

**ESTIMATING THE COST OF EMISSIONS AT TOLL BOOTHS:
CASE STUDY OF TEMA AND FRAFRAHA TOLL BOOTHS IN THE
GREATER ACCRA REGION OF GHANA.**

BY

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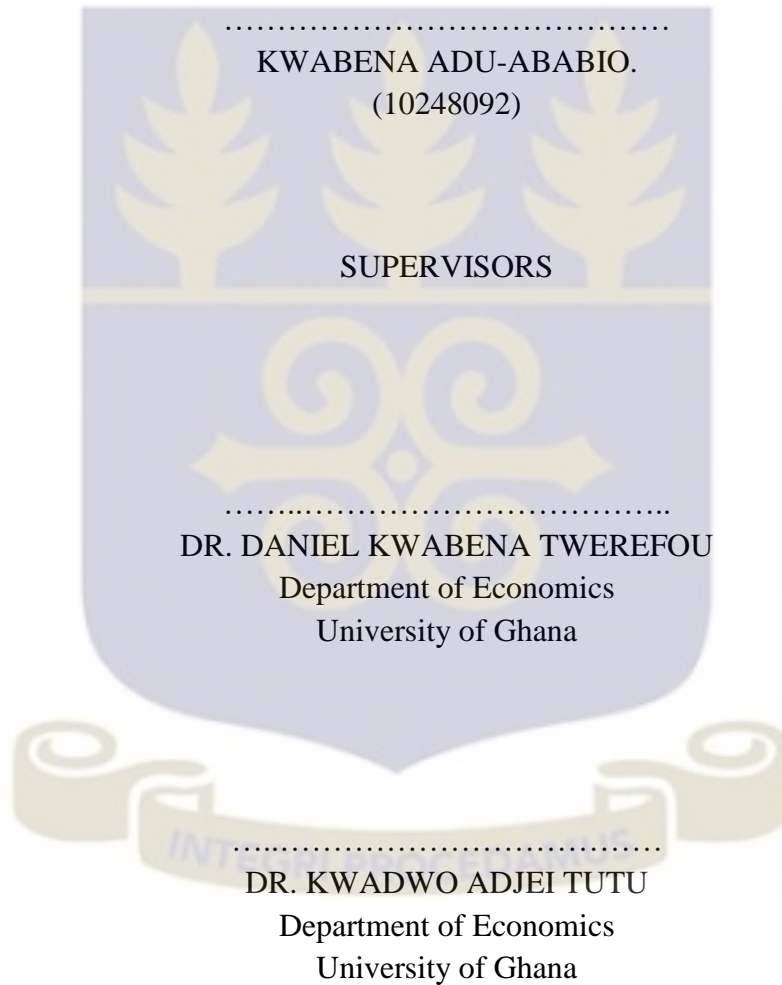
**THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA,
LEGON IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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DEGREE IN ECONOMICS**



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DECLARATION

I hereby declare that this thesis is the result of my own original research undertaken by me under the guidance of my supervisors; and that no part of it has been presented for another degree in this university or elsewhere.



ABSTRACT

Global demand for easy mobility is increasing and the environmental impact of transport has become an important concern in transportation network planning and decision-making. As a result suitable methods are required to assess fuel consumption and emissions reduction strategies that seek to improve energy efficiency and decarbonisation. This thesis looks at the contribution of toll plazas to transport CO₂ emissions as it is at these specific locations that bottlenecks and congestion usually occur. Using a mechanical formula and an integrated methodology, this study specifically analyses the influence of waiting time at Manual Toll Collection (MTC) stations on energy consumption and subsequent excess CO₂ emissions at the Accra/Tema-bound and the Oyibi/Frafraha bound toll plazas in the Greater Accra region of Ghana by considering five vehicle categories. Excess CO₂ emissions obtained is measured in tons (tCO₂) and valued in terms of Carbon Credits to obtain monetary estimates in Dollars. Case studies shows that energy consumption and CO₂ emissions are directly related to vehicle mass, engine efficiency, acceleration rate and the amount of waiting time. Articulator/Heavy Trucks records the highest per vehicle excess CO₂ emissions rate of 2.905 tCO₂ and 0.953 tCO₂ for the Frafraha and the Tema bound toll plazas respectively whiles the Saloon car category recorded the least per vehicle excess emissions of 0.162 tCO₂ and 0.054 tCO₂ for the Frafraha and the Tema toll plazas respectively. Costing results also show that Ghana can earn some amount of money in Carbon Credits for all vehicle categories considered. Per vehicle excess CO₂ emissions from Articulated/Heavy Trucks values highest - \$36.95 and \$12.12 at the Frafraha and the Tema toll plazas respectively whiles the Saloon car category excess CO₂ emissions values least - \$2.06 and \$0.69 at the Frafraha and the Tema toll plaza respectively. To achieve these monetary gains and

ensure transport sustainability, the study suggests that the application of new technologies like the Intelligent Transport Systems (ITS) to toll collection systems is an effective management strategy from an environmental point of view to tackle the issue of excess CO₂ emissions at toll plazas.



DEDICATION

This thesis is dedicated to my family Mr. and Mrs. Adu-Ababio, Kwame Agyei-Ababio, Papa Yaw Owusu-Ababio, Akua Agyeiwaa Appeagyei, Madame Leticia Kyei and Dr. (Mrs.) Joyce Asibey.



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Notwithstanding support received from supervisors and colleagues, the researcher takes the sole responsibility for any errors and omissions in this work.

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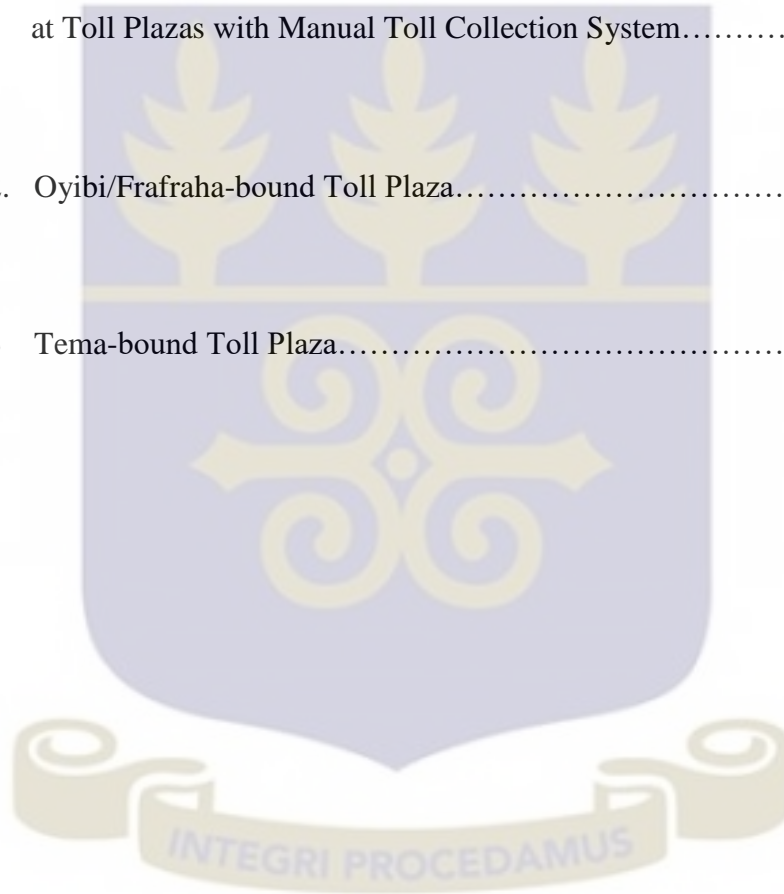
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LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
AAU	Assigned Amount Units
ADEME	Agence De l'Environnement et de l'Energie
AFOLU	Agriculture, Forestry and Other Land Use
ARTEMIS	Assessment and Reliability of Transport Emission Models and Inventory Systems
CC	Carbon Credit
CEF	Carbon Emission Factor
CER	Certified Emissions Reduction
CH ₄	Methane
CO ₂	Carbon Dioxide
CO ₂ eq	CO ₂ equivalent
COPPERT	Computer Program to Calculate Emissions from Road Transport
DVLA	Driver and Vehicle Licensing Authority
EC	European Commission
EEC	European Economic Community
EPA	Environmental Protection Agency
ETC	Electronic Toll Collection
ETS	European Trading Scheme
EU	European Union



