also a major transport link that serves as an important commuter route into and out of the CBD. Ultimately, the road segment connects major highways in the country (Mombasa Road, Thika Road and Nairobi-Nakuru highway), thus portraying a good mix of vehicles during traffic congestion. Additionally, the strategic location of the Jomo Kenyatta International Airport (JKIA) along Mombasa Road gives an indication of major traffic flow into and out of the CBD using Uhuru Highway. The major cities (Nairobi, Mombasa and Kisumu) and towns (Nakuru, Eldoret and Malindi) in the country are also connected through this highway, giving an indication of huge traffic volumes towards and outwards the CBD.

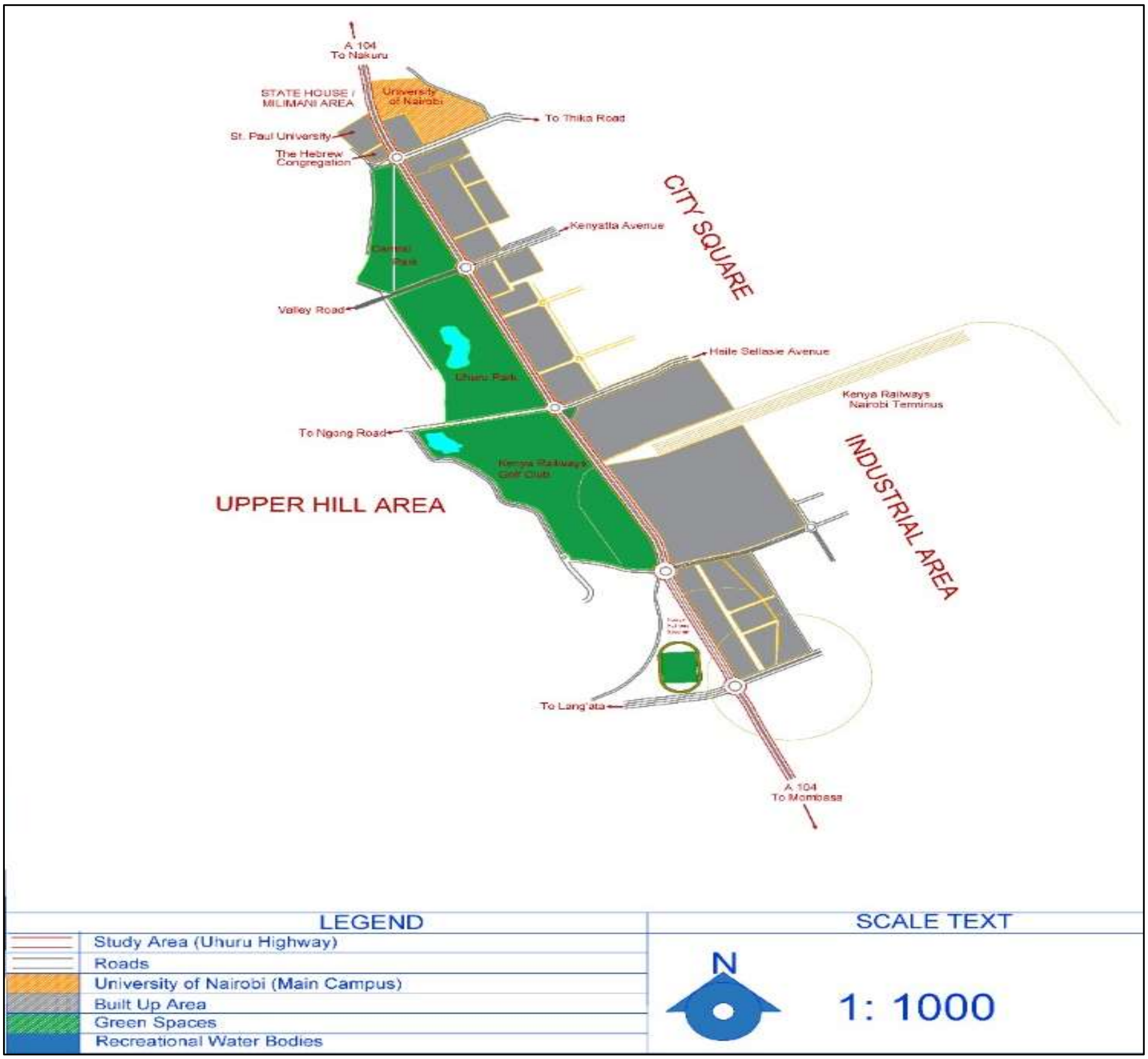

Figure 3-1: Uhuru Highway study area map, Nairobi CBD. ***(Source: Map Quest, 2019)***

3.3 Conceptual Model

The conceptual model for this study follows the DPSIR (Drivers, Pressures, State, Impact and Response model of intervention) framework that was developed by the European Environment Agency (EEA) to describe the interactions between society and the environment as illustrated in Figure 3-2.

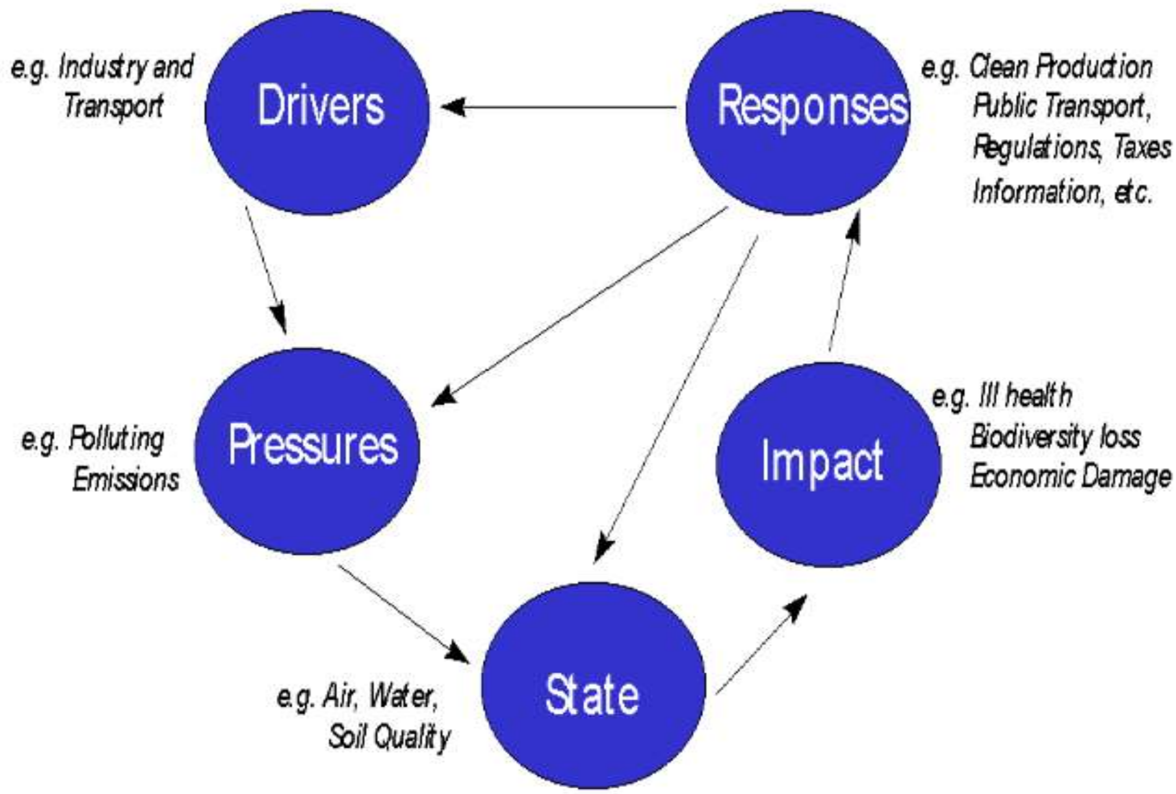

Figure 3-2: The DPSIR Framework. Source: EEA, 2016

Traffic congestion is a key driver that represents the social, demographic and economic developments in society, together with the corresponding changes in lifestyles, as well as consumption and production patterns. It is driven by various factors such as population dynamics, increase in vehicle ownership, demand factors (increased travel demands) as well as a poor road network (Bharadwaj *et* al., 2017). Human activity chief among this, transport, is a leading emitter of greenhouse gas emissions, which directly puts pressure on the environment (IEA, 2019a). In most cases, these changes are seen as negative as they affect the physical, chemical and biological state of the environment. Transport emissions cause pollution which affects the ambient air quality. Motor vehicle emissions comprise of a wide range of gases and particles. This include GHGs such as CO_2, CH_4, N_2O. However, the focus of this study is on CO_2, which is the most potent GHG emitted from the combustion of fossil fuels due to its long-term impact on warming (having a lifespan of hundreds of years) as compared to other greenhouse gases (IPCC AR4 WG-I Report, 2007).

Air quality is affected by the amount of GHG gases emitted from motor vehicles during congestion, hence causing modifications in the environmental conditions (Bharadwaj et al., 2017). Any slight alteration of the ambient air quality brings about consequences which could affect human health, the environment, the economy or even the climate system. Therefore, to bring about change, efforts need to be put in place to respond to the problem at different levels. This will eventually reduce the impact felt as well as the GHG emissions in the long run. These efforts may include formulation and implementation of policies, adaptation and mitigation strategies aimed at reducing GHG and air pollution from traffic congestion. For instance, cities such as Mexico City, Jakarta, Beijing, Singapore and Hong Kong have adopted measures such as driving restriction policy, ownership restraints policy and other programs that could limit population growth of vehicles. Such measures aid in mitigating traffic congestion which ultimately improves air quality. The conceptual framework for this study is illustrated in Figure 3-3.

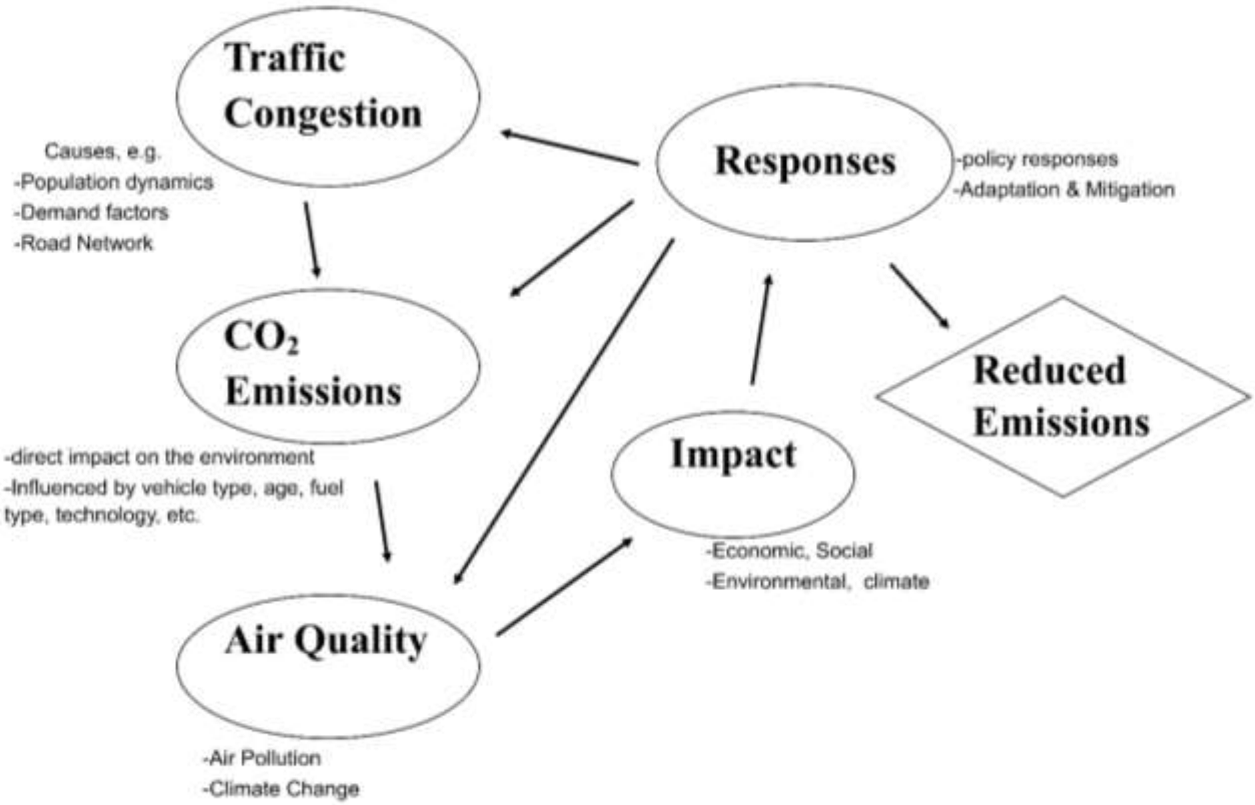

Figure 3-3: Conceptual Framework: modification of the EEA's DPSIR Framework

3.4 Sampling and Data Collection Methods

This study used two techniques of sampling: quota sampling and simple random sampling as described in Section 3.4.1. Data collection was done in two phases which included a questionnaire survey and a traffic count with the help of two research assistants. The research assistants went through training to ensure that they have adequate knowledge on the subject matter under investigation.

3.4.1 Questionnaire Survey

Data collected in the questionnaire survey included the following variables traffic congestion, ease of movement along the highway, connectivity, causes of pollution from vehicles, vehicle fleet characteristics (odometer readings, engine capacity, fuel type, fuel consumption). It was followed by an In-depth interview of opinions on measures for GHG reduction strategies from traffic congestion. The In-depth interview was relevant as it enabled the researcher get an in-depth understanding of the problem at hand, including how the participants are affected and ways to solve the problem.

Quota sampling technique was used to obtain information from the participants during the questionnaire survey. Quota sampling allows the interviewer to obtain responses from a specific number of participants. Simple random sampling was used at targeted areas considered as high-density areas, which made it easy for the researcher to obtain information relevant to the study. These areas are business parking lots and petrol filling stations located along Uhuru Highway. A sample size was determined using the population size, margin of error and confidence level based on the formula in Equation 1(Van Dessel, 2013). From this equation, a sample size of 120 questionnaires was obtained to represent the total population along Uhuru Highway.

$$\boldsymbol{SS = (Z - score)^2 \times p(1 - p) \div (margin\ of\ error)^2} \qquad \textbf{……Equation (1)}$$

Where;

Z-score = 1.96 for confidence level 95%

Proportion p is the expected outcome.

Thus, the total minimum Sample size (n) = **120**

The distribution of this sample size for the questionnaire survey is tabulated in Table 3-1

3.4.2 Traffic Count

Traffic count data played a vital role in this survey as it enabled the researcher to estimate the amount of CO_2 emissions from different vehicle types within the study area to achieve objective two of the study. To take the count, a camera was strategically placed to capture the traffic in and out of the CBD using the selected study site for a period of one week in during the month of July 2019. Two stations were identified to allow the research assistants capture videos of the traffic volume at intervals of 15 minute per hour between 10am and 3pm. The videos were then used to generate the traffic volume by counting the number of vehicles at the specified time intervals. Traffic volume data were also obtained from the KeNHA database and were used to calculate the average annual daily traffic. These results were then used to estimate traffic-related emissions of CO_2 between 2014 and 2019. Only data for the year 2014 was available at the

KENHA database. Data for the subsequent years was projected up to 2019 using the growth rate formula in Equation (2)

$$\boldsymbol{A = P(1 + r/100)^n} \qquad \textbf{..................Equation (2)}$$

Whereby:

A - is the current average annual daily traffic

P - is the Average Annual Daily T of previous year

r - is the traffic growth rate of the vehicle fleet

n - is the number of years projected

The traffic growth rates (%) were adopted from the Road Sector Investment Program (RSIP-2-2015-2019) (Kenya Roads Board Database). (Appendix IV)

Due to the limitations of AADT data availability, 2014 was used as a baseline year, from which trends and patterns of CO_2 emissions were estimated. IPCC Tier 3 methodology was used to calculate the CO_2 emissions using the formula in the Equation 3

Therefore, having this information, the following formula adopted from (Adhi, 2018), was used to estimate the total CO_2 emissions from traffic congestion along Uhuru Highway between 2014 and 2019.

$$\boldsymbol{E = A \times f \times l \times ef} \qquad \textbf{...........Equation (3)}$$

Whereby;

E – is the total CO_2 emissions (Gram CO_2 per day)

A - is the average number of vehicles type A per day

f - is the specific fuel consumption per vehicle type A (litres/km)

l - is the length of the road (km)

ef - is the emission factor (grams CO_2/litre)

Note: The specific fuel consumption per each type of vehicle is the local fuel economy obtained from Mbandi *et al* (2019), INFRAS (2017b) and INFRAS (2018), representing the specific country's (Kenya) emission factors as shown in *Appendix IV*. The emission factors used have been developed locally by INFRAS (2017b) for the country's road transport sector. Tank-towheel CO_2 emission factors have been used to develop trends and patterns from 2014-2019 for road vehicle categories along Uhuru Highway.