FAO	Food and Agriculture Organization
GEPA	Ghana Environmental Protection Agency
Gg	Gigagrams
GHA	Ghana Highway Authority
GHG	Green House Gas
GIS	Geographic Information Systems
GoG	Government of Ghana
HFC	Hydro Fluorocarbons
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
ITF	International Transport Forum
ITS	Intelligent Transport System
kgCO ₂	Kilograms of CO ₂
km	Kilometer
kt	Kilotons
MDG	Millennium Development Goals
MOVES	Motor Vehicle Emissions Simulator
Mt	Megatons
MTC	Manual Toll Collection
N ₂ O	Nitrous Oxide
NDPC	National Development Planning Commission

NEAP	National Environmental Action Plan
NMVOC	Non-Methane Volatile Organic Compounds
NYSE	New York Stock Exchange
°C	Degrees Celsius
ORT	Open Road Toll
Pb	Lead
PM	Particulate Matter
ppm	Parts Per Million
Sulphur Dioxide	SO ₂
tCO ₂	Tons of CO ₂
TOT	Truck Only Toll
UNFCCC	United Nations Framework Convention on Climate Change
US\$	United States Dollar
USDOT	United States Department of Transport
USEPA	United States Environmental Protection Agency
WDI	World Development Indicators



CHAPTER ONE

INTRODUCTION

1.1 Background to research problem

Carbon is one reason for life on our planet. Starting from the discovery of fire, our civilization virtually depends on carbon for its energy and livelihood. It is often called '*Carbon Civilization*' for this reason. Our entire way of life is physically constructed around carbon fuels, and this '*carbon entanglement*' factor is the primary reason for the very slow and modest progress of carbon mitigation policies over the last couple of decades (Chapman, 2007). This is due to the fact that individuals and nations would prefer to pollute than abate. There are clear indications, however, that the high-carbon economic model is facing serious challenges. The continued heavy reliance on a narrow set of conventional fossil fuel-based technologies is a significant threat to energy security, stable economic growth and most importantly the environment.

Climate Change is basically the effects witnessed after the emission of greenhouse gases into the atmosphere. Carbon dioxide- a greenhouse gas is naturally present in the atmosphere as part of the Earth's carbon cycle (the natural circulation of carbon among the atmosphere, oceans, soil, plants and animals). Its presence in moderate amounts in the atmosphere as compared to its abundance poses no serious problem to the earth as a whole but since it is also emitted through human activities, its attendant problems like erratic

changes in temperature and precipitation due to excess CO₂ emissions cannot be overlooked. Carbon Dioxide emissions is at the heart of Global Warming that leads to Climate Change, considered to be one of the greatest environmental threats facing the World today due to its damaging effects on a nations natural resources as well as its stability. As Ban Ki-Moon succinctly puts it ‘Land degradation caused or exacerbated by Climate Change is not only a danger to livelihoods but also a threat to peace and stability’.

In the 19th century, awareness began to dawn that accumulated carbon dioxide in the Earth’s atmosphere could create a “greenhouse effect” and increase the temperature of the planet (Armstrong & Khan, 2004). A perceptible process in that direction had already begun – an effect from the industrial age and its production of carbon dioxide and other such "greenhouse gases." By the middle of the 20th century, it was becoming evident that human action had significantly increased the production of these gases, and the process of “global warming” was accelerating. Today, it is a fact that climate change is a reality and that there is the need to stop and reverse the process now or face a devastating cascade of natural disasters that will change life on earth as we perceive it. According to Hernández et al (2013), Climate change impacts have generated global concerns.

Currently, many different policies have been enacted in an attempt to reduce CO₂ emissions. The seventh Millennium Development Goals (MDG) is Climate Change related. It deals with ensuring Environmental Sustainability and this entails integrating the principles of sustainable development into country policies and programs as well as establishing initiatives to reverse loss of environmental resources and reducing biodiversity loss through

the reduction of carbon dioxide emissions in per capita terms. Several programs and policies have been carried out to ensure the attainment of this goal of Environmental Sustainability. The Government of Ghana (2012) for example deserves to be commended for its National Environment Policy launched in 2012. This is expected to inform all relevant stakeholders about their roles in managing the environment to sustain the society at large. By the policy, government has announced a new National Environmental Action Plan (NEAP). According to Section 3.1 of the policy, the new vision for environmental management is based on an integrated and holistic management system for the environment in Ghana. It is aimed at sustainable development now and in the future. The vision for the environmental policy, therefore, is: “To manage the environment and sustain the society at large”. The policy also seeks to unite Ghanaians in working towards a society where all residents of the country have access to sufficient and wholesome food, clean air and water, decent housing and other necessities of life. This will further enable them to live in a fulfilling spiritual, cultural and physical harmony with their natural surroundings.

Research shows that stakeholders in the international community have also constantly put in measures aimed at slowing down the processes exacerbating Climate Change. The United Nations Framework Convention on Climate Change (UNFCCC) (1992) is the major framework that guides Climate Change mitigation and adaptation. It stipulates that dangerous human interference with the climate system should be prevented. The Kyoto Protocol, negotiated in December 1997, is the first international treaty to limit emissions of greenhouse gases.

According to Reid and Goldemberg (1995) the role of developing countries like China and India in helping to solve the problem of climate change is increasingly an area of political arguments. With levels of greenhouse gas emissions projected to exceed those of developed countries by 2020, some developed countries are pleading specifically with these Asian developing countries to take stronger actions to meet the commitments they have made in the UNFCCC. This review of recent policy changes in developing countries although not directed to specific sectors, suggests that policy makers are already taking steps to reduce the rates of growth in carbon emissions and consequently increasing their efforts to tackle Climate Change.

According to the United States Environmental Protection Agency (USEPA), human activities are altering the carbon cycle—both by adding more CO₂ to the atmosphere and by influencing the ability of natural sinks, such as forests, to take out CO₂ from the atmosphere. While CO₂ emissions come from a variety of natural sources, human-related emissions are responsible for the increase that has occurred in the atmosphere since the industrial revolution. This is true due to the fact that medieval cities had no problems with air pollution because the environment in its own way recycles itself if pollution levels do not exceed its assimilative capacity. However, population growth, urbanization and the advent of the Industrial Revolution, which replaced manpower with power-driven machinery as a mode of production, has resulted in a steady increase in emissions levels well beyond the environmental assimilative capacity in modern urban centers, especially industrialized cities. The main human activity that emits CO₂ is the combustion of fossil fuels (coal, natural gas, and oil) for energy and transportation (Canadell, et al., 2007). According to Canadell

et al. (2007) fossil fuels contribute to 12% of CO₂ in the atmosphere. This is due to the fact that when petrol, diesel or certain alternative fuels are burnt for energy in an engine the main by-products are water and Carbon Dioxide (CO₂).

In many countries today CO₂ emissions is gradually increasing mainly as a result of increasing road transport (Wegener, 1996). This may however not be true for developing countries such as Ghana where apparently rampant bush fires which forms part of greenhouse gas emissions from Agriculture, Forestry and Other Land Use (AFOLU) are the major causes of CO₂ emission. Even though it is difficult to quantify the exact contribution of AFOLU emissions, its addition to other emissions sources from agriculture, industry and transport can cause severe climate change impacts. Stressing on AFOLU emissions, Bamfo (2010) the Head of the Climate Change Unit at The Forestry Commission during a workshop discussing the National REDD Readiness Efforts in Ghana, stated that increased wildfire threatens and extends the forest transition zone further. He stressed that, forest biodiversity and the ability of forests to provide soil protection, habitat for species and other ecosystem services are also severely affected by wildfires.