3.4.3 Observation

This is a qualitative research technique that enabled the researcher observe participants' ongoing behaviour in a natural situation. In this case, the researcher, with the help of two research assistants, observed the behaviours of drivers, pedestrians and passengers using Uhuru Highway by taking notes and use of camera to capture the situation on the ground. This method was useful in strengthening the information provided by the participants during field survey.

3.4.4 Sampling of Pollutants Concentration and Measurements

CO_2 concentrations alongside other pollutants such as $PM_{2.5}$, CO, and nitrogen dioxide were monitored during the study for a period of six days. The pollutants were measured at 5-minute intervals using a Centre for Doctoral Training (CDT) low-cost sensor. Two sampling points were identified at roundabouts in Nairobi: - Uhuru Highway/Kenyatta Avenue and Uhuru Highway/Haile Selassie. The Low-Cost Sensor (LCS) uses the non-dispersive infrared (NDIR) technique where the amount of infrared radiation absorbed by CO_2 molecules is proportional to it concentration. However, the LCS was not able to capture CO_2 concentrations due to mechanical issues encountered during fieldwork since they were not calibrated. Therefore, CO_2 data used in this study was then generated from a simple mathematical model using variables Average Annual Daily Traffic (AADT), Average Daily Traffic (ADT), emission factor, length of the road and the specific fuel consumption (fuel economy). This simple model used was dervived from IPCC's Tier 3 methodology for quantifying greenhouse gas emissions. This methodology is known as a bottom-up approach since it starts with geographically resolved data such as traffic flow on an individual road segment. It is, therefore, an ideal method to be used at small scales and the data collected must be aggregated to higher scales to develop spatialized emission inventories as compared to Tier 1 and Tier 2 methodologies.

This research has modified Tier 3 methodology to suit the study adopted from Adhi, (2018). The primary data requirements for this approach include;

- Traffic count/flow-this provided the total number of vehicles per hour/day/week along the chosen area of study

- The total length of the road segment under investigation

3.5 Primary and Secondary Data

Primary data was obtained from the questionnaire survey and emission monitoring of ambient CO_2. The questionnaire survey used both qualitative and quantitative data. The numerical data were based on the characteristics of the fleet with variables such as fuel type, age of the vehicle, fuel consumption, distance travelled and engine capacity. The quantitative information was related to traffic congestion frequency and a traffic survey to determine the traffic volume within the road segment under study. In addition, qualitative data was obtained from the survey which provided information on different opinions on how CO_2 emissions from traffic can be mitigated. *The secondary data* came from the government databases of National Road Authorities, including KURA, KeNHA, NTSA and KRB (INFRAS, 2019; KeNHA, 2014). The online sources included websites and scientific articles on the topic being studied.

3.5.1 Road Network Data

The road network data is relevant in understanding the real situation in identifying the gaps in the phenomenon under study. Through observation, these data enable the researcher identify some of the factors that result in heavy traffic congestion, hence increased greenhouse gas emissions. This was important in achieving objective (1) of the study The road network used in this study is based on information obtained from KURA and KeNHA through the key informant interviews conducted during the survey. This information includes:linkages, lanes, intersections, roundabouts, pedestrian route/crossing, terminals/stations, signalling systems, friction points (activities that interfere with traffic flow), connectivity of the road segment, ease of accessibility, points of origin and destination, uniformity of the road segment and road user behaviour.

3.5.2 Vehicle Fleet Data

These data were necessary to classify the different vehicle categories used, which was useful in demonstrating the contribution of each vehicle catogory to emissions. These data were crucial in achieving objective two of the study. The EEA Guidebook 2013 classifies vehicle categories according to their weight, giving a standard classification across the European Union countries. (EEA, 2013). However this is not the case with Africa as these categories may not always fit the utility and classification. As such, the vehicle fleet represented in the study was based on grouping of vehicles of similar features, depending on usage and the types of goods they carry. This study limited itself to the following vehicle categories: (i) Passenger cars (ii) Matatus (iii) Light Commercial Vehicles (LCVs) (iv) Heavy Goods Vehicle (HGVs) and (v) Motor cycles (*Appendix III*). The main vehicle fleet data used in this study, including registration, fuel consumption, distance travelled and the age life was obtained from NTSA database (INFRAS, 2019). Moreover, primary data on type of fuel consumed by different vehicles, engine capacities and daily fuel consumption of the vehicles was obtained from the questionnaire survey conducted to complement the secondary data.

3.5.3 Traffic Data

The traffic data used in this study includes annual average daily traffic (AADT) for six years and Average Daily Traffic (ADT) for six days of different vehicle types for Uhuru Highway. These data were obtained from KeNHA database (KeNHA, 2014) and field work study respectively. A traffic count was carried out during the month of July 2019 to determine the traffic volume on the road section under investigation. The data was useful in obtaining the current average daily traffic, and then correlated with the emission levels, thus, attaining objective two of the study.

3.6 Actors Involved

The general public using the road section under study was the key target population for this study. This included the vehicle owners, drivers, passengers as well as pedestrians walking along that stretch of the road and the key informant personnel from relevant authorities. Table 3-1 summarizes the key actors involved, including their roles;

Table 3-1: Main Actors Involved in the study and their roles

Actor		No. of participants interviewed	Role
Vehicle Owners (Private vehicles)		20	• Provide specific information on their vehicle characteristics and opinion on the effects of traffic congestion and its effect on greenhouse gas emissions.
Drivers	**Matatus/buses**	20	• Provide specific information on their vehicle characteristics and opinion on the effects of traffic congestion and its impact on greenhouse gas emissions.
	Heavy trucks	10	• Provide specific information on their vehicle characteristics and opinion on the effects of traffic congestion and its impact on greenhouse gas emissions.
	Motorcycles	10	• Provide specific information on their vehicle characteristics and opinion on the effects of traffic congestion and its impact on carbon emissions.
Passengers		30	• Provide specific data on observable causes and effects of traffic congestion. Also, opinion on congestion and its impact on climate change and how the problem can be solved
Pedestrians		30	• Provide specific data on observable causes and effects of traffic congestion. Also, opinion on congestion and its effect on climate change and how the problem can be solved
Key Informants	Nairobi City County Government (NCCG)	2	• Provide specific information on control, management and possible solutions to improve air pollution from traffic congestion
	National Environment Management Authority (NEMA)	1	• Provide specific data on control, management and possible solutions to improve air pollution from traffic congestion
	Kenya National Highway Authority (KENHA)	2	• Provide specific information on control, management and possible solutions to improve air pollution from traffic congestion • Provide existing data on traffic management and control
	National Transport and Safety Authority (NTSA)	1	• Provide specific information on control, management and possible solutions to improve air pollution from traffic congestion • Provide existing data on traffic management

All the actors involved played a significant role in contributing to the achievement of the objectives of this study. All the information provided was interpreted to reflect the aim of this study. As such, the diverse information from the different actors was integrated and used to develop a comprehensive understanding of the phenomena, thus achieved triangulation of results. Through this convergence of information, the researcher was able to confirm the validity of the findings gain confidence in the findings that established a strong relationship between traffic congestion and greenhouse gases. Different institutions such as KeNHA, NTSA and KURA had information that helped in achieving the aims of this study. The data from their databases was essential in shaping this study into meaningful research. For example, data on traffic management and vehicle specification were the focal points of interest for the study and could only be retrieved from these government authorities. However, the only challenge observed was getting access to these data since requiring the requisite permissions and data protocols was not clear which made obtaining information needed onerous.

3.7 Data Analysis

Descriptive method of analysis: mean, median and mode was used to describe what is happening in the data collected. These formed the basis of the quantitative analysis of data. Inferential analysis was also used to deduce from the sample data about what the perceptions of the targeted population may be on the traffic congestion and its impacts on emissions. Overall and detailed conclusions were drawn from the analysis based on numerical elements: mean, mode, frequencies and percentages to describe the findings of the study. Questions with non-numeric responses were matched and an assumed opinion reached based on the frequency of the responses in which a codebook was developed with the help of SPSS software. A thematic analysis was then conducted, identifying and reviewing key themes. Each of these themes was examined to gain a deeper understanding of participants' perceptions and motivations. The output has been presented in form of graphs, charts and percentages. The estimated CO_2 emissions were then used to generate a traffic emissions inventory for different vehicle types, this is presented in *Appendix IV*.

3.8 Ethical Consideration

This research project only commenced after getting permission from the National Commission for Science Technology and Innovation (NACOSTI) and an approval letter from the Institute for Climate Change and Adaptation, University of Nairobi (*Appendix II*). The researcher employed both quantitative and qualitative means of data collection which were face-face interviews for both methods. All participants were formally provided with research information and their consent was obtained (*appendix II*) before their involvement in the research study. The participant's identity was protected and anonymised. For data management and storage, the University's Digital Repository and anti-Plagiarism policies require submission of both soft and hard copies of the student's work for digital and physical storage.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter presents the results of the study. Firstly, the general background is presented, which sets out the response rate, and how the study was carried out. Secondly, a detailed descriptive analysis of various variables is presented. Thirdly, the final section provides an interpretation of the results, including the policy implications of the findings from the questionnaire survey. The following variables were obtained; road network typology, causes of congestion, traffic volume, traffic patterns and road user behaviour. A codebook was developed with the help of SPSS software to code all the quantitative data generated from the questionnaire survey. For qualitative data, codes were manually assigned to words and phrases in each of the open-ended questions' responses generating common themes in the respondents' language. This in turn helped in interpreting, analysing and summarizing the results of the survey accurately.

4.1 Questionnaire Response Rate

According to the sample size estimation, this study required a sample size of 120 respondents. Statistically, having sample size important when conducting a survey from the larger population as it allows you to gain more reliable insights of the topic under investigation (Van Dessel, 2013). To achieve this, 130 participants were invited, out of which the researcher obtained 105 correctly filled questionnaires with all the needed information. Therefore, this represents a response rate of 80.7%, which according to Baruch and Holtom (2008), a face-to-face means of administering questionnaires of about 80-85% is within the acceptable range.

4.2 Objective 1: Factors that contribute to Traffic Congestion along Uhuru Highway

The study sought to identify the various factors that lead to congestion along Uhuru Highway to achieve the first objective. The variables consisted of the road network typology and factors that result to congestion. These factors were generated from the coded phrases and responses on qualitative information provided during the questionnaire survey as part of the respondents' opinions.

Figure 4-1 represents responses to the questionnaire interviews classified into six categories as follows: I) traffic management II) Attitude III) Road network IV) Urbanization V) Vehicle fleet and VI) Unforeseen.

The categories in this figure were classified by grouping together responses as follows; all issues related to poor traffic control by the police officers or poor functioning of traffic lights as the main cause of congestion were classified under traffic management. Issues of having too many roundabouts or the road capacity being too small to accommodate the growing number of vehicles were classified under road network factor. Issues of ignorance of traffic rules by the drivers and careless driving were classified under attitude while circumstances such as accidents or vehicle breakdown were classified under unforeseen circumstances. Vehicle fleet simply implies that congestion was caused by a specific type of vehicle fleet which may either be personal cars, matatus or light commercial vehicles among other. Lastly, the reasons given as due to increased motorization rates in Nairobi as well as the reasons of too many vehicles observed to be using the highway at the same time resulting in congestion were classified under urbanization factor. In ranking these variables, it was observed that road network was the highest, followed by vehicle fleet and the third place was traffic management. Attitude and urbanization came in fourth while unforeseen circumstances came in last.

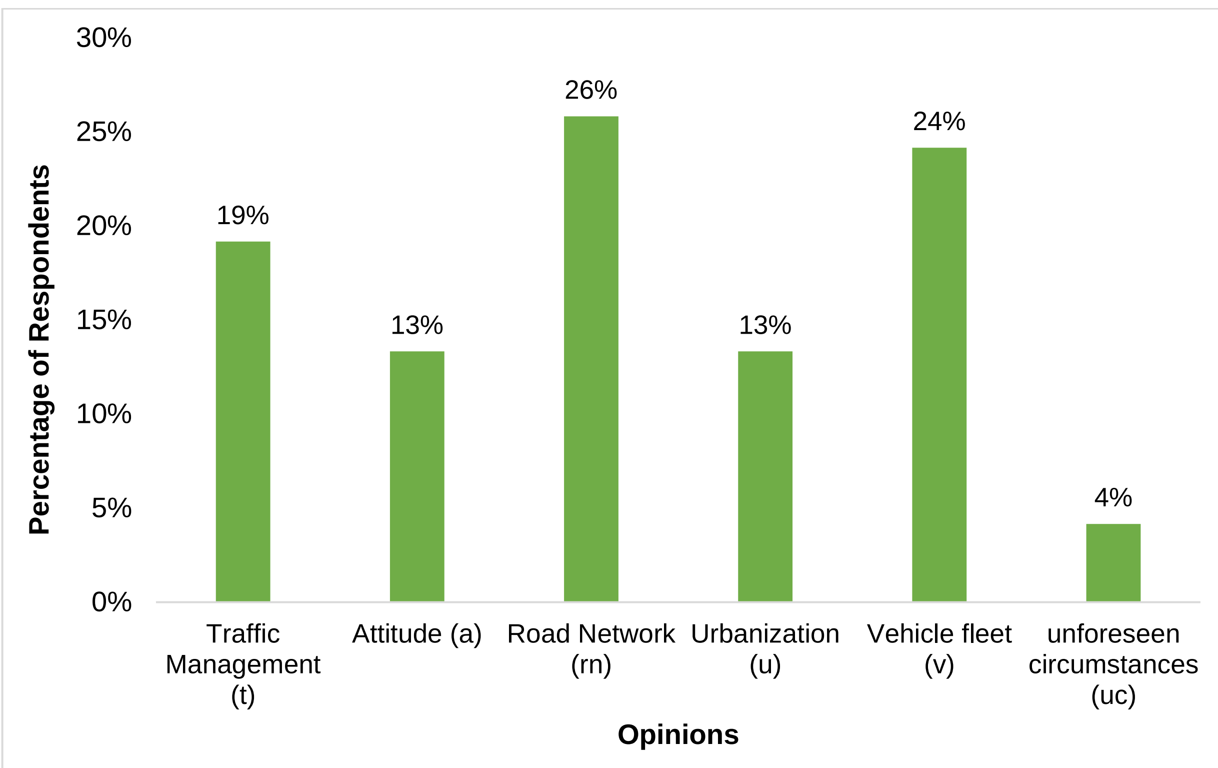

Figure 4-1: Respondents' opinion on factors that contribute to traffic congestion

Responses on how long respondents spend in traffic were plotted and presented in Figure 4-2. These were categorised into five-minute intervals, ranging from less than 5 minutes, between 5 and ten minutes, fifteen and thirty minutes, forty to sixty minutes and sixty minutes and above. This shows that most participants spent at most 5-10 minutes and that heavy congestion was observed during the weekdays in the mornings and evening which has become a normal occurrence for residents of Nairobi. Public holidays and weekends were reported to have smoother traffic situations as majority of the participants would take less than 10 minutes to pass through the highway.