Although AFOLU emissions may be high in developing countries, Van Wee (2002) explicitly says that if in a poor or developing country incomes start to rise, car ownership and vehicle use rapidly increase. Ghana as a developing country is experiencing increases in vehicular volume. Gronau (1991) estimated vehicle count in Accra, Tema and Takoradi as 800, 500 and 350 vehicles per hour respectively in 1991. However, Mahama et al. (2013) in their survey showed that the maximum average traffic volume was 3138 vehicles per

hour and 3985 vehicles per hour for the morning and evening peak periods respectively in the Secondi-Takoradi metropolis. This in comparison to the year 1991 for the Takoradi metropolis is about nine fold the current situation. This points to the fact that vehicular volume has increased significantly in Ghana.

It is a fact that economic growth is linked to improved mobility of people. Thus, as a result of increased incomes there is the tendency for the demand for vehicles to increase and consequently CO₂ emissions. The increase in demand for transportation as discussed has warranted policy makers to find avenues to generate some revenue from this sort of demand to finance road construction. This has translated into an increase in the number of toll booths in most developing countries. Based on the fact that the increase in transport demand has also increased the wear and tear of road networks (Engel, Fischer, & Galetovic, 1997). As a developing country, Ghana has not been left out. In a span of ten years, toll plazas have more than doubled as well as toll fares also tripling in this same period since as a country of such status, financing road construction is key to national development (Opoku-Boahen, Adams, & Salifu, 2013).

Not to downplay the importance of innovative pathways of industrialization and revenue accumulation, sight should not be lost of the fact that toll plazas are major hubs for transport emissions as a result of prolonged idleness of vehicles mainly due to the inefficient ways the fares are collected. In Ghana as well as other less industrialized countries, toll plazas are predominantly manually operated which increases the service time spent by each vehicle.

1.2 Statement of Research Problem

It is generally believed that the private automobile has been the primary cause of the expansion of cities over wider areas (Wegener, 1996). Global demand for mobility is increasing and the environmental impact of transport has become an important issue considering its effects on Greenhouse gas emissions which leads to Climate Change. As Van Wee (2002) succinctly describes it, urban traffic makes people move and is a necessity for the urban economy. However, it has negative local and regional environmental effects by contributing to large-scale environmental problems such as excess CO₂ emissions and acidification. Transportation has become a necessary evil for development in all economies. However, sight should not be lost of the fact that this increase in global demand for transportation, especially road transport has negative environmental effects due to the vehicular emissions which are the gases and particles that are released into the air by these motor vehicles. According to the United States Environmental Protection Agency (U.S.EPA), an individual driving a car alone not considering vehicle sharing and public transportation is the single most polluting activity that most individuals carry out.

Emissions from an individual car are generally low, compared to the smokestack, which many associate with air pollution, but as motor vehicles multiply in numbers and emissions from millions of vehicles on the road add up, the automobile being driven alone by single persons becomes the single greatest air polluter (Engelstaedter, Tegen, & Washington, 2006). In particular the high energy consumption of transport in low-density cities has become an issue of growing concern as explained by Wegener (1996). A significant share of world CO₂ emissions is produced by the transport sector, accounting for 23% of overall

CO₂ emissions from fuel combustion and 15% of overall GHG emissions at a global level according to country data of Greenhouse Gas Emissions recorded in 2007 (ADEME, 2007). On a wheel-to-wheel basis, the International Energy Agency in 2011 estimated that transport accounts for nearly 27% of total CO₂ emissions from fossil fuel combustion and concluded that transport is the second largest CO₂-emitting sector after electricity production. All this points to the fact that the share of CO₂ emissions from the transport sector is increasing.

In Ghana road transport is very important to the Ghanaian economy. According to the National Development Planning Commission (NDPC) the main modes of transport in Ghana are road, marine, inland water, air and rail transport. Of these modes, road transport is the dominant mode conveying over 97% and 94 % of freight and passengers respectively. Ghana's road network was about 38,000 kilometers in the year 2000 and increased to about 67,448 kilometers by the end of 2009 (NDPC, 2014). Passenger traffic has been growing at 8% per annum in the last five years. A survey by the Ghana Environmental Protection Agency (GEPA) reveals that transportation is estimated to contribute about 43% of CO₂ emissions and therefore focusing on energy efficient transport system and management is quite imperative (GEPA, 2014).

Road transportation also produce the bulk of transport emissions worldwide, some 75% as stated by the International Energy Agency (IEA, 2004). Research on transport GHG emissions by the IEA focusing on Spain as expressed by Mendiluce and Schipper (2011) showed that increasing road transport is the main reason for the rise in GHG emissions.

According to their report, from 1990 to 2009, road traffic volume in Spain increased by 94%. Consequently, GHG emissions from road transportation rose by 65% in that period as explained by the Spanish Ministry of Development in its Statistical yearbook (Hernandez, Monzon, & Sobrino, 2013). Moreover, vehicular idling time contributed to over 70% of CO₂ emissions generated by transportation, the report added. All the above revelations point to the fact that the amounts of CO₂ emanating from local and global road transportation in the atmosphere is increasing regardless of sensitization by international organizations and pressure groups.

Following this some countries mainly in Europe (Norway, Sweden, Spain etc.) and the United States in conjunction with their various Environmental Protection Agencies (EPA's) are in the process of ensuring sustainable transportation. Jeon and Amekudzi (2005) succinctly put it that although there is no standard definition for sustainable transportation, several adopted definitions reflect that a sustainable transportation system should be effective and efficient in providing safe and equitable access to basic economic and social services, promote economic development and support environmental integrity. With especially the latter in mind these above mentioned EPA's have theorized that idling time by vehicles irrespective of size or cubic capacity contributes to a significant share of CO₂ emissions generated by transportation (USEPA, 2008). The United States Environmental Protection Agency defines vehicular idle time as a stoppage for relatively short period as observed in drive-thru lanes, at toll gates, at stop lights and in very heavily congested traffic but excludes *hoteling* situations where the engine may be idling for periods of hours at a

time with many accessories being operated from engine power. Armed with this information they have taken steps to reduce idling time by vehicles through efficient transportation management so as to tackle the problem of CO₂ emissions from road transportation.

One area where most attention is being focused are toll plazas since these are points on any road network where idling due to congestion usually occurs. These are being done through the introduction of management strategies aimed at reducing the energy consumption of toll road networks, removing bottlenecks and congestion points. This is done by incorporating Intelligent Transport Systems (ITS) which contributes to improving driving behaviour by reducing acceleration and deceleration, idling, traffic congestion, etc. According to these countries mentioned above with the support of their EPA's, Toll plazas are key to any plan to reduce the GHG emissions of toll road operations.

In Ghana, efforts at reducing CO₂ emissions emanating from transportation are now being addressed partly due to pressures from international organizations. This makes it necessary to ascertain whether efficient tolling systems are significant measures for CO₂ emissions reductions and if so whether the reduction could trigger the demand for carbon credits which could supplement the road fund of the country? Moreover the issue of toll plaza management regarding service periods which may contribute significantly to CO₂ emissions at Ghanaian Toll plazas has not been thoroughly researched. Service time plays a major role in the efficient management of toll plazas and can help exactly ascertain the idle time of vehicles at specific toll plazas. If service time is greatly improved it is assumed that

vehicular idle time will reduce and the country could also use this information to demand carbon credits.

Although a number of studies have been done on transportation emissions in general, the contribution of toll plazas to these emission has eluded most researchers due to the manner in which the previous studies were conducted. Most studies in this field for example Kylander et al (2003) start by looking at total transportation emissions in general and do not consider the fact that different stages in vehicular movement entail different emission levels. A study in Ghana by Kwakye and Fouracre (1998) also contend that at present, vehicular emissions are not a serious problem, but in the longer term Government will have to establish emission standards and a means of enforcing them. These are some of the reasons why this particular study aims at examining the extent to which Toll Plazas contribute to transport emissions.

There has also not been extensive studies on Ghanaian vehicle categories and their individual level of emissions or simply studies that help gain knowledge concerning which vehicle category in the country emits the most of greenhouse gases. This is important due to the fact that all vehicle categories have diverse emission levels and it will be imperative for a developing country like Ghana to know the common vehicle category and its emission level so as to know how to control emissions. Excess emissions control can be done by asking pertinent questions to ascertain the contributions of various vehicular categories to emissions as well as also reducing them through crisp and direct policy recommendations. This is one major reason why research should target and critically tackle these issues.