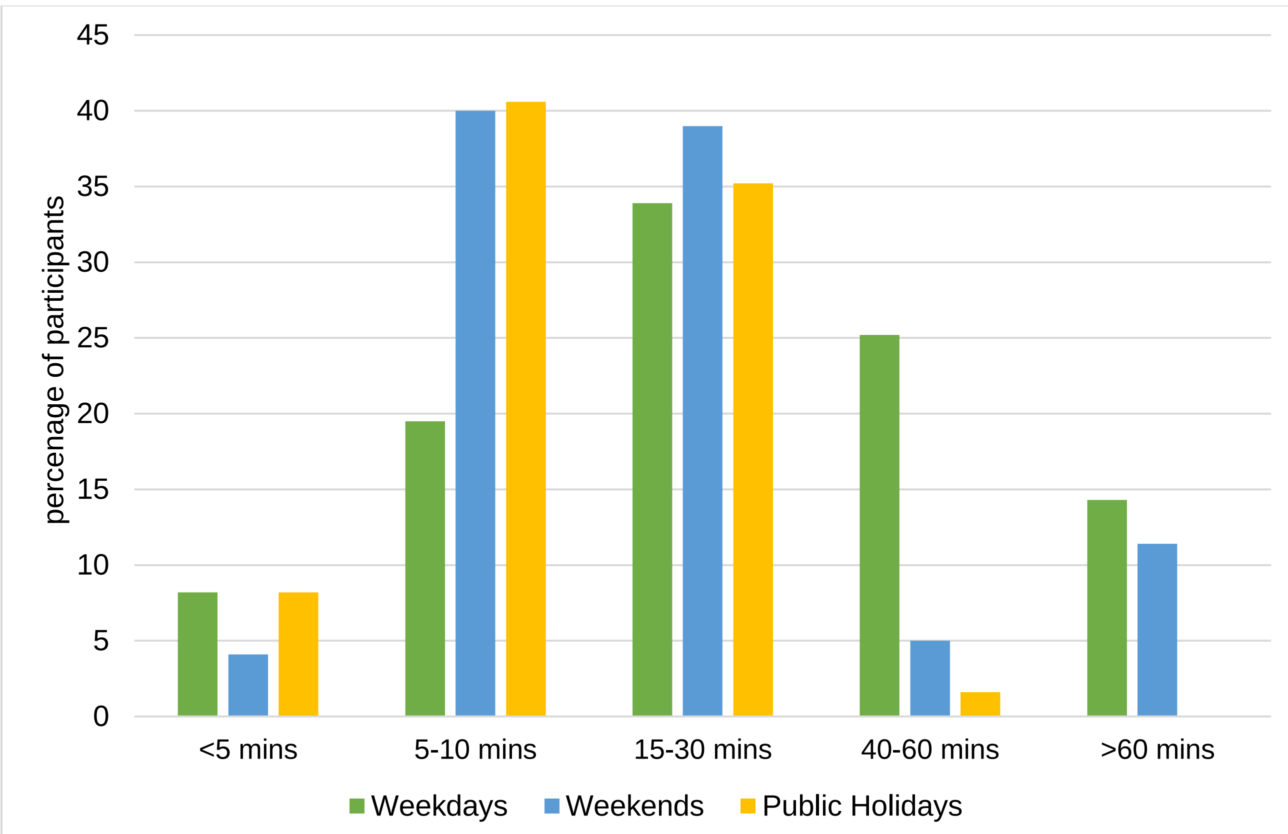

Figure 4-2: Average time spent on traffic along Uhuru Highway on different occasions.

The traffic survey was done for Uhuru Highway in Nairobi City, in which the travel time index was obtained for each of the vehicle categories as shown in Table 4-1 below.

Table 4-1: Travel time and travel time index for vehicles along Uhuru Highway, Nairobi

Vehicle Type	Average No. Trips	Distance Travelled (km)	Average Travel Time (minutes)		Average Travel Time Index
			Peak hour (7-10am, 4-7pm)	Off-peak hour (10am-3pm)	
Passenger Cars	1	2.83	45	15	3
Matatus	5	14.15	30	10	3
Light Commercial Vehicles (LCVs)	2	5.66	45	15	1.5
Heavy Goods Vehicles (HGVs)	1	2.83	45	15	3
Motorcycles	8	22.64	10	5	2

The information provided for the average travel time in both peak and off-peak hours was based on the feedback from the questionnaire survey. Travel Time Index (TTI) was used as a congestion indicator to determine the extent of congestion on Uhuru Highway, computed as the ratio of peak hour to off-peak hour for different vehicle categories. On average, different vehicles have different TTI. Therefore, taking the average of the five different vehicle types represented here, the approximate TTI of Uhuru Highway is 2.8, indicating that for every 10 minutes trip when there is free flow of traffic, the vehicle will take 28 minutes during peak hours.

The average speed for different vehicles was also calculate and presented in Figure 4-3. Results show that passenger cars travel at an approximate speed of 6km/h, matatus at 4km/h, LCVs at 6km/h, HGVs at 6km/h and motorcycles at 11km/h. this is the average speed taken by the vehicles when using Uhuru Highway regardless of the time (peak and off-peak hours)

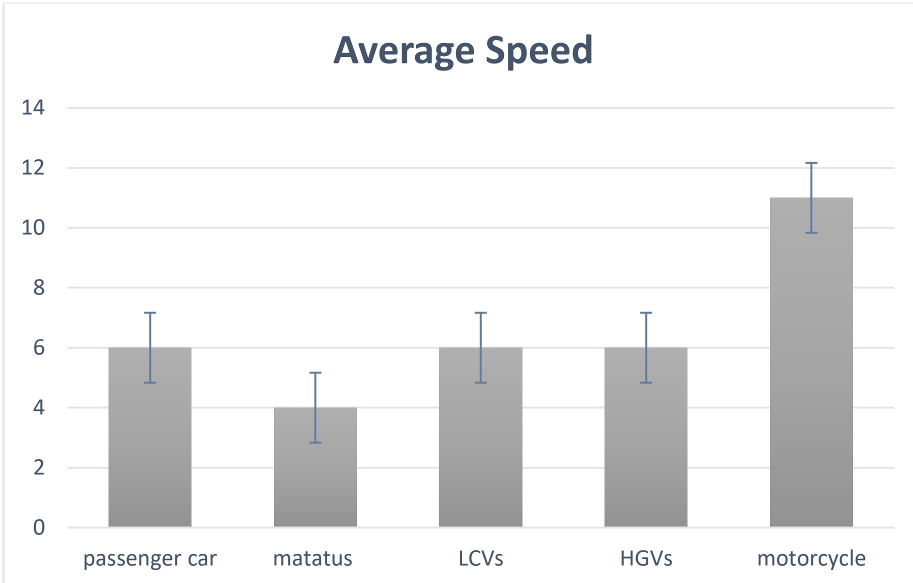

Figure 4-3: Average Speed for different vehicles in Uhuru Highway

4.3 Objective 2: Emission Levels from Different Vehicle Categories along Uhuru Highway

Objective two of the study sought to analyse the CO_2 emission levels of different vehicle categories along Uhuru Highway. The results are presented in Sections 4.3.1, 4.3.2 and 4.3.3.

4.3.1 Current Traffic volume along Uhuru Highway

A traffic count was carried out for six days in the month of July 2019. Figure 4-4, represents the traffic count for different days of the week. The plot shows the traffic volume of different vehicle categories on different days of the week. A similar pattern is observed for every day of the week with the passenger vehicles having the highest traffic volume, recording an average number of more than 600 vehicles within a span of 15 minutes on a daily basis. The count also revealed that passenger cars have the highest traffic volume on Uhuru Highway on different days of the week. Wednesday and Friday had the highest traffic volume from the observed vehicle fleet, recording a total of 1934 and 1862 vehicles respectively. It was closely followed by Tuesday and Thursday which also recorded an equally high volume of 1821 and 1861 respectively. During the weekend, the traffic volume appeared to be moderate as the number of vehicles observed were not as many as those observed during the weekdays which averaged to 1304 vehicles on Saturday and 807 vehicles on Sunday.

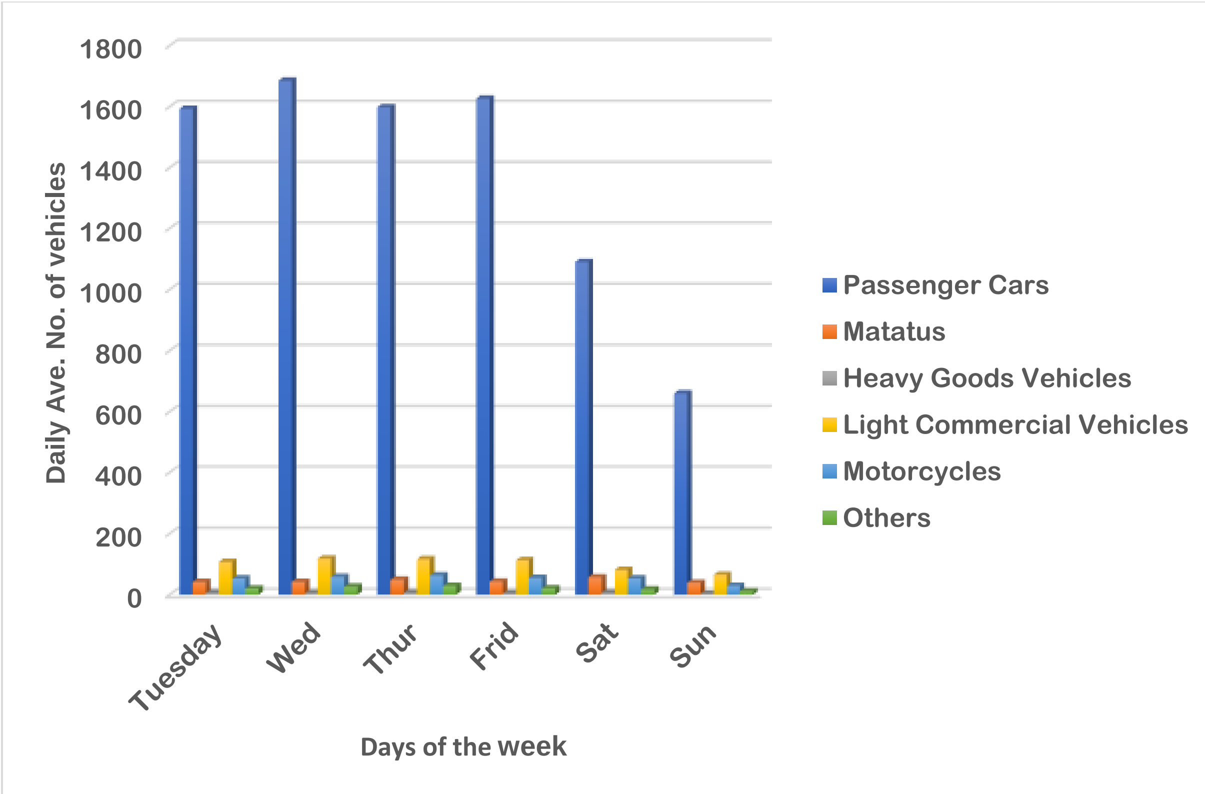

Figure 4-4: Average Daily Traffic Volume along Uhuru Highway

Traffic composition was represented in Figure 4-5 along Uhuru Highway. The highest frequency of vehicle category was found to be passenger cars comprising of 88% of the total traffic volume. This was followed by Light Commercial Vehicles with 6% of the total traffic. Motorcycles came in the third-place constituting to 3%, followed by Matatus with 2% while Heavy Goods Vehicles were the least with less than 1% of the total traffic volume.

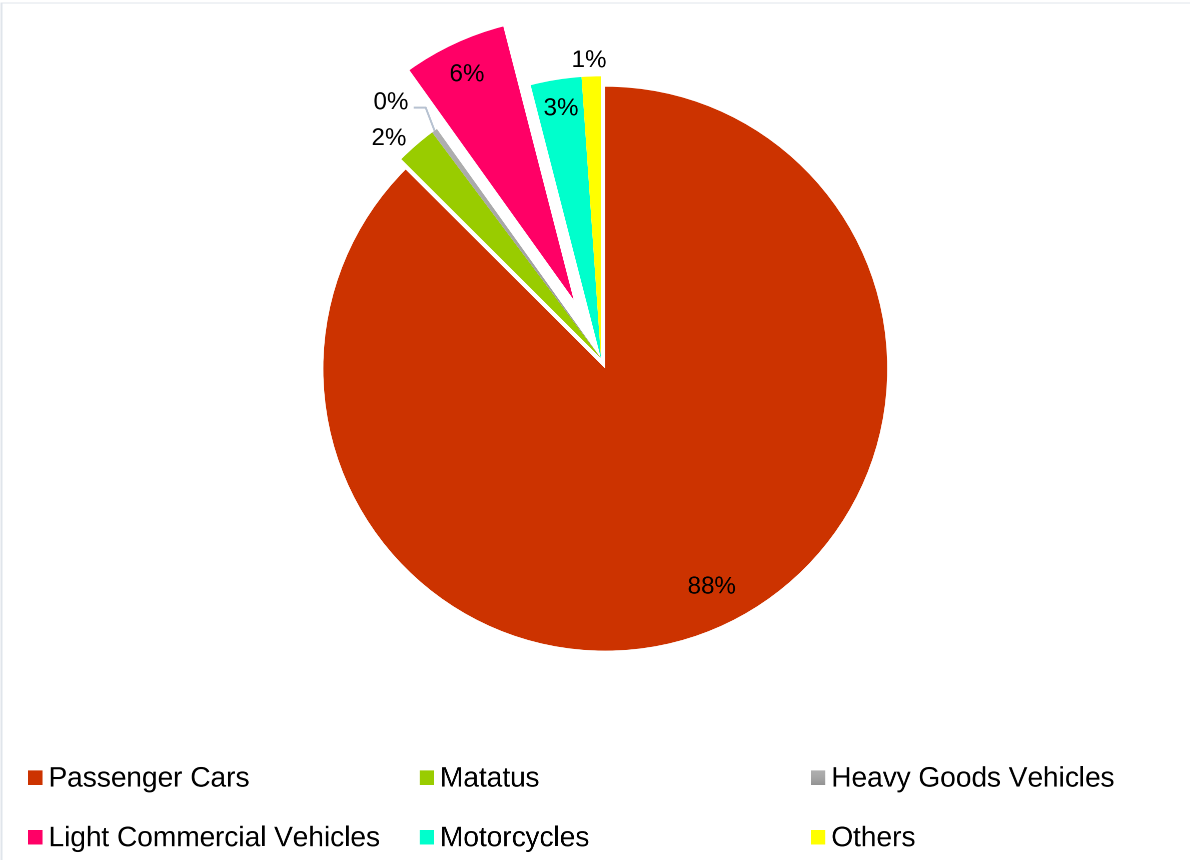

Figure 4-5: Traffic Volume Composition along Uhuru Highway

4.3.2 Vehicular Contribution to CO_2 Emissions

Figure 4-6 represents the total number of new vehicular registration in Kenya from 2010 to 2017. It was observed that the trend has not been steady (as seen in Figure 4-7) for the past seven years with increase and decrease of new registrations for the subsequent years. However, 2017 recorded the highest number with 272,000 new registrations. This was followed by 2015 which recorded 243,000 then 206,000 and 203,000 new registrations for 2014 and 2016 respectively. However, in 2012 there was a decline in the number of new registrations having recorded 163,000 new registrations as compared to 2010 which had 187,000.