There are many ways and efforts underway in some industrialized countries to reduce carbon emissions and promote activities which help to store and remove carbon. This has made carbon a valuable economic commodity through Carbon finance, which is another avenue for revenue generation. To find a common unit for this commodity all GHG's are converted to CO₂ equivalents. These are traded on Carbon markets which work similarly to financial markets. In these markets the currency used on these markets is Carbon Credits as stated by the FAO (2011). The carbon trade in simple terms is an agreement made between a buyer and a seller of carbon credits. Those who reduce emissions or sequester carbon, receive payments and those who have to decrease emissions can buy carbon credits to offset their emissions. "Carbon offsetting" means to compensate emissions which cannot be avoided by paying someone else to save/sequester GHGs. During 2009 the prices ranged from €1.90 to €13 per ton of CO₂. Over the last few years several financial instruments mechanisms and markets have emerged (FAO, 2011).

Ghana as a developing country should also make efforts to tap into the revenue stream as regards to Carbon Finance so as to generate 'Green Revenue' and also fulfil some of the environmental sustainability pacts the country has ratified. One may even inquire about the necessity of a Manual Toll Plaza now that there exist as a result of technology better and efficient ways of collecting revenue instead of creating structural bottlenecks as well as congestion arising from these MTC systems. This is also another reason why research should target revenue options such as Carbon Financing.

1.3 Research Questions

From all these generalizations this study would want to ask the following questions:

1. What is the volume of excess CO₂ emissions resulting from vehicular idle time at toll plazas?
2. What vehicle category in the country contributes most to excess CO₂ emissions at toll plazas?
3. What is the average waiting time at big and small Ghanaian Toll plazas?
4. What is the value of excess emissions resulting from vehicular idle time at Toll Plazas?
5. How much will the country earn in Carbon Credits by introducing efficient tolling systems?
6. What research tells policy makers on implementing efficient Tolling systems on our roads?

1.4 Objectives of the study

This study generally aims at valuing the level of CO₂ emissions resulting from vehicular idle time at the Tema (Big Plaza) and Oyibi/Frafraha (Small Plaza) toll plazas.

The study will focus on achieving the following specific objectives:

1. To estimate the volume of excess CO₂ emissions resulting from vehicular idle time at big and small toll booths.

2. To ascertain the vehicle category in Ghana that contribute most to excess CO₂ emissions at these toll booths.
3. To identify the average vehicular waiting time at big and small Ghanaian Toll Plazas.
4. To estimate the value of excess CO₂ emissions resulting from vehicular idle time at these toll booths
5. To ascertain how much Ghana will earn in carbon Credits if waiting time is reduced?
6. To advice policy makers on the need to change to more efficient tolling systems on our roads.

1.5 Justification of the study

This study is important for a number of reasons. First of all the findings will help Ghana find other means for income generation. The income from toll booths goes to the road fund which in turn supplements the budget of the country in financing road construction. In this study if CO₂ emissions are found to be significant, proceeds from carbon credits could be used to supplement the road fund which can equally help improve revenue generation.

Moreover since this study is a pilot for two toll plazas and provides a methodology to calculate excess CO₂ emissions, the study could be upscaled for the whole Ghana. In that case the relevance is that the country will know exactly the quantum of emissions present at specific toll plazas in the country. This information will help the country know if toll

plazas are being efficient in their management or if more measures should be put in place to reduce idle time.

Knowledge of the average waiting time at every toll booth is important since policy makers will be able to make accurate judgments on how to implement measure to reduce excess emission. Since this study seeks to investigate the average waiting times at the toll plazas in question its findings will make it easier in implementing mitigation policies linked to reducing transport CO₂ emissions specifically at Toll plazas. Average waiting time is directly linked to emissions, hence its knowledge could help policymakers know the exact excess time to reduce which will in turn reduce excess emissions.

The millennium development goals on environmental sustainability are indirectly targeted at reducing carbon dioxide- a Greenhouse gas and this will require the interplay of various factors which will be analyzed thoroughly in the study since the study will basically provide information on how to undertake efficient tolling. In this way policies could be geared towards the substitution of inefficient toll collection with other efficient tolling systems and if the study realises bigger gains from Carbon Credits as compared to revenue from toll fares.

Finally, this study would be a valuable add up to the body of literature on how toll plazas contribute to the increase in Greenhouse Gases specifically CO₂ and how much revenue in terms of Carbon Credits can be generated from these emission if idle time is avoided.

1.6 Limitations of the Study

In this kind of survey, measurement error could potentially be a serious problem. Therefore, the study in the following paragraphs tries to explain some factors that may result in the diverse kinds of measurement error and also partially limit accuracy while the study was being conducted.

For the purposes of this study data on vehicular volume at two toll plazas was collected to estimate their individual emissions. This was done with the help of records of the Ghana Highway Authority (GHA) when each vehicle went through the toll plaza. The limitation to this is that not all vehicles in Ghana passing through a toll booth is mandated to pay the toll fare. Vehicles with government registered number plates, military vehicles, ambulance and service vehicles in general are exempted from the payment of toll and are hence not recorded by the GHA. The aggregation of these vehicles are left out when calculating emissions from these toll plazas.

In addition, the study is limited as regards to some vehicle measurement issues due to lack of accurate and reliable data. Most motor vehicle agencies did not have all the information needed concerning some specific vehicle measurements like frontal area, weight and engine efficiency for some common vehicles¹ found in Ghana. Due to this, the study adopted vehicle measurements from European and American motor vehicle dealers.

¹ Benz “207” and the “Bone Shaker”

For the purpose of studying the relationship between operations at toll plazas and the reduction in carbon emissions, it should be noted that emissions in the study have been limited to just Carbon Dioxide (CO₂). The theoretical model converts any other gas from vehicles into its CO₂ equivalent. Although Nitrogen, Water vapor and CO₂ form the main components of fuel combustion gas, the interest of the study is limited to CO₂ and CO₂ equivalent gases since it is considered as a greenhouse gas among the components.

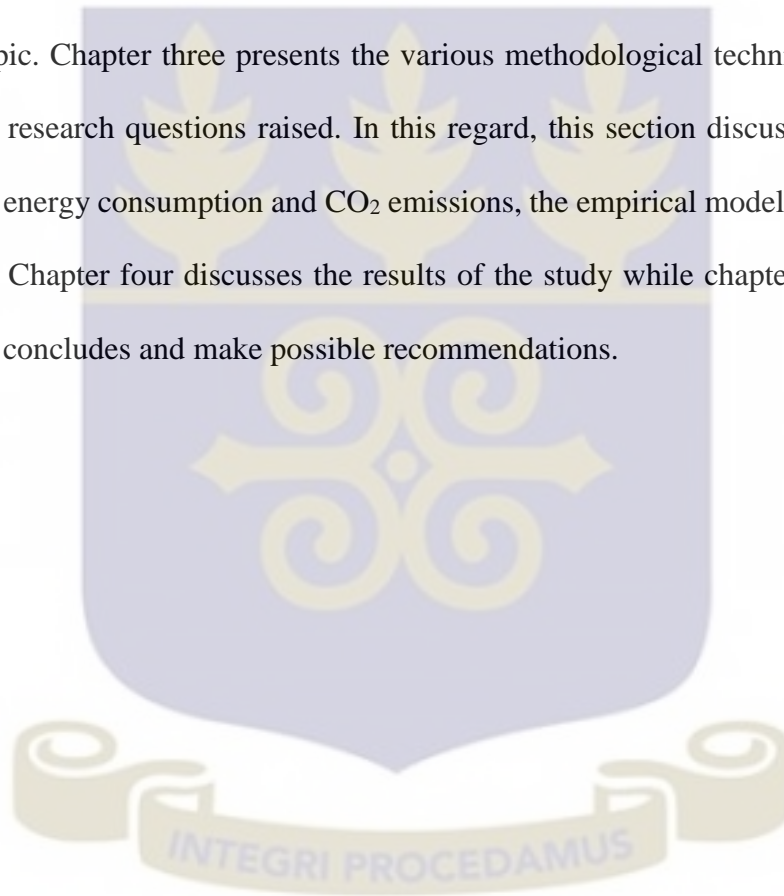
Also the study is limited concerning the calculation of peak and non-peak waiting time. It is evident that peak and non-peak periods are observed at all toll plazas during the week. The study however ignores this fact since data obtained from the GHA on vehicular traffic at toll stations was not aggregated into peak and non-peak traffic volume. The study uses average waiting time to calculate excess CO₂ emissions. This limits the study in a way that, during field observations the study realized that some periods record significant vehicular volume and waiting time than others which can also translate to significant emissions. However, since this is not an everyday occurrence the study generally considers the average waiting time for excess CO₂ calculations.

One assumption made is that Saloon cars are the only vehicle category that uses gasoline/petrol engines. Any other vehicle category considered in the study is assumed to have a diesel engine. This may not always be the case. The limitation here is that in the survey, excess emissions from Saloon cars with diesel engines as well other vehicle categories with gasoline/petrol engines are omitted. This was done because the researcher could not obtain information on the share of Saloon cars that use diesel engines. However information from

the Driver Vehicle and Licensing Authority (DVLA) show that about 93% of Saloon cars use petrol engines.

1.7 Organization of the Study

Chapter one introduces the study by explaining the research question, the objectives and the justification. Chapter two reviews related theoretical and empirical literature on the related topic. Chapter three presents the various methodological techniques employed to tackle the research questions raised. In this regard, this section discusses the theoretical model for energy consumption and CO₂ emissions, the empirical model and the method of valuation. Chapter four discusses the results of the study while chapter five summarizes the study, concludes and make possible recommendations.



CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter is a review of the theoretical and empirical research on the cost estimation of transportation emissions at toll booths within countries and between countries. The study begins by providing a theoretical review of general issues in transportation research as well as an overview of Climate Change caused by Greenhouse Gases produced by the transport sector including existing trends in Greenhouse Gas emissions in Ghana. Further we discuss the literature focusing mainly on passenger car use, road freight and aviation which are the principal contributors to greenhouse gas emissions from the transport sector as well as some models or methodologies that have been used to quantify the emission levels in the sector. The review will also touch on approaches to reduce emissions from the transport sector.

2.2 Theoretical Review

There are not many studies on transportation emissions which look particularly at CO₂ emissions at toll plazas however there are models that can estimate emissions from these booths in environmental and geographical research fields (Soylu, 2007). Most studies have looked at transportation emissions as a whole and its contribution to total greenhouse gases in the atmosphere (Fuglestvedt & al, 2007).

Since the Kyoto Protocol, transport policies have been oriented toward achieving more sustainable mobility patterns due to the fact that parties are requested to report annual emissions of some important pollutants. In general, these involve a set of coordinated actions aimed at the improvement of energy efficiency and the reduction of environmental impacts which focus on interurban and urban scales. As a result of this, most countries have tried to ascertain their levels of transport emissions in order to shape policies that will achieve the UNFCCC goals.

The genesis of transport sustainability started when Wackernagel and Rees (1996) drawing fundamental ideas from Hardin (1968) proposed the concept of ecological footprint or as they put it “measuring human load” as a standard methodology for evaluating the direct environmental impacts of a human being during his or her lifetime. In their study they inverted the standard carrying capacity ratio and extended the concept of load, and then developed a tool for assessing human carrying capacity. Rather than asking what population a particular region can support sustainably, they ask a critical question: How large an area of productive land is needed to sustain a defined population indefinitely, wherever on Earth that land is located?

From this initial study, researchers like Daily (1997) as well as Cascio and Glenn (1992) started to develop theories and models that analyzed human-environment interaction and its contributions to climate change. These studies looked at sectors where human activities in one way or the other contributed to a change in the structure of the environment. This change in environmental structure as they debated could be as a result of greenhouse gas

emissions, over extraction of natural renewable and non-renewable resources and pollution of all kinds. Studies of this nature postulated that human and natural systems are integrated systems in which people interact with natural components and were mainly undertaken to deepen understanding of complex interactions of this nature.

This dawn of the human-environmental interaction era of research gave way to other studies that started to concentrate solely on human interaction in specific sectors like forestry (McPherson, 1998), mining (Strode, Lyatt, & Noelle, 2009), transport (Soylu, 2007) etc. and has given so much information through literature contribution on how far human activities go to influence the natural environment. The natural environment in these research contexts has not been viewed in totality but in sections so as to ascertain various levels of impacts as a result of human interaction (Stern, 2000). A breakdown into sectorial contributions has also paved way for research into policy analysis on how these human interactions can be managed so as to create perfect synchronization between the environment and humans (Dhakal, 2009; Parry & Robertson, 1999). However, since this study seeks to concentrate on CO₂ emissions at toll plazas which is a sub sector of the transport sector, it is appropriate for this study to review literature on transportation emissions as a whole.

2.3 Literature on Transportation Emissions

According to Stead (1999), transport produces a number of emissions and a range of environmental impacts. Emissions include global pollutants (such as carbon dioxide which contributes to global warming), national or regional pollutants (nitrogen oxides which pro-

duces acidification or ‘acid rain’ for example) and local pollutants such as Particulate Matter (PM) which contribute to respiratory problems including the increased susceptibility to asthma. Transport's contribution to environmental pollution in urban areas is particularly large, where transport is by far the most significant contributor of most emissions.

According to the USEPA (2014) GHGs are also produced from multiple sectors of the economy, including industrial sources, electric power plants, residences, agriculture and not ignoring the different transportation modes. Research by Patz and Kovats (2002) as well as Turaga et al (2011) has shown that unlike the well-known air pollutants, the main GHG emissions from the transport sector are global in nature. They do not create toxic “hot spots,” but rather are well-mixed in the atmosphere in the long-run. Thus, the impacts of one ton of carbon dioxide emissions are the same no matter where it is emitted, or by what sector of the economy. In that sense, the relative effect of transportation emissions on the global climate can be approximated by their relative magnitude compared to all other global emissions (Transportation Research Board, 2008). The primary GHGs produced by the transportation sector are carbon dioxide, methane, nitrous oxide and hydro fluorocarbons (HFC). Carbon dioxide, a product of fossil fuel combustion, accounts for 12 percent of transportation GHG emissions in Ghana and has been on the rise for the past decade (GEPA, 2014).

In the debate on the impacts of how we use our natural surroundings in relation to the mode of transport we might choose, Van Wee (2002) in his research reveals that two questions are of particular importance in terms of the impact of transportation on the environment:

(1) does environmental use affect travel behaviour and (2) if environmental use affects travel behaviour, should land-use policies be partly based on (expected or assumed) transport impacts? According to Van Wee (2002) there is enough evidence to conclude that land use can influence travel behaviour and modes of transportation which in the long run affects the type of GHG emissions we may experience in the various sectors of the economy. However, this does not mean that policy-makers should choose land-use alternatives with the lowest level of car use even though the emphasis on the latter has some negative environmental externalities. Rather possible future land-use and transport plans should be evaluated according to a broad range of factors. It is evident from this research that transportation plays a role in the type of emissions observed.

In recent decades, a variety of definitions and procedures for the calculation of transport carbon footprints have been employed as described by Pandey et al (2011). Chi and Stone (2005) have pointed out that “the principal advantage of the CO₂ footprint measure in the environmental impact analyses is that it adopts a physical variable as a common metric such as Car volume (Transport sector), Fertilizer use (Agricultural sector) and Number of Industries (Industrial sector) in comparing alternative options or models for calculating the exact amount of emissions. Moreover with regards to emissions from the transport sector of which this study focuses , carbon footprint data from transport helps in the management and evaluation of emissions mitigation measures such as enforcing the use of fuel efficient vehicles, an achievement which can be included as an indicator of sustainable development (Pandey et al. 2011).

Stead (1999) in his paper explores the relationship between transport emissions and various measures of passenger travel patterns in Britain. The study examines the usefulness of various measures of travel patterns as environmental indicators of vehicle emissions and energy use. The argument put forward in the study is that if certain measures of travel patterns were reasonable proxies for vehicle emissions and energy use, and could be collected relatively easily without complex measurement or calculation, they would be useful for environmental monitoring and the assessment and development of transport policy. The method developed in this paper identifies how a range of vehicle operating conditions can be incorporated into calculations of vehicle emissions and energy consumption using data from the National Travel Surveys.