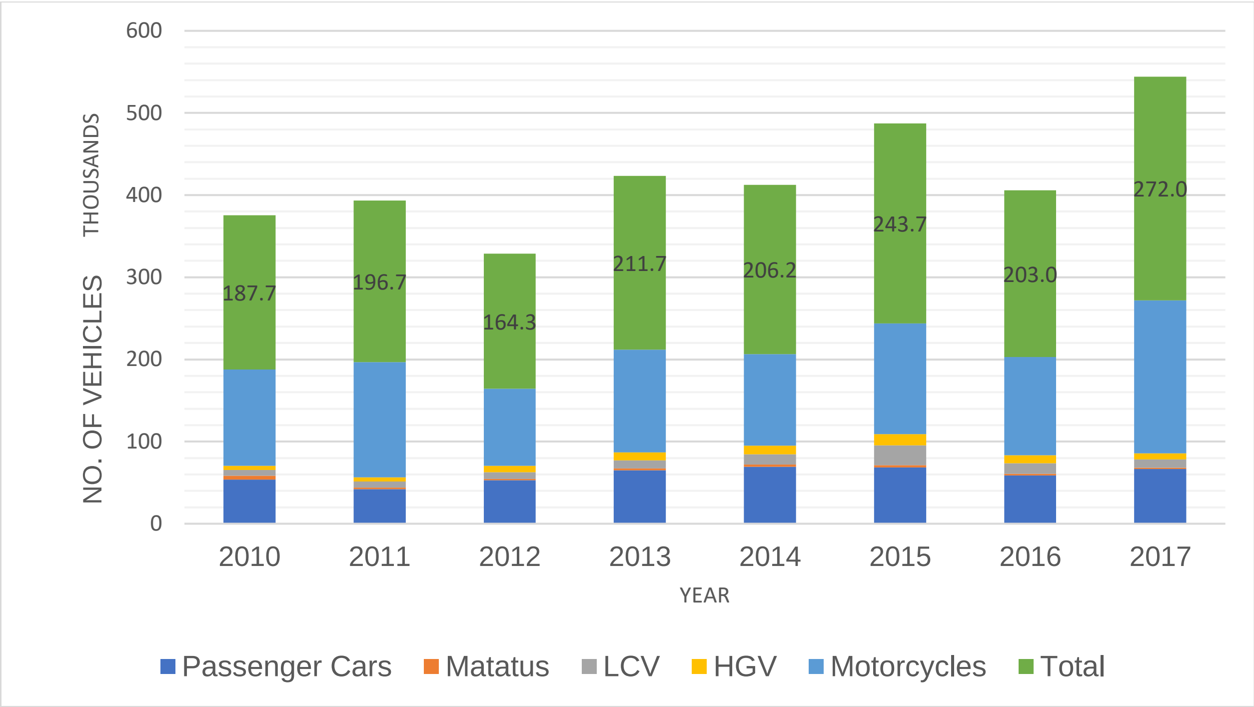

Figure 4-6: Trends of New vehicle registration between 2010 and 2017

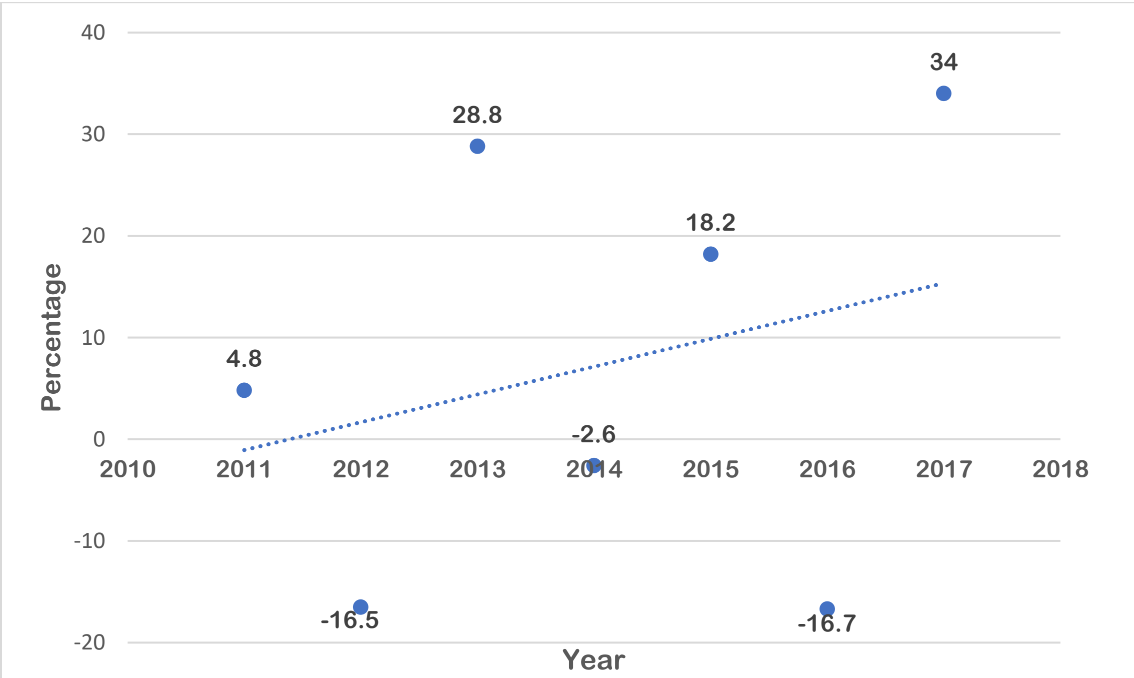

Figure 4-7: Analysis of new vehicle registration in Nairobi City

Different vehicles have different emission levels. To achieve objective two of the study, a total of 60 questionnaires were administered with specific vehicle information obtained from different vehicle fleet as shown in Table 4-2

Table 4-2: Questionnaire Survey participants

Vehicle Type	Frequency	Percentage
Personal car	20	33.3
Pick-up/Van	5	8.3
Bus/Coach	6	10.0
Heavy Trucks	4	6.7
Public Service Vehicles	15	25.0
Motorcycle	10	16.7
Total	60	100.0

The results in Figure 4-8 show that according to the respondents' opinions, Heavy Trucks pollute the most, representing 36% of the total number of respondents, followed by matatus (29%), Buses and coaches (25%), personal cars (7%) while pick-ups and vans polluting the least. This information was obtained from the questionnaire survey, representing the opinions of participants, shown in Figure 4-8.

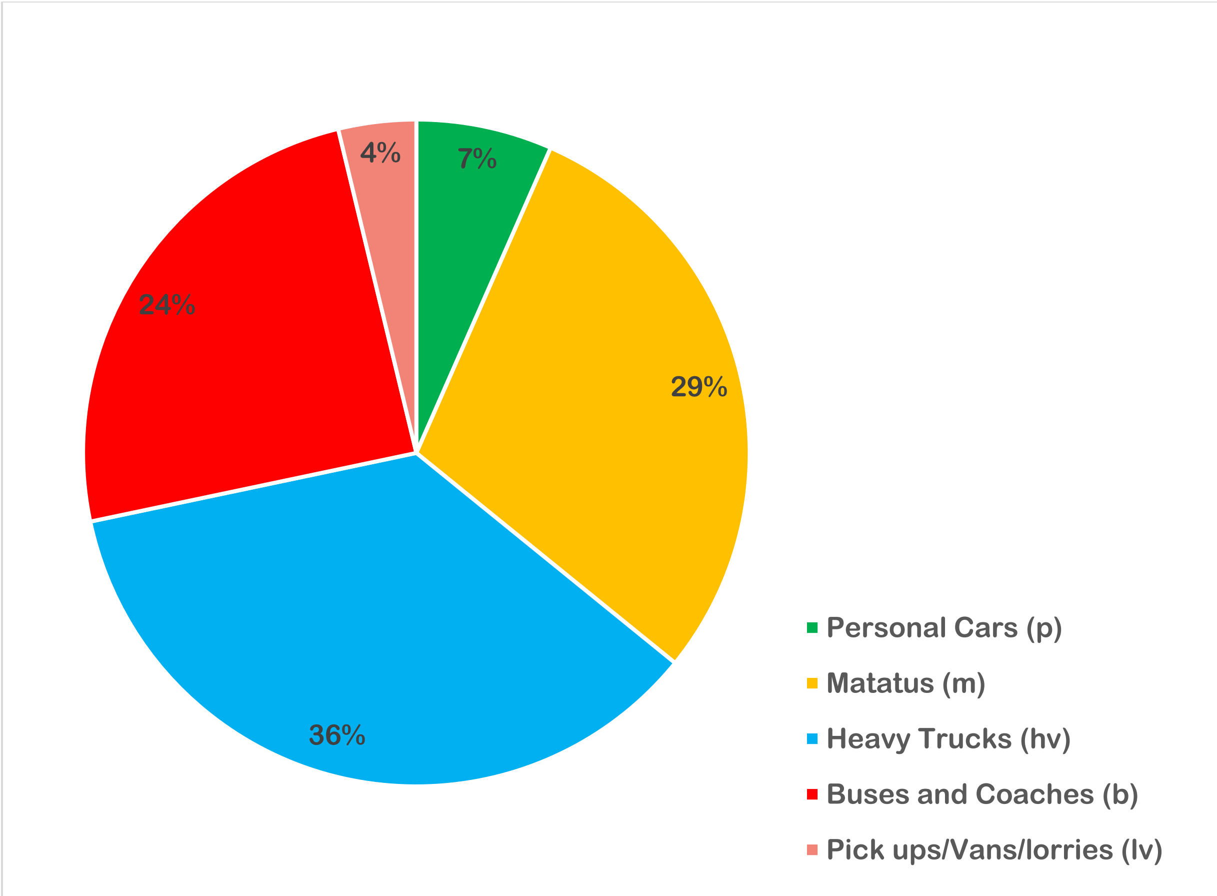

Figure 4-8: Individual opinion on vehicle category that pollutes the most in Nairobi City

Lack of proper maintenance of these motor vehicles was cited as the main reason why their pollution level is high, representing 43% (Figure 4-9) of the total respondents during the survey. Public Service Vehicles, heavy truck and buses were reported to be poorly serviced and maintained due to their poor conditions. Personal cars on the other hand were reported to be too many on the roads, hence increasing the emission levels. Consequently, the quality of fuel was also reported to influence emissions because of the subsequent reported cases of adulteration/substitution.

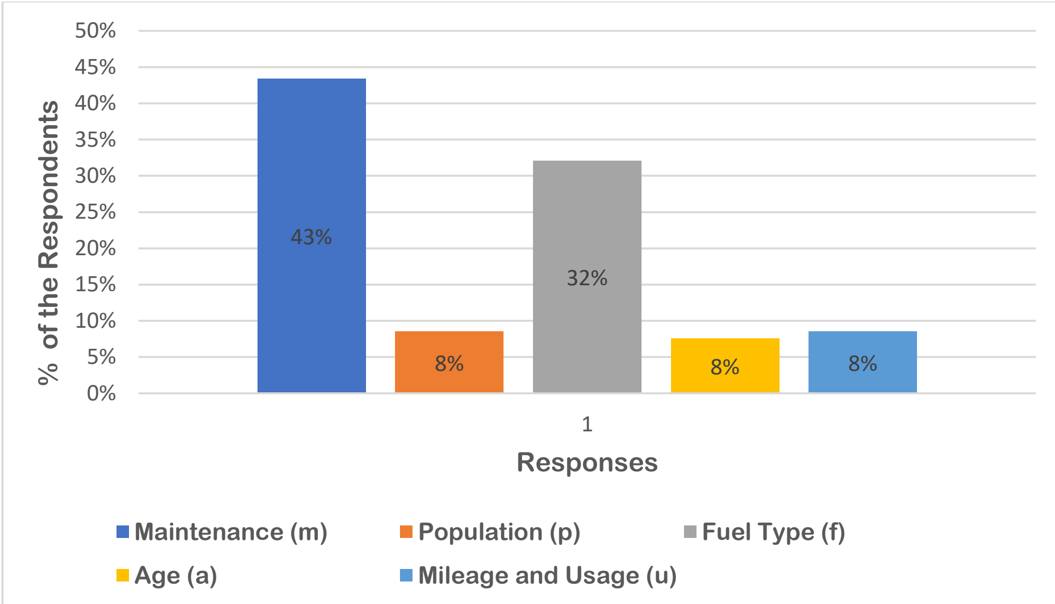

Figure 4-9: Respondents' opinion on the reasons for pollution in Nairobi City

❖ Fuel Consumption

52% of the residents in Nairobi use petrol fuel while 48% use Diesel. This was drawn from the traffic survey conducted.Only two types of fuel were depicted in Figure 4-10, as the amount of carbon content in different fuel types vary,therefore, the variance in emission levels. None of the motor vehicles used gas, electricity or bio-fuel.

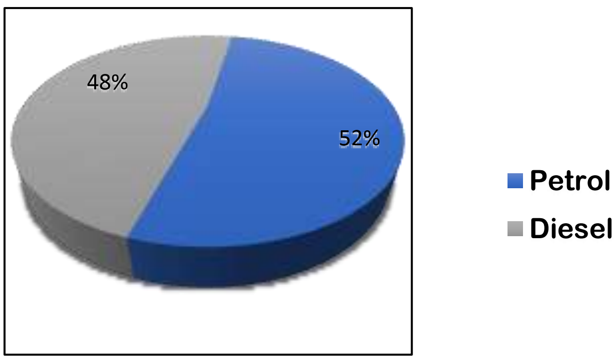

Figure 4-10: Pie Chart showing Fuel type used by motorists in Nairobi City

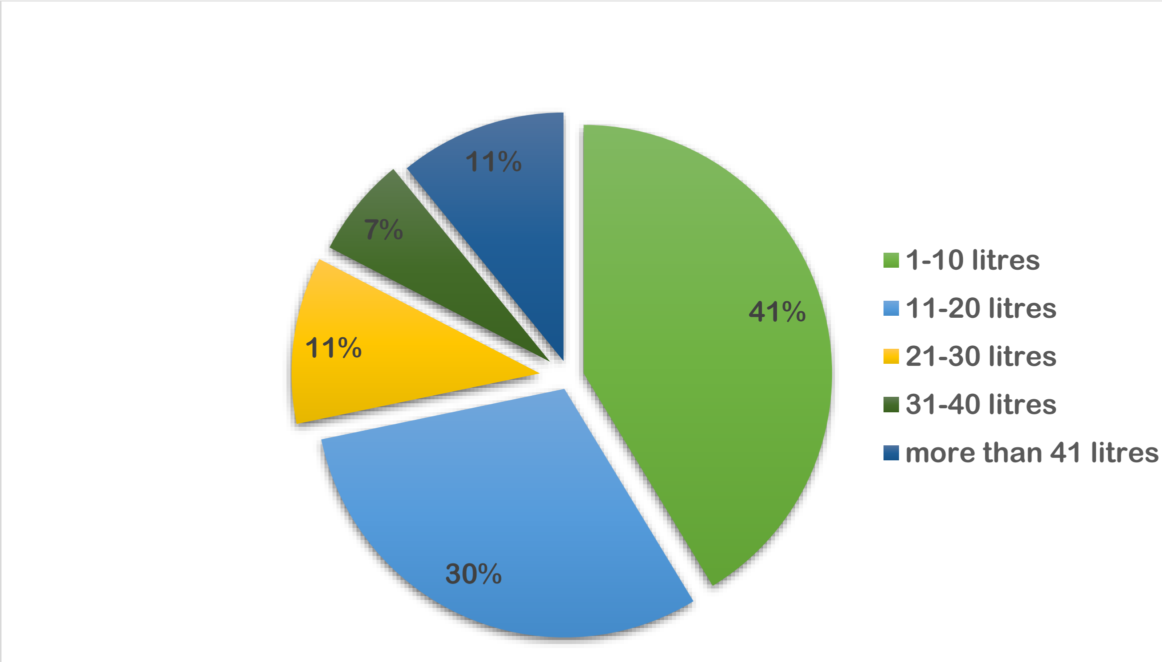

Figure 4-11: Volume of fuel consumed by different vehicles per day

The study survey found out that majority of road users in Nairobi consume about 1-10 litres of fuel as represented by 42% of the respondents during the survey, shown in Figure 4-11. Some consume up to 40 litres (7%) while others more than 41 litres (11%) on a daily basis, depending on the usage of the vehicle. Traffic congestion was identified as a major factor that had a great influence on vehicle fuel consumption

From the study, Figure 4-12 represents majority of the respondents who agreed that human health, environment, climate and the economy are highly affected by pollution from the road transport sector. Very few disagreed, while some were not aware of how the emissions affect the climate system as well as the economy. There were few responses to the effects of vehicular emission on the climate system (38%) and the economy (41%) as indicated in Figure 4-12 because the respondents lacked basic knowledge on the relationship between the economy and emissions as well as climate and emissions.