2.4 Greenhouse Effect and Climate Change

According to Hester and Harrison (2002), it is an established fact that some 175 years ago, the presence of greenhouses such as Carbon Dioxide that absorb in the infrared part of the spectrum leads to a warming of the earth surface through the greenhouse effect. The first quantitative calculation on the effect on the atmosphere of increased carbon dioxide concentrations was made by Swedish scientist Svante Arrhenius in 1896.

Greenhouse effect is the capacity of greenhouse gases in the atmosphere to trap heat emitted from the surface of the earth (Pidwimy, 2006). The greenhouse effect acts as a thermal blanket regulating the temperature of the earth's surface, without which, the average earth's temperature would be 3°C cooler (Pidwimy, 2006). The anthropogenic modification of this natural process resulting in increased levels of heat-trapping gases (greenhouse gases) in

the atmosphere have presented the current rapid warming of the earth, altering the global weather patterns, particularly rise in temperature of the earth's atmosphere, increased precipitation, sea levels and stormy activities, called climate change. The greenhouse effect causes the atmosphere to trap more heat energy at the earth's surface and within the atmosphere by absorbing and re-emitting long wave energy or radiation. Of the long wave energy emitted back to space, 90 % is intercepted.

The gases involved in the human-induced enhancement of the greenhouse effect include carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and chlorofluorocarbons (CF_xCl_x) and tropospheric ozone (O₃). Of these gases, the single most important gas is CO₂, which accounts for about 55 % of the change in the intensity of the earth's greenhouse effect. The contributions of the other gases are 25 % for CF_xCl_x, 15 % for CH₄ and 5 % for N₂O. Ozone's contribution to the enhancement of greenhouse effect is still yet to be quantified (Pidwimy, 2006).

2.5 CO₂ Emissions in Ghana

The most abundant greenhouse gas produced and emitted in Ghana is CO₂ (GEPA, 2011). From 1989 to 2007, the emission of CO₂ measured in kilotons (kt) in Ghana has generally shown an upward trend with the exception of the years 2000, 2005 and 2007. With 3344kt emission in 1989, CO₂ emissions increased till 1999 where it dropped from 6549kt to 6288kt in 2000, after which it increased till 2004 (to 7275kt) and dropped to 6956kt in 2005. It increased to 9578kt in the year 2007 (WDI, 2012). The emission of CO₂ in Ghana is about 0.05% of the total global emissions and it places 108th in the world. It represents

a total per capita emission of nearly 1Mega ton of CO₂ per person as of 2006 (GEPA, 2011). The Energy sector contributes the largest to emissions in the country accounting for about 41% of the nation's emissions between the years 1990 and 2006. This is followed by the agricultural sector contributing about 38% of the emissions and the waste industry emitting 8% (GEPA, 2011). Report by the IEA (2012) indicates Ghana emitted 1.7, 1.5 and 4.8 million tons of CO₂ from electricity and heat production, manufacturing industries and consumption and transport respectively in 2009. CO₂ per population was 0.38 tons in 2009 and this represents 109.1% increase from 1990.

In 2000, the total GHG emission in Ghana was estimated to be about 12.2MtCO₂e. These gases included CO₂, methane, nitrous oxide and per fluorocarbons. It represents a 173% increase above the figure for 1990 of -16.8MtCO₂eq and 96% below of that of 2006 emissions accounting for 23.9MtCO₂eq. There has been a 242.3% increase between 1990 and 2006. CO₂ emissions accounted for -16.3Mt in 1990, 13.3Mt in 2000 and 22.9Mt in 2006 of the total GHGs emitted. CO₂ forms the largest portion of GHGs emitted in Ghana. It accounted for 44% of GHGs emitted in 2000. On the average, it accounted for 81.3% of the total GHGs between 1990 and 2006. In Ghana it is mainly emitted from energy, land and forestry usage and industrial processes. In 2000 the energy sector, land and forestry and industrial processes accounted for 55%, 37% and 14% of CO₂ emissions respectively. Projections of GHGs indicate that their emissions could increase from 7,278Gg to 118,405Gg between 1994 and 2020, rise to 234,135Gg by 2030 and 519,826Gg by 2050. The EPA indicates that though Ghana's emissions of CO₂ relative to other countries might be low, it

has very high potential in the short to medium term to increase as the economy continues to expand highly especially in the agriculture, forestry, oil and gas sectors.

2.6 Climate Change in Ghana

There is strong evidence supporting the fact that changes in the climate of the earth are associated with the release of GHGs (Ghana, EPA, 2011). Over the past 30 years, temperature in Ghana has risen by 1°C and projections show that there is a high possibility of temperature increasing between 1.7°C and 2.04°C by 2030. In the Northern Savannah, temperature is likely to rise to as high as 41°C. A 20 year observed data by the EPA indicates that temperature is rising in all ecological zones and rainfalls have been reducing generally. There is a high probability of sea levels rising by an average of 0.3cm from 3.6cm by 2010 to 34.5cm in 2080.

According to Adger et al (2003) nearly all human societies and activities are sensitive to climate in one way or the other. This is because to a large extent where people live and how they generate a livelihood and wealth is influenced by the ambient climate. From this line of reasoning climate change could worsened the poverty situation in the country especially in the north where temperatures are already high. Livelihoods could be affected in the region leading to a lower agricultural productivity and periodic flooding in the country. It could also increase the pace of migration of the youth from the north to the south as a result of the low agricultural productivity that comes with climate change.

The EPA (2011) also indicates that climate change has a potential for increasing pressure on water and reducing the potential for hydropower, reducing access to water, increasing the incidence of diseases, food insecurity, causing loss of biodiversity, soil fertility and land degradation. All these are as a result of the increasing pace of CO₂ emissions in the country and its effects on the environment (EPA, 2011).

2.7 Transport and Climate Change

Transport accounts for 23% of global and 30% of OECD CO₂ emissions and is one of the few industrial sectors where emissions are still growing as stated by the International Transport Forum (2010). Car use, road freight and aviation are the principal contributors to greenhouse gas emissions from the transport sector (Chapman, 2007).

According to the International Transport Forum (2010) man-made emissions of greenhouse gases – principally carbon dioxide (CO₂) – have grown by 45% from 1990 to 2007, led by emissions from the road sector in terms of volume and by shipping and aviation in terms of highest growth rates. Atmospheric CO₂ concentrations have increased from a pre-industrial value of 250-280 parts per million (ppm) to between 350-385 ppm in 2008 and are growing at an accelerated pace. The current level of CO₂ concentration in the atmosphere significantly exceeds the natural range for the past 650 000 years which was between 180-300 ppm) as stated by the International Transport Forum (ITF, 2010). The Intergovernmental Panel on Climate Change (IPCC) in its fourth Assessment Report finds that the accelerating warming trend observed since the mid-20th century is very likely due to the increase in man-made greenhouse gas concentrations coming from the transport sector.

Under “business-as-usual”, including many planned efficiency improvements, global CO₂ emissions from transport are expected to continue to grow by approximately 40% from 2007 to 2030 – though this is lower than pre-crisis estimates. However, the economic crisis of 2008 has led to a prolonged downturn in economic activity and has led to the sharpest drop in emissions in the past 40 years (estimates range from 3% to 10%). Depending on the strength of the economic recovery, may translate into approximately 5% to 8% decrease in 2020 emissions from their pre-crisis projected levels.

2.8 Empirical Review

A literature search in October 2014 for the term “Toll Plaza emissions” (i.e. where these three words stand next to each other in this order) in all scientific journals and all search fields covered by Scopus², Science Direct, Emerald Insight as well as JSTOR for the years 1960 to 2014 yielded 21 hits but only 12 hits in terms of relevance to the subject matter.

Most articles in this field have examined the potential effect of the introduction of Intelligent Transport System (ITS) technologies on the environmental impacts of toll plazas and how best its introduction can reduce GHG emissions. Most of the studies have also focused on the reduction of air pollution by the implementation of Electronic Toll Collection (ETC) in toll plazas (Hernandez, Monzon, & Sobrino, 2013; Saka, Agboh, Ndiritu, & Glassco, 2001).