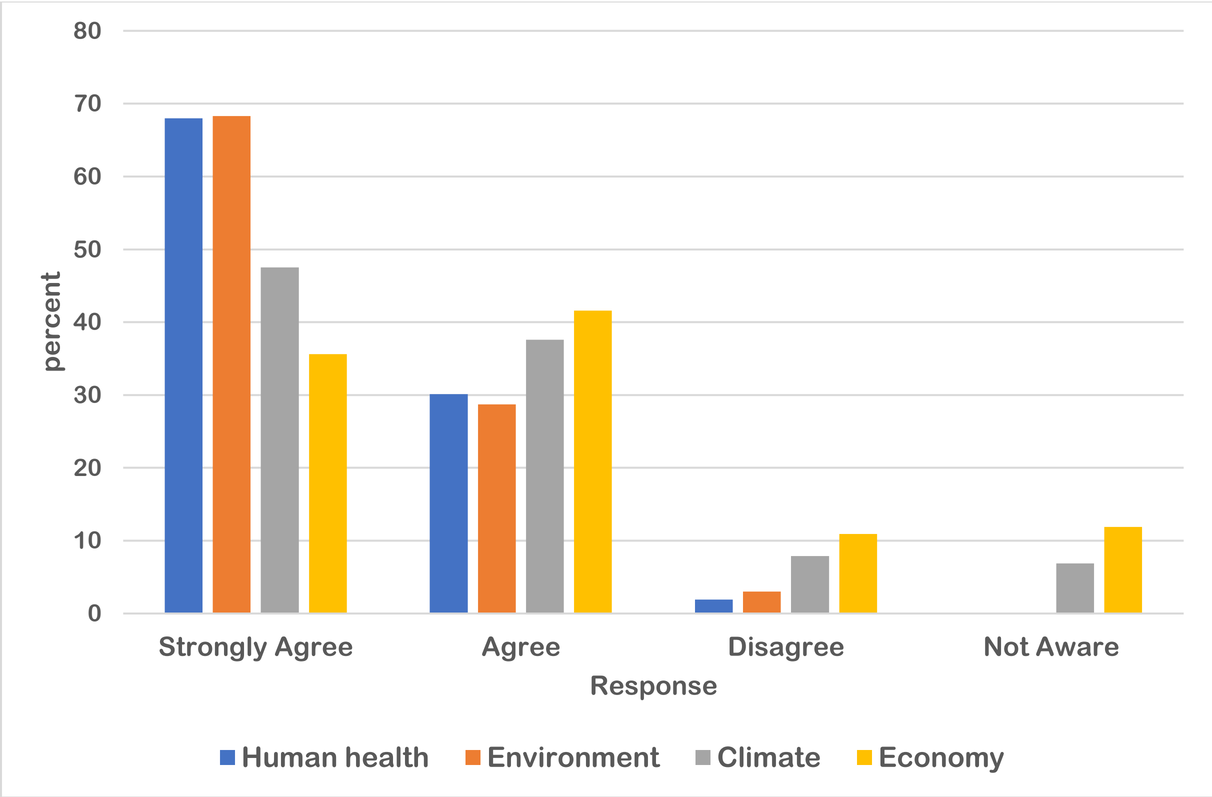

Figure 4-12: Respondents' opinions on the effects of vehicular emissions

The results in Figure 4-13 show that poor maintainance of vehicles has a great influence on pollution as 59% of the respondents were in agrrement with the this, citing that negligence of the exhaust after-treatment could lead to increase in emissions. Poor fuel quality, atrributed to adulteration or subsitution was also reported to cause unnecessary emissions. Even though majority of the respondents either stronlgy agreed or just agreed that the factors discussed earlier highly influence emissions, some disagreed that age of vehicle(39%) and high mileage (38%) are not associated with emissions. The remaining few respondents were not aware that such factors could result in increased emissions.

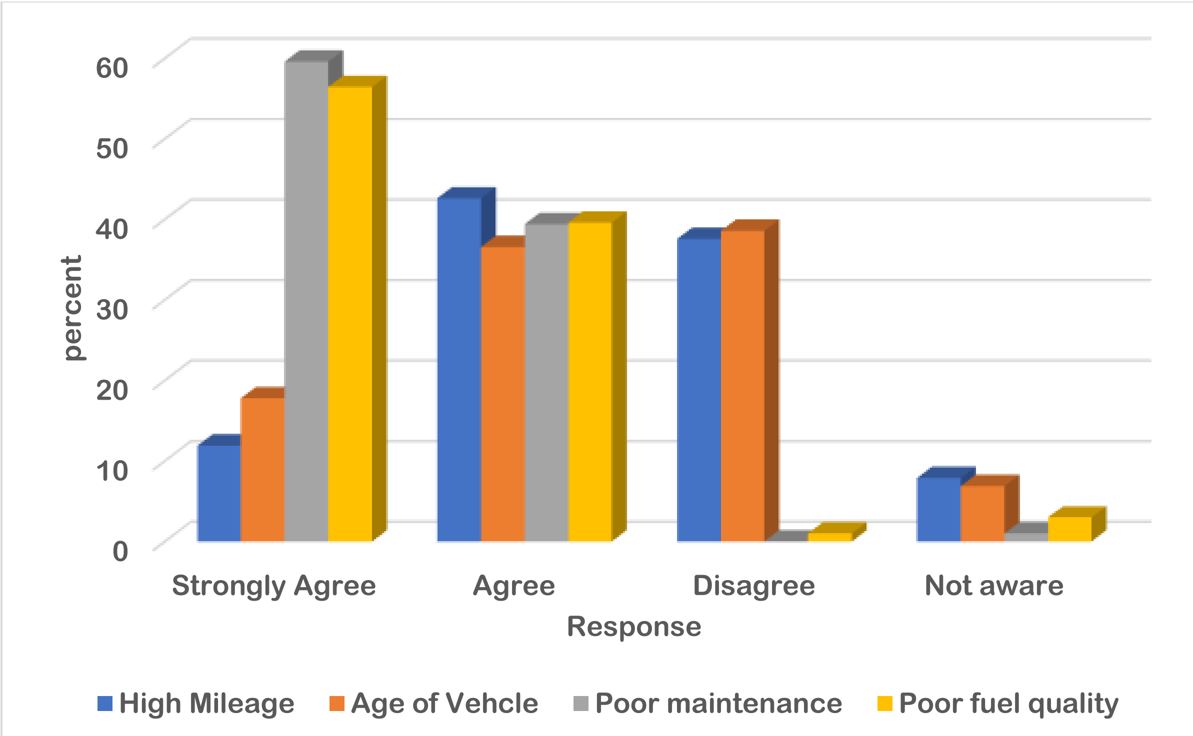

Figure 4-13: Respondents' opinions on the influence on emissions

- **Contribution of Passenger Cars**

Private cars including station wagons and 4WD (four-wheeled drive) were all classified as passenger cars in this study. The results indicate that passenger cars were the biggest contributors of CO_2 emissions. This is because they are the majority on the highway, contributing cumulatively to a total of about 25 million grams of CO_2 equivalent per kilometre, from 2014-2019 as shown in Table 4-2. The increase in the total number of vehicles translates to increase in CO_2 emissions.

Table 4-2: Cumulative estimated CO_2 emissions from 2014-2019 on Uhuru Highway

Total estimated CO_2 emissions by vehicle category in 2019					
Vehicle fleet	**Motorcycle**	**Passenger Cars**	**(PSV)**	**LCV**	**HGV**
CO_2 emissions ($MtCO_2e/km$)	0.18	25.35	6.89	1.82	0.25
Total No. of fleet	28072	293165	47296	54485	608

- **Contribution of Public Service Vehicles (PSV)**

All public service vehicles (excluding taxis) providing public transport were categorized as matatus. This category of vehicles came in second after the passenger cars, contributing to about 6.9 million grams of CO_2 equivalent per vehicle kilometre as shown in Table 4-2. The number of matatus on the highway has been on the rise since 2014 resulting to an increase in CO_2 emissions.

- **Contribution of Light Commercial Vehicles (LCV)**

This category of vehicles includes all medium-sized vehicles that are used for commercial purposes such as medium-sized lorries, pick-ups, vans as well as light buses. LCVs contribute a significant amount of CO_2 emissions whose trends have been increasing since 2014. Besides, their emission factor is high, implying that they are among the worst polluters. LCVs have been estimated to contribute to about 650,000 gCO_2e/km by the end of 2019.

- **Contribution of Heavy Goods Vehicle (HGV)**

Heavy goods vehicles such as trucks and trailers recorded to have the lowest traffic volume on the highway. However, the number has been increasing gradually, with 2019 likely to have an average annual daily traffic of 160 trucks using the highway. Despite this group of vehicles having the least numbers, they are the worst polluters because of their emission factor being high compared to the other vehicle fleets. By 2019, HGVs will have cumulatively contributed to about 250,000 gCO_2e/km, which is higher than that of motorcycles (181,000 gCO_2e/km).

- **Contribution of Motorcycles**

Motorcycle are the least contributors of CO_2 emissions. They also have the least emission factor as compared to other motorized transport systems, making them the least polluters. The results show that there has been a steady increase of CO_2 emissions by motorcycles on the highway. This trend is expected to increase owing to the increase in the number of motorcycles as a result of rapid urbanization, motorization as well as increase in population.

4.3.3 Emission Levels

To estimate the CO_2 emissions from the different vehicle fleets, a bottom-up approach was adopted. The primary data requirements were; the average daily traffic volume on Uhuru Highway, activity data of the vehicle fuel consumption), emission factors and the total length of the road segment. Figure 4-14 represents the trend of the average annual daily traffic of different vehicles along Uhuru Highway. The trend analysis shows that the AADT has been increasing yearly with 2014 having a total average of 32,602 vehicles of all types operating along the road. 2015 also marked an increase in traffic volume recording a total of 36,191 vehicles, and 44,602, 61029, 92,727 and 156,477 in 2016, 2017, 2018 and 2019 respectively. A steady increase of all the passenger cars, motorcycles, matatus, LCVs and HGVs were also observed between 2014 and2019 as represented in Figure 4-14.

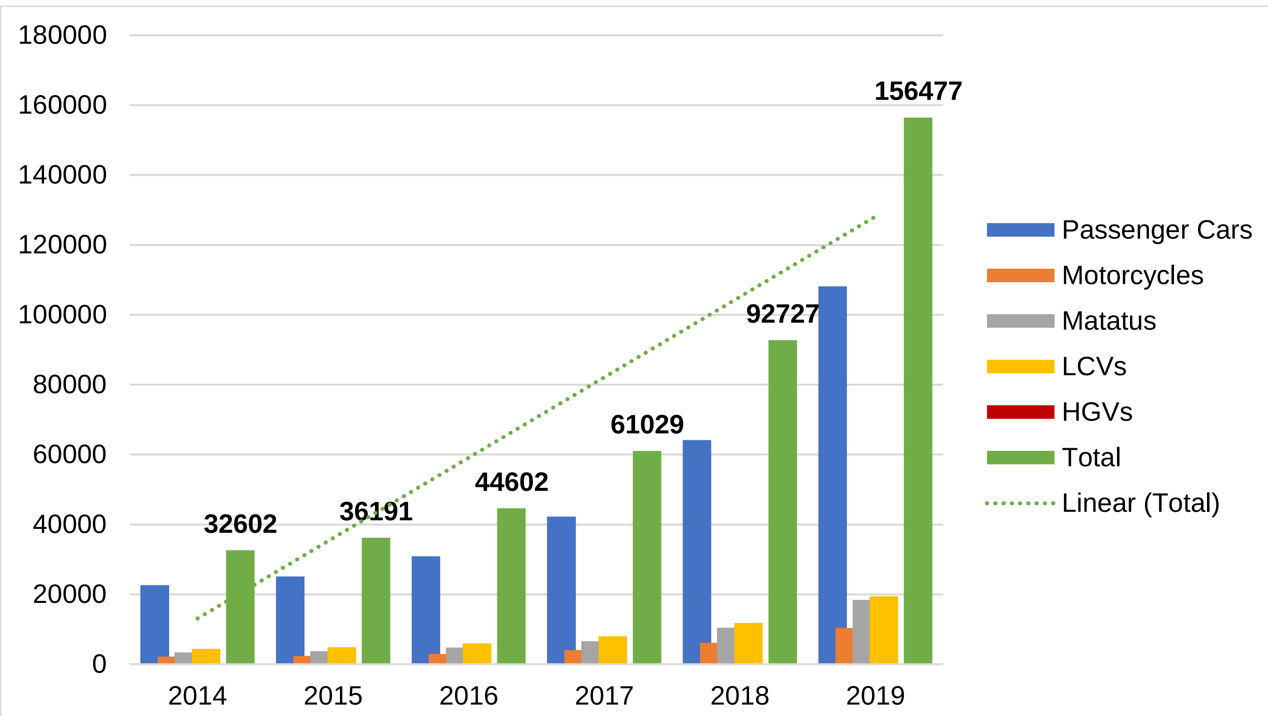

Figure 4-14: AADT Trend along Uhuru Highway, between 2014 and 2019

The AADT observed was relevant in determining the emission levels of different vehicles. These are represented in Figure 4-14.

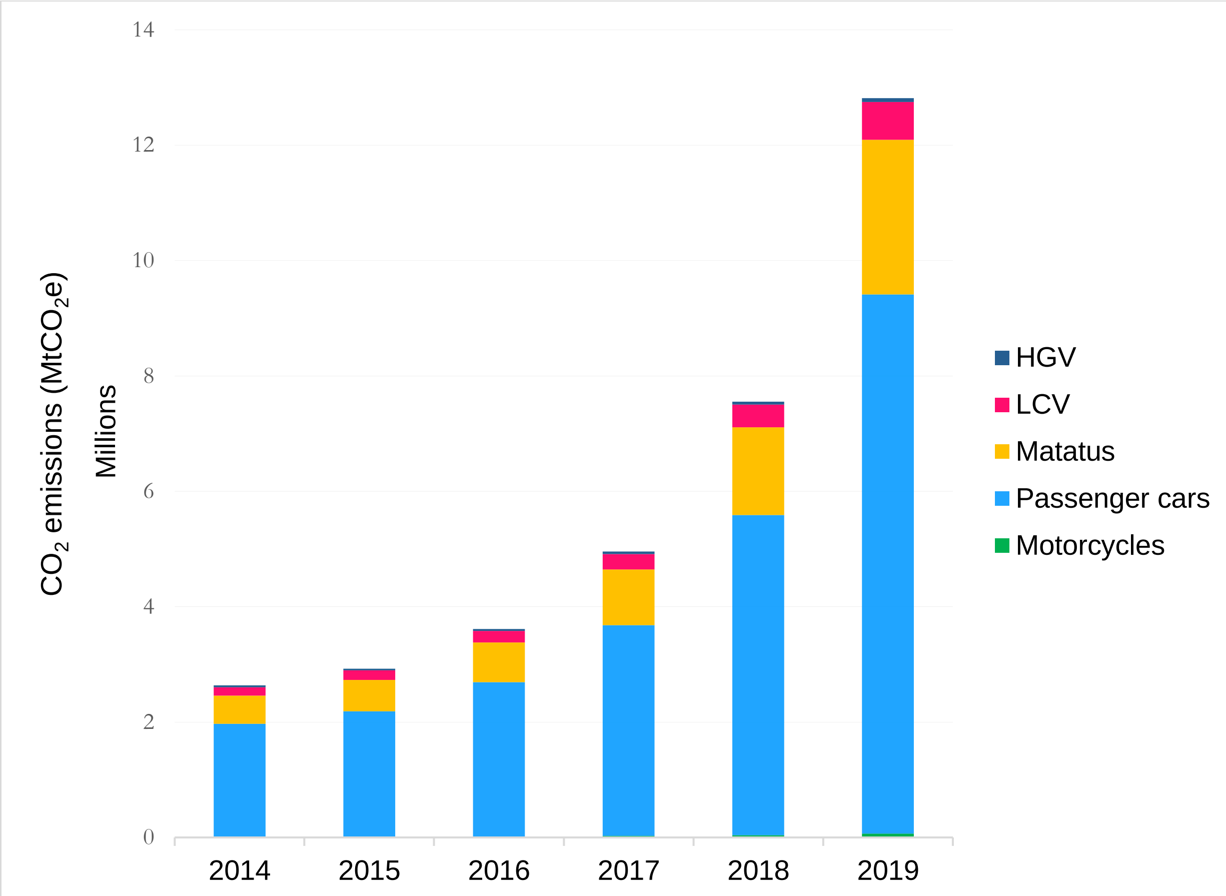

Figure 4-15: Total estimated CO_2 emissions by vehicle category on Uhuru Highway between 2014 - 2019

From Figure 4-15 the CO_2 emissions were observed for passenger cars, motorcycles, matatus, LCVs and HGVS and were reported to have a steady increase between 2014 - 2019. By 2019, passenger cars were estimated to have contributed to 9.3MtCO$_2$e, motorcycles 0.067 MtCO$_2$e, Matatus 2.7 MtCO$_2$e, LCVs 0.65 MtCO$_2$e ang HGVs 0.067 MtCO$_2$e.

Figure 4-16 shows individual contribution of CO_2 emissions by different vehicle categories along Uhuru Highway. Passenger cars are the highest contributors representing 73% of the total emissions followed by Matatus (20%), LCVs (4%), Motorcycles (2%) and finally, the least contributors are the HGVs with 1%

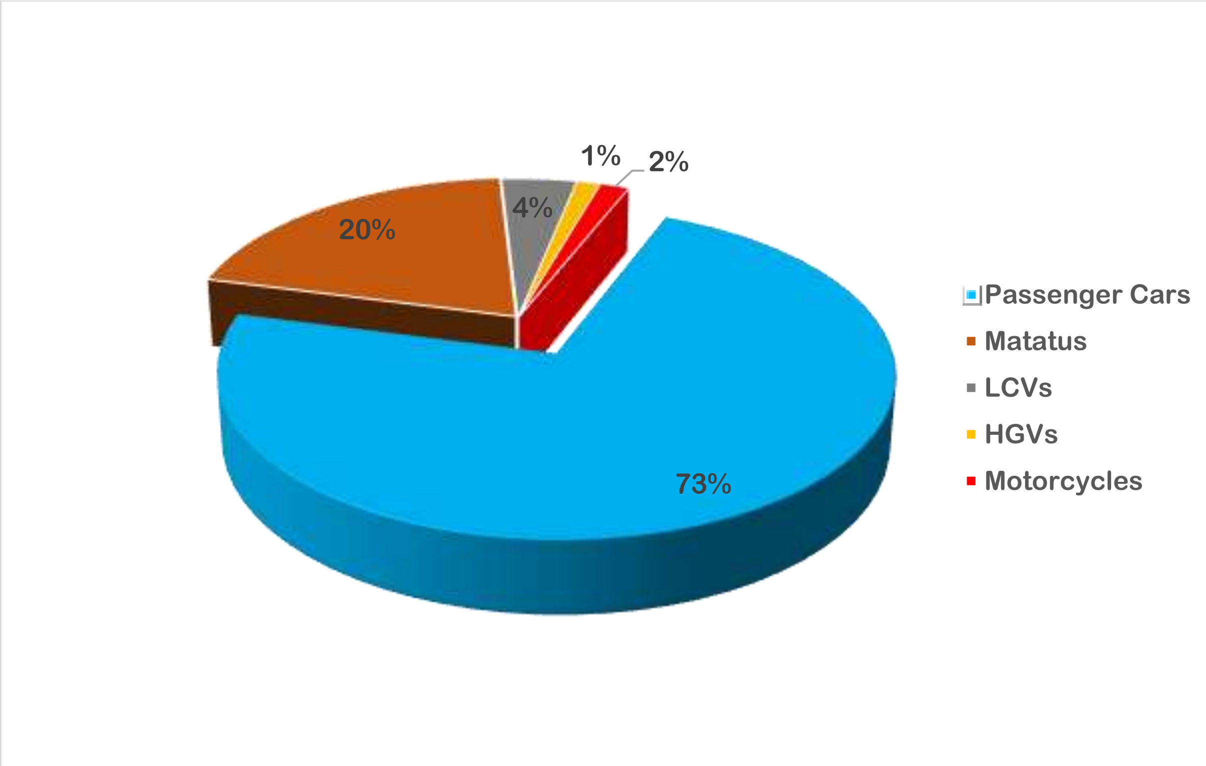

Figure 4-16: Contribution of CO_2 Emissions by different Vehicle categories in Uhuru Highway

Figure 4-17 represents the daily CO_2 emissions combined for all the vehicle categories. It was observed that Tuesday, Wednesday, Thursday and Friday had the highest emission levels contributing to 180,720 gCO_2 189281 gCO_2, 187,373 gCO_2 and 183,979 gCO_2 respectively. On Saturday and Sunday, the emission levels were observed to be lower as compared to the weekdays, contributing to a46,652 gCO_2 and 92668 gCO_2 respectively.

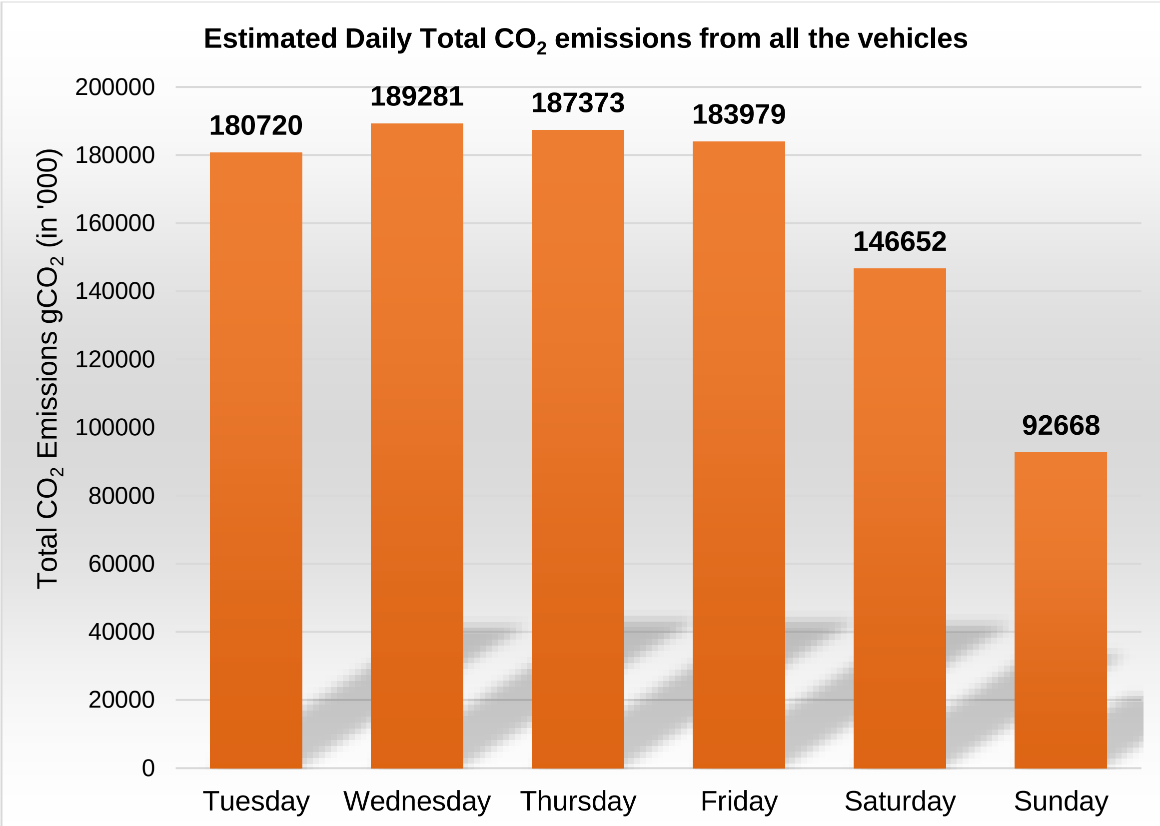

Figure 4-17: Estimated daily total CO_2 emissions along Uhuru Highway

4.4 Objective 3: Interventions to reduce CO_2 emissions from Traffic Congestion along Uhuru Highway

The finding of the study indicate that several measures need to be put in place to ensure that vehicle emissions from traffic congestion along Uhuru Highway are mitigated. The following interventions were suggested by the respondents during the questionnaire survey as represented in Figure 4-18. 28% of the respondents reported that enforcement of fiscal policies would be the best option to reduce CO_2 emissions from traffic congestion. This includes elimination of old and unroadworthy vehicles on the road, and imposing stricter rules on those that defy the already established regulations. Second strategy was ensuring proper inspection and maintenance, and improving vehicle efficiency of all vehicles which was supported by 20% of the respondents. Modal choice came in third with 18%, use of quality fuels was supported with 10% and lastly was vehicle technology which was supported by 5% of the respondents.

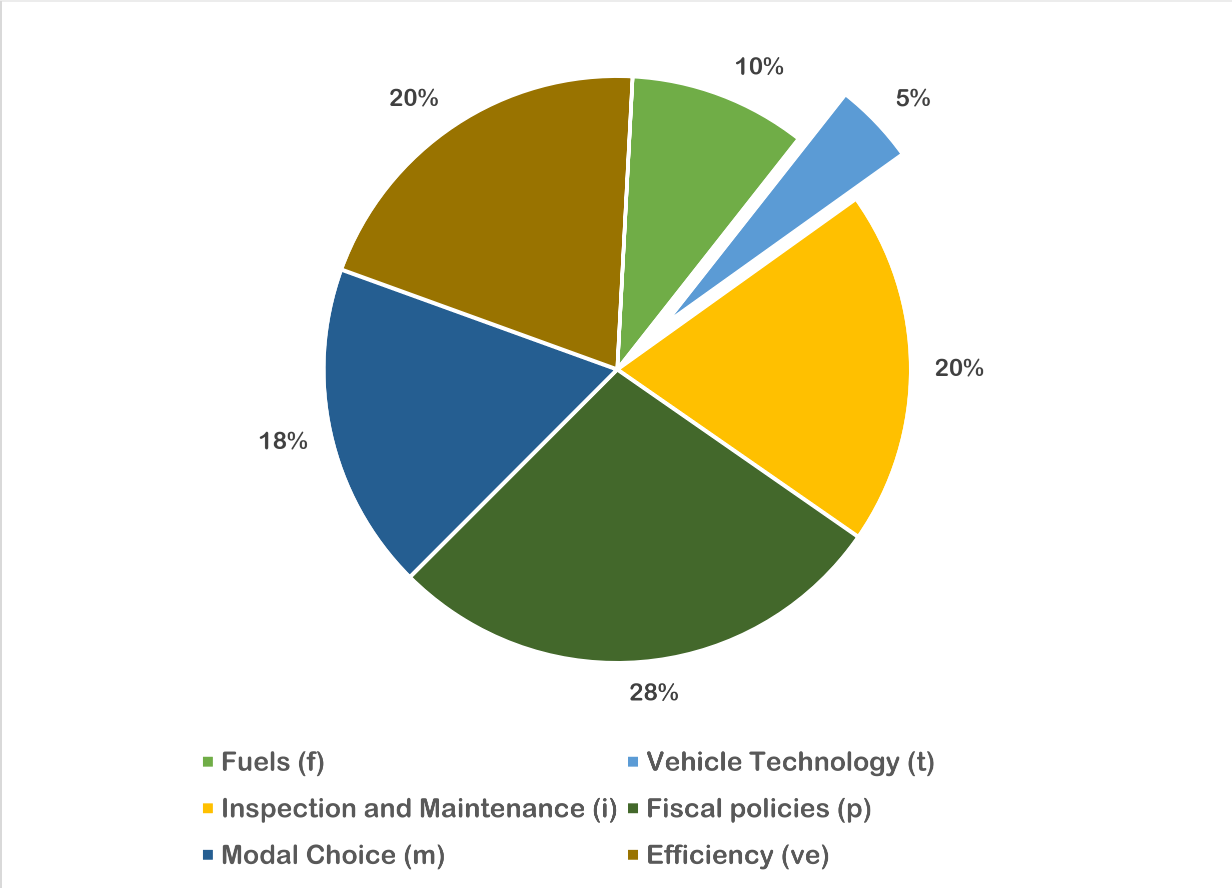

Figure 4-18: Suggested Measures/strategies to reduce CO_2 emissions from traffic congestion along Uhuru Highway

4.5 Discussion

The sections below discuss the findings of this study in relation to the findings on other studies done on the same topic of investigation.

4.5.1 Factors Influencing Traffic Congestion and CO_2 Emissions along Uhuru Highway

This study has demonstrated that traffic congestion contributes significantly to greenhouse gas emissions in cities such as Nairobi that experience heavy congestion especially during peak hours. CO_2 emissions were examined as a function of traffic congestion, showing that the emissions vary greatly depending on the amount of fuel consumption, vehicle speed, distance travelled and fuel type.

During the survey, the respondents acknowledged that congestion along Uhuru Highway is mainly caused by too many roundabouts and that the capacity of the road is too small to accommodate the growing number of vehicles. This means that the demand factors exceed the supply factors and as a result, vehicles move at sluggish speeds and greater speed variation, causing congestion. These findings conform with those of Koźlak and Wach (2018) that established demand-side factors to be more important than supply-side factors, hence contributing to congestion in an urban traffic.

In this study, factors such as poor planning of the city, poor traffic management, increase in population, illegal parking, among others emerged to be the major causes of traffic congestion along Uhuru Highway. Studies by Rahane and Saharkar (2014) also conform to these findings, citing on street parking as the major cause of congestion in cities. Additionally, Zhang *et al* ((2011) also noted that congestion mainly occurs as a result of rapid increase in car ownership and use, especially during rush hour periods in work zones. However, this study was only limited to specific types of vehicles during peak and off-peak hours on different days of the week in a specific work zone within the CBD of Nairobi City. Attitude which includes arrogance, discipline and generally drivers' behaviours also emerged as a key contributing factor to traffic congestion along Uhuru Highway

4.5.2 Vehicle Category Emission Differences along Uhuru Highway

According to Kang and Oh (2016) factors such as population, length, size and commuters tend to influence emissions. The bigger the traffic volume, the higher the emissions. Different fleet composition contributes significantly to CO_2 emissions when stuck in traffic congestion. This study found out that in Nairobi, passenger cars contribute the most to traffic congestion, hence being the highest contributors of CO_2 emissions as they cause majority of the movements within the city. The calculations conform with those of Nejadkoorki (2008) who found out that passenger cars were the main sources accounting for 72.5% of all CO_2 emissions in Norwich. A similar study conducted in Tehran by Kakouei (2012) also revealed that private cars were the main sources of greenhouse gas emissions, contributing about 88% of CO_2 emissions from the road transport. In Nairobi passenger cars are also contributing the most to CO_2 emissions. Thus, drawing a conclusion that high traffic volumes dominated by passenger cars, increased fuel consumption and inadequate public transport system could be accountable for the high CO_2 emission levels in the environment of Nairobi.

4.5.3 Interventions to reduce CO_2 emission levels from traffic congestion

Traffic congestion is global concern which needs a prompt action from the key personnel involved. In this case, governments are the main entities that take up this action to ensure its citizens are living a comfortable life. The Kenyan government has already shown its commitment to mitigate the traffic menace in its major city of Nairobi. Through a public-private partnership, the government has already begun the construction of the Nairobi Express Highway Project with the aim of decongesting the city. This move is also expected to lower the emission levels as well as mitigate air pollution. In this regard, more strategies to reduce vehicular emissions need to be adopted, some of them have been discussed below;

(i) Age of Vehicle

About 40% of the respondents agreed that the age of the vehicle plays a great role in influencing emissions Therefore, they suggested that the Nairobi City County Government could ensure that aged, poorly-maintained and unroadworthy vehicles should be eliminated from all the roads to reduce the CO_2 emission levels from traffic congestion. The respondents suggested that policies that include mileage and usage of vehicles could be enforced to enhance reduction of CO_2 emission levels. For instance, the government can provide subsidy schemes to incentivise the purchase of efficient vehicles. By doing so, it will help to promote recycling of the aging vehicles which are inefficient. This has been adopted by other African countries such as Egypt. In 2010, Egypt implemented such a scheme which had old inefficient scrapped and recycled into newer, less carbon-intensive (Hogarth **et al.**, 2015).

(ii) Use of Electric Vehicles

Emissions could be reduced drastically through technology such as hybrid electric or pure electric vehicles. 5% of the respondents agreed that the use of electric vehicles in Nairobi could potentially reduce CO2 emissions from traffic congestion. Ayetor *et al* (2020) also agrees with this by stating that it could be a technology that would help many African countries achieve some of the Sustainable Development Goals (SDGs) on clean environment. For example, Mauritius has already started the process of adopting hybrid and pure electric vehicles (Mathieu and Damar-Ladkoo, 2016). This shows that it is also possible for a country like Kenya to adopt the use of electric vehicles with Nairobi being on the lead.

(iii) Pedestrianization of the Streets

About 18% of the respondents suggested alternative modal choices which could be effective in mitigation traffic-related greenhouse gases. Encouraging people to walk more or use trains and bicycles would also reduce CO_2 emissions from traffic congestion. Some suggested that initiatives such as car free days which have been adopted in several cities in SSA such as Cape Town, Kigali and Addis Ababa could also be adopted in Nairobi. Adoption of car free initiative has also been pointed out by Campbell and Casas (2018), and Farda and Balijepalli (2018) as one of the strategies to reduce CO_2 emission levels. By doing so, it enables the local residents to reclaim their streets to demonstrate a healthy community where residents can walk, run, skate, cycle and explore the city in a car free environment. Moreover, the residents could actively redesign their streets while connecting with each other and equally share the public space in a safe and clean environment.

(iv) Clean Public Transport

Another possible strategy that the study found to reduce CO_2 emissions is to improve the public transport system by making it more efficient, thereby encouraging more people to and use the public means. The use of clean public transport systems will be more efficient and reliable. This could mean adoption of compressed natural gas as it has already been used in Dar es Salaam (IEA, 2014) as well as mass transit system which Nairobi City is in the initial process for its implementation. The Kenyan government has also launched a commuter rail system as part of the Nairobi Metropolitan Transport Master plan to ease traffic congestion, and at the same time create an efficient mass transport system for the city. In this regard, efficiency of vehicles was also seen as a possible solution to mitigate traffic-related air pollution representing 20% of the respondents who participated in the survey. To ensure efficiency for ease movement on the highway, it was suggested that building of an overpass could reduce traffic, hence CO_2 emissions. Moreover, proper traffic management including installation of functioning traffic lights and getting rid of traffic police who sometimes cause confusion at the roundabouts could also help in easing congestion. This eventually will lead reduction of greenhouse gas pollution.