²Scopus (www.scopus.com) is currently the largest abstract and citation database of peer-reviewed research literature. Scopus is updated daily and covers over 30 million abstracts of 15,000 peer-reviewed journals from more than 4,000 publishers ensuring broad interdisciplinary coverage.

Pérez-Martinez et al (2011) within their framework, developed a methodology for managing motorways based on a target of maximum energy efficiency. It included technological and demand-driven policies, which are applied to two case studies. Various conclusions emerged from this study. The results clearly indicated that to achieve the best carbon footprint savings it is necessary to design sustainable strategies to manage each motorway section. That basically means to use trunk roads, motorways and also parallel roads exactly in line with their carrying capacity not exceeding the total traffic flows of cars and heavy duty vehicles. Another important finding relevant to this particular study is that substantial GHG reduction emissions could be achieved in the toll plazas with the application of Electronic Toll Collection (ETC) and Open Road Tolling (ORT) schemes.

Saka et al (2001) in their study firstly used a microscopic simulation model to simulate the existing traffic situations at the Fort McHenry Tunnel toll facility, the largest toll plaza in the state of Maryland, USA and used observed field data to validate the simulation results. Second, they captured the benefits inherent in the use of Electronic Toll Collection (ETC) technology by undertaking a comparative analysis of pre-ETC and post-ETC scenarios. Results from the latter simulation scenario was called M-Tag. The primary measures of effectiveness realised after the study were (1) increased throughput and hence reduced waiting time at the toll plazas; and (2) reduced mobile emissions [hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxide (NO_x)]. It was determined from the simulation and mobile emissions models that the current deployment level of M-Tag, the ETC technology used improves the average travel speed by more than 125% and has decreased the

mobile emissions rate by up to 41% at the Fort McHenry Tunnel toll plaza. It was concluded that the use of ETC is an effective tool for mitigating mobile emissions at toll plazas.

Tseng et al (2013) in their research of transport emissions linked to Toll plazas argue that the implementation of Electronic Toll Collection (ETC) on highways aims to reduce toll transaction time and thereby increase service capacity. In their paper, they considered the separation of manual toll collection (MTC) and ETC lanes, and develop a method to estimate the carbon dioxide (CO₂) emissions, transaction time, and the associated external cost incurred by vehicular traffic at four toll plazas on a northern-central highway in Taiwan. Three vehicle types were considered: passenger cars, buses and trucks. Results showed that the CO₂ emissions were reduced by 12.4% as the number of ETC lanes for all four toll plazas increased. The reduction of external costs fell by 60.1% in terms of value of transaction time, which will arguably lead highway authorities to actively promote ETC.

Coelho et al. (2005) developed a methodology to quantify the traffic and emissions impacts of toll facilities on urban corridors. This was the pioneering methodology to actually segment a vehicles trajectory into various stages that yield different levels of emissions. The approach was based on experimental measurements and attempts to explain the relationships between various operational variables (stops, queue length, and emissions). One of the results was that the use of ETC systems could reduce CO₂ emissions by 70% with respect to conventional tolls when there is a queue of 20 vehicles. For a queue of only one vehicle, the savings is 11%.

Bartin et al. (2007) presented a microscopic simulation-based estimation of the spatio-temporal change in air pollution levels as a result of ETC deployment on the New Jersey Turnpike. Results showed that in the short term, ETC deployment would reduce overall network air pollution; but in the long term, its benefits would not be enough to compensate for the increase in main-line air pollution due to annual traffic growth.

Most recent studies focus on Open Road Toll (ORT) technologies and their air pollution impacts. ORT is a kind of toll collection system where service time is zero. This is due to the fact that, technological advancements have made it possible for Toll plazas to capture details of vehicles as they pass through the toll booth since aggregated fares are paid monthly, quarterly or yearly by drivers. The toll booth will allow only vehicles that have paid to go through by going through a database of vehicle registration numbers. All which can take a maximum of a second. Klodzinki et al. (2012) in their study analyzed the benefits of ORT at a real toll plaza in Orlando by collecting data prior to, during, and after the building phase. The analysis showed an average delay reduction of 49.8% for manual cash customers and 55.3% for automatic coin machine customers; the speed in the ETC express lanes increased by 57%. Staying with ORT, Lin and Yu (2009) also developed a methodology based on air dispersion models to assess an Open Road Toll's air quality. They then concluded that implementation of ORT can reduce the CO₂ levels by up to 58% according to their findings.

Other studies have focused on truck-only toll (TOT) lanes as a means of improving the flow of trucks, reducing freeway congestion and controlling climate change impacts. An

application of TOT lanes in the Atlanta area suggests that TOT lanes as a freeway management strategy could have significant benefits with respect to CO₂ emissions, offering a 60% reduction (Chu & Meyer, 2009). The scenarios created by the United States Department of Transport (USDOT) in this regard led to the conclusion that separate lanes should be created for vehicles that fall in the “truck” category. Since it is believed that such vehicles emit high amounts of GHG’s, their idling status should be managed differently and efficiently (USDOT, 2010)

Liu et al. (2011) proposed an operational model for toll stations integrated with a modal emissions model. Scenarios were defined to analyze the impact of ETC lanes with respect to manual booths lanes. In ETC lanes, the main benefits are the reduction of delays by 55%, of fuel consumption by 48%, and of emissions by 51.78% with respect to manual payment lanes (Liu, Liao, Yu, & Cai, 2011).

Different models are used worldwide for the estimation of road traffic emissions and energy consumption. Some of them are widely used and a typical example is COPERT – Computer Program to calculate Emissions from Road Transport (Gkatzoflias et al. (2007) which is the most commonly used computer program to calculate emissions from road transport within the European Union. The program estimates quantities of GHG emissions; carbon dioxide (CO₂), methane (CH₄), nitrous oxides (N₂O) and local emissions; carbon monoxide (CO), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC), Particulate Matter (PM), and fuel-related emissions such as lead (Pb) and sulphur dioxide (SO₂), which are emitted from road transport vehicles (passenger cars, light

duty vehicles, heavy duty vehicles, mopeds and motorcycles). There are several versions of COPPERT³.

There is also MOBILE 6, an emission factor model for predicting gram per mile emissions of Hydrocarbons (HC), Carbon Monoxide (CO), Nitrogen Oxides (NO_x), Carbon Dioxide (CO₂), Particulate Matter (PM), and toxics from cars, trucks, and motorcycles under various conditions and its recent version MOVES –Motor Vehicles Emission Simulator– (U.S.EPA, 2009), COPERT and MOBILE use their own databases to obtain the emission factors as a function of the average cycle speed. The former is mostly used in Europe and the latter in the U.S. ARTEMIS or VERSIT+ is also another model used to obtain the emission factors as function of the aggregated kinematic parameters of the driving cycle (speed distribution, acceleration etc.), drawing the information from proper databases of emissions measurements. There are other types of micro-scale models for measuring local emissions which are classified according to the instantaneous kinematic parameters (emission maps with speed and acceleration).

ARTEMIS –Assessment and Reliability of Transport Emission Models and Inventory Systems– (Monzon & Hammarstrom, 2000), or VERSIT+ pioneered by Smit, Smokers and Rabe (2007) is also a known model. All these energy consumption and emission models provide tools to evaluate measures, strategies, and scenarios. They also help to integrate energy and carbon footprint management into decision making processes (Affum et al.

³ COPERT III does not calculate Hydrocarbon (HC) emissions separately. The total of the NMVOC and CH₄ emissions are assumed to be the HC emissions.

2003; Szeto et al. 2013). These empirical framework models have been put into practice through different assessment approaches to evaluate climate change impacts of road traffic.

Vanhulsel et al, (2014) used COPPERT to calculate emissions from automobiles, light and heavy duty vehicles, including busses, mopeds and motorcycles. They estimated road transport emissions within what they labelled “E-Motion Road”, a framework designed to calculate energy consumption and emission for road transport. It did not only focus on drawing up inventories, but also enabled projections to be made of energy consumptions and emissions. To estimate fuel consumptions and emissions, the study used the functions from the COPERT 4 methodology as stipulated by Ntziachristos and Samaras (2010). However, E-Motion Road tailored the COPERT 4 methodology to permit projections to be made, and to estimate the effect of various policy measures on future energy consumptions and emission levels.