4.5.4 Study Findings and Comparison with previous Studies

A comparative analysis with regards to measures of reducing vehicular emissions has been done with other sub-Saharan cities such as Addis Ababa, Cape Town and Kigali. It shows that Nairobi city is twice more likely to have increased CO_2 emissions contribution from traffic congestion. Therefore, needs to put in more efforts towards decongestion as well as improving the air quality for its city dwellers. These cities have demonstrated that the concept of Open Street can be successfully implemented in African cities where the local people can reclaim their streets in a demonstration of healthy recreation and community(Campbell and Casas, 2018). An open street initiative reserves a network of streets for people to walk, run, skate, cycle and explore the city in a car-free environment either on a weekly or monthly basis.

In 2013, Cape Town held its first Car-Free day which saw thousands of people connecting and equally sharing the public space in a safe environment. Today, this initiative has evolved into a movement of people who actively redesign their streets and connect with each other across deeply rooted social and spatial divides (Campbell and Casas, 2018). Following the success of this initiative in Cape Town, Kigali also launched its first Car-Free day in 2016 to encourage pedestrian to reclaim their streets and public spaces. Later, Addis Ababa and other cities in Ethiopia also joined the movement and launched the first Car-Free day in December 2018 with the aim of encouraging non-motorized transportation as well as fight against air pollution. Lessons learnt from these cities posit a crucial need for the government to invest in the safety and accessibility of walking and cycling infrastructure, and also prioritize the use urban public spaces.

The findings of this study show that it is possible for Nairobi to adopt such measures which will help in making the city improve its air quality, particularly from traffic congestion. However, lack of relevant policies that govern the country's vehicle emission standards coupled with lack of political good will could also act as a limitation during the implementation of such programs.

4.5.5 Policy Implications

The analysis of the study shows that traffic congestion in Nairobi city increases the amount of fuel consumption and also CO_2 emissions. This conforms with the findings of Bharadwal *et al* (2017) in a study conducted in Mumbai Metropolitan Areas in which traffic congestion was reported to have a great impact on fuel consumption, travel time and CO_2 emissions. However, with the steady increase in registered vehicles in the city, there is very little chance for improvement of the traffic situation, unless, relevant policy measures are taken. This section discusses the practical policy implications resulting from the research.

The stakeholder-led narratives reveal that the rapid growth rate of the economy in Nairobi city is a major driving force to traffic congestion. As the economy grows, there is increasing demand for a better lifestyle, including vehicle ownership (Brand *et al*, 2018). This could explain the steady increase in the number of vehicles, especially the passenger cars. However, there is little investment on our roads as compared to other economic sectors. Since the Nairobi City County Government (NCCG) is aware of these driving forces to traffic congestion in the CBD, it is trying to put in a lot of efforts to decongest the city, with the ultimate goal of improving air quality. According to a Nairobi City County Government official, blueprints have already been done to decongest the city; this includes light rails, installation of intelligence traffic lights, traffic Marshalls and also, more plans are underway for innovative ways to ease traffic by connecting peri-urban and diverting traffic from the CBD. However, one of the biggest challenges pointed out was inadequacy of resources and lack of clear policies to implement programs and initiatives geared towards decongestion and CO_2 reduction strategies. This highlights the importance of policies in reducing CO_2 emissions from the transport sectors.

In the context of transport policy options, the findings for this research are applicable particularly in priority setting for decision makers. This study found that, rather than prioritizing the introduction of BRT, LRT or improving vehicle efficiency, they should also focus in the possibilities of implementing local action plans to govern vehicle technology as well as initiatives to decongest the city. Additionally, there should be effective stakeholder engagement for impactful interventions that benefits both the public and promote sound environmental stewardship. The main lessons learnt from Populus cities such as Hong Kong, Mexico City, Beijing, Singapore, among others highlight the importance of investing in mass public transportation systems to limit private cars, hence, improving the traffic conditions.(Chavez-Baeza and Sheinbaum-Pardo, 2014; Goh, 2002; Li and Jones, 2015; Xu and Lin, 2015) Therefore, the first crucial development priority must be to fast-track the shift to electro-mobility which will help in cutting down the emissions, hence meet the goals of the Paris agreement (Transport and Environment, 2018).

In a bid to lessen traffic congestion and ultimately improve air quality, megacities such as Mexico City, Jakarta, Beijing, Singapore and Hong Kong have adopted measures such as driving restriction policy, ownership restraints policy and other programs that could limit population growth of vehicles (Li and Jones, 2015; Song *et al*., 2018). Nairobi is still lagging behind when it comes to implementation of policies and regulations that could help mitigate congestion and emissions. Nevertheless, the city has limited policies and regulations that govern motor vehicle inspections as it only applies to public vehicles.

In comparison with the megacities around the world, it is clear that policies are very effective in mitigating traffic congestion. Beijing city implemented a Driving Restriction policy is 2010 (Li and Jones, 2015) which was effective in reducing congestion. However, Hao *et al* (2011) though that this policy stimulated the growth of vehicle ownership and therefore needed to be backed up by a driving restriction policy. Therefore, Grange and Troncoso (2011) confirmed that for driving restriction policy to work effectively, ownership restraints also need to be put in place as in the case of Mexico City, Singapore and Hong Kong where fiscal actions have been used to limit ownership of automobiles. Singapore is known for its Electronic Road Pricing Program of 1998, which restricts the growth of vehicle ownership and reduces traffic in congested areas (Goh, 2002).

It must be acknowledged that this century offers a daunting challenge to control greenhouse gas emissions without affecting economic development, especially in fast-urbanizing cities like Nairobi, where economic development, unemployment and improving people's living standards are at the forefront. As a result, the steady growth of private vehicles in such cities will continue to have a significant impact on resource depletion and global warming if nothing is done to control the growth. Therefore, it is important to have institutional coordination and appropriate policy tools in place so as to achieve carbon dioxide emissions reduction in the urban transport. In addition, governance of urban transport must be strengthened, ensuring that transport policies are integrated into urban development plans. Also, in order to ensure that there is notable progress towards low-carbon transport, there must be involvement of a wide range of stakeholders as well as partners with a common goal and interest.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter provides summarize the key findings of the study which are; (a) the demand-side factors are the key contributing factors to traffic congestion in Nairobi which significantly contributes to CO_2 emissions, (b) passenger cars are the highest contributors of CO_2 emissions within the Nairobi CBD, while HGVs are the least emitters. (c) policies play a vital role towards the reduction of CO_2 emissions from traffic congestion. The conclusions drawn are based on the findings of the study. Recommendations for the solution of the problem identified in the study have also been addressed based on the existing solutions globally.

5.1 Summary and Conclusion

The researcher concludes that traffic congestion plays a significant role in increasing emissions, which have social, economic and environmental impacts. This is illustrated in Figure 5-1. Traffic congestion being the key problem under investigation, corresponds to the density of traffic and the frequency of acceleration and deceleration. When this happens, more emissions are generated. On the other hand, these emissions are linked to the fuel consumption rates as the amount of carbon content in the fuels vary, hence reflecting on the vehicles' consumption rates which are dependent on their operations. The ultimate goal of this study was to identify the possible measures that could be adopted to reduce emissions from congestion.

To respond to this problem, two responses have been identified; first, improve congestion which may correspond to improved total emissions, and second, develop, assess and optimize policies that are directly linked to congestion and emission reduction. However, as much as improving congestion may seem to be an option, it may not always correspond to improved total emissions. This is because, during free flow vehicles move at high speed but can still generate high emissions while lower travel times may also encourage drivers to make more and lower trips which amounts to increased emissions as well. Moreover, the spatial distribution of emissions may also be negatively affected by measures that improve traffic congestion. For instance, while the introduction of traffic signals and ramp metering may prevent congestion, it may consequently lead to higher concentration of emissions in the proximity of the signals. Therefore, to ensure total reduction of both emissions and congestion, it is important to consider policy development, assessment and optimization which will be beneficial to all.

When considering policy development, two things need to be put in place. First, modelling should be considered as a key decision support system that can help in managing traffic congestion and emissions. modelling will provide the decision makers with quantitative estimates, trends as well as insights on the relevant policies to be stimulated. Therefore, to ensure effective management of and control of congestion and emissions, both modelling and policies should be synchronized together. For example, modelling will require data and actions from the policy support system, stimulates the policy then sends back the indicators of congestion and emissions to the policy makers who will use the information to evaluate the policy.

Policy generation may occur at different scales and this may include taking measures such as; vehicle technology measures which are aimed at reducing engine-out emissions by using cleaner fuels, or reducing tailpipe emissions by using effective catalytic converters. Conventional transportation measures such as improving the infrastructural system which may involve expansion of road networks. Lastly, innovative measures can also be adopted as part of the Intelligent Transportation Systems (ITS). These include application of technologies to transportation systems.

Modelling can also be done at various spatial scales depending on the demand and supply of transportation needs which determine the traffic flows and patterns on the road network. The specific modelling approach chosen will depend on the objective as well as on the constraints in terms of data availability and computational time. For example, transportation demand such as trip generation, trip distribution and modal choice may be useful in choosing the best modelling approach to be used. Likewise, transportation supply options emanating from the physical transportation needs such as road network configuration, travel cost and time and also the traffic flow patterns are also relevant in determining the suitable modelling approach.

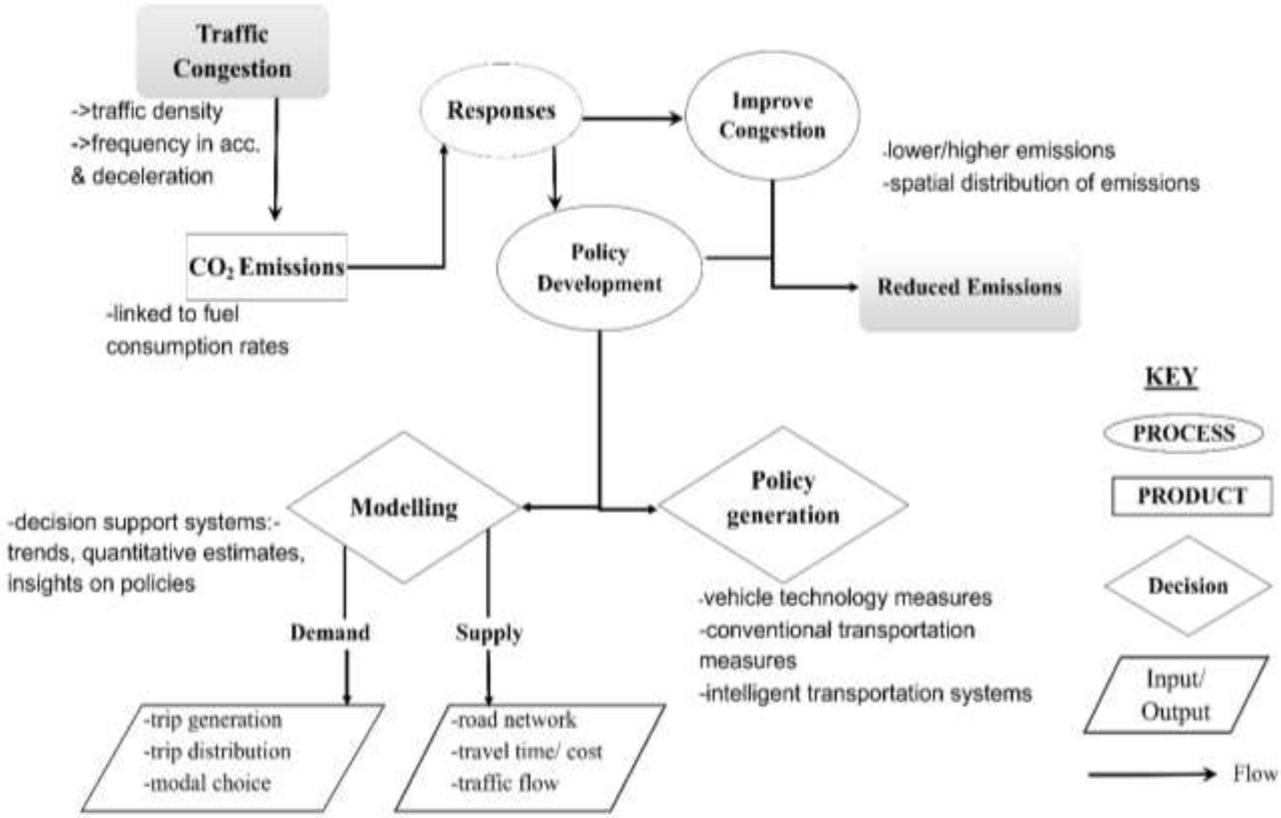

Figure 5-1: Conceptual framework for the summary on traffic congestion and emissions

This study has achieved its main objective by demonstrating that traffic congestion is a significant contributor to greenhouse gas emissions, particularly CO_2 emissions. The analysis of results presented here support the conclusion by Gastaldi *et al* (2017) that CO_2 emissions emitted from road traffic have a major influence on air quality, and are highly dependent on traffic volume, road conditions and vehicle features**.** The objectives aimed at identifying the relationship between traffic congestion and CO_2 emissions from road transport sector. The findings not only highlight the link between congestion and greenhouse gas emissions, but also brings forth other factors such as atmospheric conditions and driving patterns, that affect congestion, that have an impact on emission levels.

Taking Uhuru Highway as a case study to account for CO_2 emissions from congestion in Nairobi, the findings indicate that passenger cars are the highest contributors of CO_2 emissions, attributable to the huge volume they constitute on the road segment. As such, more efforts need to be put in place in a bid to decongest the city, hence, reducing CO_2 emissions. In comparison with other cities in the region and around the world, adoption of car free days could help in lowering congestion in the city. Metropolises such as Kigali, Addis Ababa and Cape Town have already proved that car-free initiatives can work in sub-Saharan cities. Therefore, this could also be an effective way of reducing congestion in Nairobi city.

Nairobi city is growing fast and experiencing rapid growth in transport emissions. Allocation of the city's road space needs to be more equitable in order to accommodate people's needs. There is a strong desire for more sustainable mobility options within the city to reduce travel times and emissions. Thus, create healthier and more liveable cities. Most importantly is to implement effective policies that guide the changes in mobility within the city. More investment needs to be done to acquire data that will inform scientific interventions. For instance, installation of air quality sensors along major highways could be a great initiative. Therefore, policy makers need to understand and manage emissions from traffic congestion in order to make informed decisions towards reducing the impacts of congestion on CO_2 emissions in Nairobi.

5.2 Recommendations

The IPCC attributes global rising temperatures to human activities, which currently emit 42 billion tons of carbon dioxide annually. Global carbon emissions have increased tremendously in recent years, with an increase of 1.7% in 2017 and a further 2.7% in 2018 (Mulvaney, 2019). For this reason, all UNFCCC parties are required to report their national efforts to lessen greenhouse gas emissions, which will contribute to the global reduction target. According to Barth and Borisboone (2008), there is potential for CO_2 emission reduction strategies of up to 20% depending on different conditions. This study presents some of the mitigation strategies that could be adopted to reduce CO_2 emissions from traffic congestion in cities such as Nairobi where motorization rates are high. The recommendations imply that if these approaches are implemented at a local level, then it will contribute towards the country's efforts in CO_2 reductions.

The study recommends the Avoid, Shift and Improve (A-S-I) principle.

a) Nairobi residents should avoid the need to travel. The study revealed that the major cause of traffic congestion along Uhuru Highway is that the road is too small to accommodate the growing number of vehicles. This typically implies that the demand factors such as vehicle ownership, trip generation and trip distribution exceed the supply factors such as the infrastructural development i.e. road network. As a result, traffic congestion causes an increase in CO_2 emission levels. Based on this finding, the study recommends the need to avoid and reduce travel distance. This can be done through implementation of urban development policies and proper integrated transport and urban planning.
b) There is need to shift to more energy efficient mode of transport. Passenger cars were found to contribute the most to CO_2 emissions, accounting for 73% of the total CO_2 emissions. Based on this finding, the study recommends that shifting to more environmentally and socially sustainable modes of transport such as public transport, walking and cycling could be an effective way of reducing the CO_2 emission levels. Passenger cars could be replaced with an efficient public transport system such as the Mass Rapid Transit Systems (BRTs and LRTs) which are at their initial stages of implementation in Nairobi City. Initiatives such as the car-free days could also be adopted to promote active transport, thus keeping the CO_2 emission levels down.
c) Improve vehicle efficiency through vehicle technology. The study revealed that policies play a significant role towards the reduction of CO2 emissions from traffic congestion. Based on this finding, the study recommends improving vehicle and operation efficiency by promoting the use of clean public transport vehicles such as BRTs and also promoting the use of efficient transport behaviour such as carpooling which will help in reducing the number of cars on the road. The NCCAP Volume III (2018) advises that a mass transit system in form of Bus Rapid Transit (BRT) and Light Rail Transit (LRT) for Nairobi City and its environs will have the largest mitigation potential by 2030. This means that shifting to electro-mobility will help in the reduction of CO_2 emissions since there will be zero emissions produced.

5.3 Areas for further research

This study was developed with data which was available from the main bodies accountable for the transport sector in Nairobi. However, data on traffic count were not kept up to date by the responsible agency. This creates a challenge in modelling future projections due to unavailability of historical data. Having adequate data would be paramount for future CO_2 emissions modelling from traffic congestion.

This study was only limited to CO_2 emissions as a greenhouse gas. However, there were very limited instruments for measuring gaseous pollutants which were expensive as most of the locally available low-cost sensors could only capture particulate matter. This limited the study to estimation of CO_2 levels using the IPCC methodologies. Future studies could focus on measurement of real-time emissions from on-road vehicles to capture ground measurements especially during heavy traffic congestion. More studies could also focus on bottom-up approaches to create traffic emissions inventories which are needed to inform local policies that can make significant changes in a city’s emissions profile. This is particularly important as latest satellite data such as TROPOMI are available, providing an extraordinary overview of cities' CO_2 emissions profiles and urban air quality.

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APPENDICES

Appendix I

Approval Permits

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

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Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref. No. **NACOSTI/P/19/12308/30606**

Date: **29th May, 2019**

Cynthia Nanjekho Sitati
University of Nairobi
P.O. Box 30197-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Assessing the contribution of traffic congestion to greenhouse gas emissions in the Central Business District of Nairobi County, Kenya,"*** I am pleased to inform you that you have been authorized to undertake research in **Nairobi County** for the period ending **29th May, 2020.**

You are advised to report to **the County Commissioner and the County Director of Education, Nairobi County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

DR. STEPHEN K. KIBIRU, PhD.
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Nairobi County.

The County Director of Education
Nairobi County.

National Commission for Science, Technology and Innovation is ISO9001: 2008 Certified

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Ref: I58/7764/2017

18th March,2019

TO WHOM IT MAY CONCERN

RE: INTRODUCTION LETTER FOR CYNTHIA SITATI – I58/7764/2017

This is to confirm that Ms. Cynthia Sitati is a Masters student in the Institute for Climate Change and Adaptation (ICCA), University of Nairobi.

Ms. Sitati has completed her taught courses and she is currently working on her research for her thesis titled "Assessing the Contribution of Traffic Congestion to GHG Emissions in the Central Business District of Nairobi City".

Any assistance accorded her to support her research will be highly appreciated.

Yours Sincerely

DIRECTOR
INSTITUTE FOR CLIMATE CHANGE & ADAPTATION
CBPS
UNIVERSITY OF NAIROBI
18/3/19

Prof. Shem O. Wandiga FRSC, D.Sc. (hc)
Professor of Chemistry
AND
Ag. Director, ICCA

Appendix II

Participant Consent Form

I confirm that I have read and understood the information about the study as provided in the Participant information sheet dated July/2019

I also understand that the answers I provide here are to be used strictly for academic purpose and therefore, should be treated with utmost confidentiality. My participation in this study is voluntary and I am free to withdraw at any time without giving a reason and without any forthcoming consequences.

Name:

Signature:

Appendix III

Current Traffic Count Data on Uhuru Highway

18th June-Tuesday

Vehicle type	10am	11am	12pm	1pm	2pm	3pm
Passenger Cars	1437	1411	1622	1711	1508	1869
Matatus	18	15	62	78	27	49
Heavy Goods Vehicles	0	1	4	0	1	0
Light Commercial Vehicles	83	85	111	117	110	134
Motorcycles	37	46	50	64	49	71
Others	18	27	9	18	22	26

19th June- Wednesday

Vehicle type	10am	11am	12pm	1pm	2pm	3pm
Passenger Cars	1532	1460	1714	1802	1610	1988
Matatus	25	23	69	95	37	69
Heavy Goods Vehicles	3	2	2	1	3	2
Light Commercial Vehicles	98	95	121	127	121	144
Motorcycles	43	51	55	69	54	75
Others	23	33	14	23	27	31

20th June- Thursday

Vehicle type	10am	11am	12pm	1pm	2pm	3pm
Passenger Cars	1442	1416	1627	1715	1513	1874
Matatus	31	31	77	72	33	46
Heavy Goods Vehicles	5	3	11	4	7	1
Light Commercial Vehicles	88	105	118	127	112	143
Motorcycles	47	56	60	74	59	81
Others	28	37	19	25	32	29

21st June-Friday

Vehicle type	10am	11am	12pm	1pm	2pm	3pm
Passenger Cars	1398	1471	1605	1789	1551	1941
Matatus	20	23	72	80	26	36
Heavy Goods Vehicles	0	0	3	0	4	4
Light Commercial Vehicles	90	105	121	102	113	146
Motorcycles	32	35	58	74	52	77
Others	17	33	5	13	27	28

22nd June-Saturday

Vehicle type	10am	11am	12pm	1pm	2pm	3pm
Passenger Cars	1105	945	1413	1512	876	689
Matatus	81	42	66	76	45	31
Heavy Goods Vehicles	5	6	4	0	1	2
Light Commercial Vehicles	86	40	103	80	76	99

23rd June-Sunday

Vehicle type	10am	11am	12pm	1pm	2pm	3pm
Passenger Cars	837	535	811	631	713	432
Matatus	25	16	64	38	39	48
Heavy Goods Vehicles	0	0	1	1	0	2
Light Commercial Vehicles	36	47	82	70	68	82

Motorcycles	69	21	34	71	56	64	Motorcycles	15	21	25	31	29	48
Others	9	13	15	20	14	31	Others	9	15	5	13	10	13

Average Daily Traffic along Uhuru Highway								
Tuesday	Passenger Cars	1593	**Wednesday**	Passenger Cars	1685	**Thursday**	Passenger Cars	1598
	Matatus	42		Matatus	42		Matatus	49
	Heavy Goods Vehicles	6		Heavy Goods Vehicles	5		Heavy Goods Vehicles	6
	Light Commercial Vehicles	107		Light Commercial Vehicles	118		Light Commercial Vehicles	116
	Motorcycles	53		Motorcycles	58		Motorcycles	63
	Others	20		Others	26		Others	29
	Total	1821		Total	1934		Total	1861
Friday	Passenger Cars	1626	**Saturday**	Passenger Cars	1090	**Sunday**	Passenger Cars	660
	Matatus	43		Matatus	57		Matatus	39
	Heavy Goods Vehicles	4		Heavy Goods Vehicles	6		Heavy Goods Vehicles	3
	Light Commercial Vehicles	113		Light Commercial Vehicles	81		Light Commercial Vehicles	65
	Motorcycles	55		Motorcycles	53		Motorcycles	29
	Others	21		Others	17		Others	11
	Total	1862		Total	1304		Total	807

Appendix IV

Traffic Emission Inventory for Uhuru Highway Vehicle Fleet, Nairobi	
Traffic Emission Inventory for Uhuru Highway Vehicle Fleet, Nairobi	
Length of road in Km:	2
Equation: E = A × FC× L × EF, Modified from IPCC: GHG emission=activity data x emission factor	

where: A is the average number of vehicles

FC is the specific fuel consumption

L is the length of the road

EF is the emission factor obtained from INFRAS (2017b) for the country's road transport sector

FC = Fe x A x L

where: Fe is the fuel economy (litres/km) obtained from Mbandi et al (2019), INFRAS (2017b) and INFRAS (2018)

Adopted Vehicle Category Details
Passenger cars: All private vehicles with a capacity not exceeding 7 passengers
Matatus: All public vehicles operating within Nairobi with a capacity of 14-54 passengers
Light Commercial vehicles: All private vehicles including vans, pick-ups and light lorries
Heavy goods vehicles:
Motorcycles:

Tank-to-Well emission factors used

Basis for calculation: Handbook of Emission Factors for Road Transport (HBEFA Version 3.3, Source: - INFRAS 2017 and INFRAS 2018

Vehicle Category	2015	2017	2020	2030	2040	2050
Passenger Car (PC)	189.6	181.1	170	137.9	120.5	107.1
Light Commercial Vehicles	220.2	216.8	213.8	195.3	173.9	154.6
Matatus petrol (part of LCV)	167.9	166	162.3	147.7	132	117.6
Matatus Diesel (Part of LCV)	150.7	149.8	148.1	136.4	121.7	108.3
Buses	860.1	862.6	864.8	866.7	866.7	866.7
Heavy Goods Vehicles (HGV)	772.3	761	742.5	671.7	608.1	574.7
Motorcycles (MC)	70.1	70.1	69.1	64.2	62.9	62.6

Current Average CO_2 Emissions per Vehicle Type (July 2019) for 1 week (gCO_2e/km)							
Vehicle Type	**Ave Number of vehicles**	**Average number of trips**	**Total distance covered (km)**	**Fuel consumption (litres/km)**	**Emission factor (g/l)**	**Fuel consumption (litres)**	**CO_2 emissions (g)**
Passenger cars	1375	1	2	0.228	189.6	627	118879.2
Matatus	45	5	10	0.331	220.2	148.95	32798.79
Light Commercial vehicles	100	2	4	0.076	220.2	30.4	6694.08
Heavy goods vehicles	5	1	2	0.268	772.3	2.68	2069.764
Motorcycles	51	8	16	0.046	70.1	37.536	2631.2736
Total (per day)							**163073.11**

CO_2 Emissions per Vehicle Type (gCO_2e/km)						
Vehicle Type	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Passenger cars	1953942	2168875	2672232	3654649	5547984	9348660
Matatus	489795	548542	688046	966617	1520989	2680462
Light Commercial vehicles	147538	162867	198513	267127	396825	650765
Heavy goods vehicles	28977	30633	34358	40567	50502	66646
Motorcycles	13956	15491	19090	26106	39630	66781
Totals	**2634208**	**2926408**	**3612239**	**4955066**	**7555930**	**12813314**

Appendix V

UNIVERSITY OF NAIROBI, INSTITUTE FOR CLIMATE CHANGE AND ADAPTATION

MASTERS OF CLIMATE CHANGE ADAPTATION

Title of Research Project: **Assessing the Contribution of Traffic Congestion to Greenhouse Gas Emissions in the Central Business District of Nairobi City: A Case Study of Uhuru Highway**

INTERVIEW SCHEDULE WITH KEY INFORMANTS

The information given here is confidential, will be treated with ultimate confidentiality and will be used for the purpose of academic research only.

(please provide detailed information on the questions)

DATE……………………………ORGANIZATION…………………………………………………….

NAME……………………………………...…TITLE/POSITION…………………………………...

1. What do you think contributes the most to traffic congestion along Uhuru Highway?
2. Are there specific measures you (your organization) have put in place to manage vehicular traffic along Uhuru Highway?
3. Traffic Congestion results in emission of harmful pollutants, among them, the greenhouse gases such as CO_2, CH_4, and N_2O. Are there any measures that have you (your organization) put in place to reduce pollutants like CO_2 from traffic congestion along Uhuru Highway?
4. What are some of the challenges that you (your organization) experience in implementing programs that aim to reduce GHGs from traffic congestion/road transport sector?
5. In your opinion, who should be the key player (s) in reducing GHG emissions from traffic congestion along Uhuru Highway?
6. What are some of the current policies and regulation guidelines for GHG reduction from traffic congestion in Nairobi CBD?
7. What is the vision/your plan (your organization) for GHG reduction from traffic congestion? How do you plan to achieve this?
8. In your opinion, what do you think could be done to reduce GHG emissions from traffic congestion along Uhuru highway?
9. Is there anything else that I have not asked you, and would like to say about traffic congestion and its contribution to GHG emissions along Uhuru Highway in Nairobi CBD?

Thank you very much for taking time to take part in this survey!!!!!

Appendix VI

UNIVERSITY OF NAIROBI, INSTITUTE FOR CLIMATE CHANGE AND ADAPTATION

MASTERS OF CLIMATE CHANGE ADAPTATION

Title of Research Project: **Assessing the Contribution of Traffic Congestion to Greenhouse Gas Emissions in the Central Business District of Nairobi City: A Case Study of Uhuru Highway**

ROADSIDE INTERVIEW QUESTIONNAIRE

The information given here is confidential, will be treated with ultimate confidentiality and will be used for the purpose of academic research only. You are being invited to participate in this research because you are considered as having vital information and opinions relevant to achieve the aims of the study.

Questionnaire No…………...Date…………….……Site Section……………………………

Background Information

i). Name (Optional)……………………………………......…………………

ii) Gender: □ Male. □Female

iii) Age category

□ 15-20 □21-30 □31-40 □Over 40 years

iv) Occupation (optional)…………………………

(v) Education Level

□ Primary □Secondary □Dip/Cert level

□Bachelor's degree □Masters level □PhD Level

Section One: Factors that contribute to Traffic Congestion

1. What is the purpose of your trip to the CBD?

□Work □Shopping □Leisure/Social □Other (specify)

2. What is the average number of trips you make in a day to the CBD?

□1 trip/day □2 trips/day □3 trips/day □4 trips and above

3. How many hours, in a single trip, do you experience traffic jam along Uhuru Highway?

□Less than 1 hour □1-2 hours □2-3 hours □More than 4 hours

4. what is the average number of trips in a day that you make using Uhuru highway

□ 1 trip □2-3 trips □4-5 trips □More than 6 trips

4. How long does it take you to drive through Uhuru highway during: (*Please tick where applicable*)?

Duration	*Weekdays (Mon-Friday)*			*Weekends (Sat and Sun)*			*Public Holidays*		
	Morn	N/AF	Even	Morn	N/AF	Even	Morn	N/AF	Even
Less than 5 mins									
5-10 mins									
15-30 mins									
40-60 mins									
More than 60 mins									

5. In your view, what do you think contributes to traffic congestion along Uhuru Highway?
6. In which way do the following affect your ease of movement along Uhuru Highway

(*Please tick where applicable*)

	Vehicle breakdown	*Careless driving*	*Ignorance*	*Confusion*	*Other (specify)*
1. Private Vehicles					
2. Public Vehicles					
3. Tuktuks					
4. Motorcycles					
5. Pedestrians					
6. Traffic police					
7. Traffic lights					
8. Roundabout					
9. Other (specify)					

7. Apart from Uhuru Highway, do you have alternative route to your destination?

□Yes □No

If yes, how often do you use the alternative route and why?...

Section Two: Degree of Emission Levels from different Vehicle Categories

8. Traffic congestion has a great impact on smoke (air pollution)? *(please tick only one box)*

□Strongly Agree □Agree □Disagree □Not aware

9. In your opinion, which types of vehicles pollute the most? *(please tick only one box)*

□personal cars/taxis □Buses and Coaches □ Matatus

□Pick-ups/Vans □Lorries and trucks □ Tuktuks □ Motorcycles

Explain your answer above……………………………………………………………………

10. Pollution from vehicles are influenced by: (*Please tick one box on each of the variables*)

	Strongly agree	*Agree*	*Disagree*	*Not aware*
1. High mileage and usage				
2. Age of vehicle				
3. Poor maintenance of vehicles				
4. Poor fuel quality/adulteration				

11. Pollution from vehicles affects the following: (*Please tick one box on each of the variables*)

	Strongly agree	*Agree*	*Disagree*	*Not aware*
1. Human health				
2. Environment				
3. Climate				
4. Economy				

Only proceed to next question if the participant is in a vehicle of motorcycle. If not, terminate

12. General information about the different vehicle types; *Please provide information on the vehicle you operate/drive*)

Vehicle Characteristics

Vehicle type	Manufacturer	Model	Registration year/model year
Odometer readings	Engine size	Fuel type	Fuel consumption/ amount spent of fuel/day
Car Service frequency			

Section Three: Recommendations

13. In your opinion, what measures can be put in place to reduce air pollution from traffic congestion along Uhuru Highway?

Thank you very much for taking time to take part in this survey!