General results showed that another parameter that influences GHG emissions is the use of mobile air conditioning (A/C) in cars and light commercial vehicles. Results from the projections show that by 2030 34.7% of the diesel passenger cars in the Belgian fleet or 22.2% of the passenger cars will be small diesel vehicles (cylinder capacity below 1.4 l), a category included in E-Motion Road. Moreover a decrease of up to 5.80% of the CO₂ emissions of all cars and a corresponding decrease of 2.80% of all road transport related CO₂ emissions are observed. Using the COPERT III program, an inventory of Turkish road transport emissions was also calculated by Soylu (2007) and the contributions of road transport to global and local air pollutant emissions were examined for the year 2004. It was observed

that passenger cars are the main source of CO₂, HC, and Pb emissions while heavy duty vehicles are mainly responsible for NO_x, particulate matter (PM), and SO₂ emissions.

Some Sub-Saharan African countries have also done some considerable research in the field of tail pipe vehicular emissions. Notable among them is South Africa where Thambiran and Diab (2011) develop an emissions inventory for the road transport sector, using it as a basis to explore intervention opportunities that are likely to simultaneously reduce air pollution and greenhouse gas emissions in the sector. Basing their arguments on Wong and Dutkiewics (1998) as well as Stone (2000) who provided emission factors for tailpipe exhaust emissions applicable to South African for diesel (light and heavy vehicles) and petrol (passenger and light commercial vehicles for non-catalytic and catalytic) motor vehicles for coastal and interior, elevated conditions in the country using COPPERT for their inventory analysis. These researchers found out that emission factors in the country in general were in agreement with the emission factors that are used in the European Economic Community (EEC) computer program, the (COPERT) model which is used in Europe to calculate emissions from Road Transport (Wong & Dutkiewics, 1998).

Thambiran and Diab (2011) conclude that reducing the vehicle kilometers travelled by privately-owned motor vehicles and improving the efficiency of road freight transport offered the greatest potential for achieving co-benefits of greenhouse gas emissions reduction. Not only programs and models such as those listed above have been used to gauge GHG emissions. Programs like Geographical Information Systems (GIS) can also be used to estimate and cost transportation carbon emissions. In a study by Armstrong and Khan (2004) in the

development of methodology that can assist the decision-making process for reducing vehicle emissions in urban areas, the benefit of using geographic information systems (GIS) in enhancing the reliability of data was realized to be indeed significant. It was realized that there are other positive features that could be used to enhance analyses and to prepare information in support of decision-making. These include: visualization of analysis results, improved communication with decision-makers, new analytical tools for testing transport technology innovations and investigating travel behaviour. The overall framework for urban transportation planning, including emissions estimation, was introduced in the paper and the role of GIS was highlighted in terms of enhancing the reliability of data.

There have also been studies that have developed models that try to project global emissions in the future. Notable among such research is Yan et al (2014), where global emissions of gases and particles from the transportation sector are projected from the year 2010 to 2050. The Speciated Pollutant Emission Wizard (SPEW)-Trend model, a dynamic model that links the emitter population to its emission characteristics, is used to project emissions from on-road vehicles and non-road engines. Unlike previous models of global emission estimates, SPEW-Trend incorporates considerable detail on the technology stock and builds explicit relationships between socioeconomic characteristics of drivers and technological changes, such that the vehicle fleet and the vehicle technology shares change dynamically in response to economic development. Moreover emissions from shipping, aviation, and rail were estimated based on other studies so that the final results encompassed the entire transportation sector. The study concludes that at the global level a common feature of the emission scenarios is a projected decline in emissions during the first one or

two decades (2010–2030), because the effects of stringent emission standards offset the growth in fuel use. Emissions increase slightly in some scenarios after 2030, because of the fast growth of on-road vehicles with lax or no emission standards in Africa and increasing emissions from non-road gasoline engines and shipping. On-road vehicles and non-road engines contribute the most to global CO₂ and Total Hydro Carbon emissions, while on-road vehicles and shipping contribute the most to NO_x and PM emissions. It is important to note that results from such studies have important implications for emissions of gases and aerosols that influence air quality, human health, and climate change.

Monzon et al (2013) in their research developed a unique framework that is used in this study. Their study attempts to evaluate the carbon footprint of toll plazas considering different types of toll collection systems. The integrated methodology was proposed for three toll collections systems; Manual Toll Collection (MTC), Electronic Toll Collection (ETC) and Open Road Tolling (ORT). The study considered the different operational stages involved in each collection system; deceleration, service time, acceleration, and queuing – of the different toll collection systems and the impacts of CO₂ emissions levels associated with each stage and the best collection system to adopt so as to reduce the emission levels at toll plazas using Intelligent Transport Systems (ITS). The research concluded that ORT is the most climate friendly toll collection system followed by the ETC and MTC systems. It was proved that the most advanced ITS gives the highest efficiency to reduce climate change impacts and improve energy savings. The integrated methodology the study proposed enabled the assessment of energy consumption and CO₂ emissions of toll plazas on a stage by stage basis and provides an efficient management toll for toll booths meaning

that wider applications of new technologies will lead to more sustainable management of toll plazas in the future.

Lastly it should be noted that since the average number of years a vehicle has spent on road plays an important role in the amount of transport CO₂ emissions obtained. As a result the study tries to find a way of incorporating this into the model employed in the study. A review of transport literature showed and explained by Burón et al. (2005), the circulating fleet referring to the real number of vehicles using a highway must be adjusted in terms of its composition taking into account the fact that the number of highway kilometers travelled on highways decreases with the vehicles age. Some previous studies have considered mileage correction factors. Hickman et al. (1999) included vehicles' annual mileage as a correction factor for fleet composition. Borcken et al. (2000) proposed a method in which a new vehicle counts as one unit while an older vehicle counts as a fraction of a unit; hence the older the vehicle the smaller the fraction. Logghe et al. (2006) also used a mileage factor in order to calculate traffic flow emissions. Most recently, Ntziachristos et al. (2008) justified the importance of taking into account the annual mileage factor and proposed a method to estimate annual mileage factors. This study will incorporate the Ntziachristos et al. annual mileage factors in order to establish the actual composition of the current circulating fleet.

2.9 Carbon Credits

The Collins English Dictionary defines a carbon credit as “a certificate showing that a government or company has paid to have a certain amount of carbon dioxide removed from the environment”.

The United Nations' Clean Development Mechanism (CDM) scheme awards tradable carbon credits to projects that reduce developing countries' greenhouse gas emissions – such as wind farms, solar power, or the capture of methane. Each carbon credit, known as a Certified Emission Reduction (CER), represents a ton of carbon dioxide, or equivalent for other greenhouse gases, which is not emitted. In order to be awarded credits, project developers' plans must be approved by the mechanism's executive board, which has drawn up strict methodologies that projects must adhere to.

According to Sharma and Prakash (2013) a Carbon Credit (CC) is a form of environmental currency and a generic term for any tradable certificate or permit representing the right to emit one ton of carbon dioxide or the mass of another greenhouse gas with a carbon dioxide equivalent to one ton of carbon dioxide. Carbon credits and carbon markets are a component of national and international attempts to mitigate the growth in the concentrations of greenhouse gases. One carbon credit is equal to one metric ton of carbon dioxide, or in some markets, carbon dioxide equivalent gases. The concept of carbon credits came into existence as a result of the increasing awareness of the need for controlling emissions. There was an Earth-Summit in 1992 at Rio de Janeiro, Brazil where the IPCC (2007) observed that:

“Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to significantly invest in low-Green House Gases products, technologies and processes. Such policies could include economic instruments, government funding and regulation while noting that a tradable permit system is one of the policy instruments that has been shown to be environmentally effective in the industrial sector, as long as there are reasonable levels of predictability over initial allocation mechanism and long-term price”.

Under the Kyoto Protocol which is linked to the UNFCCC (2007) adopted in Kyoto, Japan in December 1997, the ‘caps’ or ‘quotas’ for greenhouse gases for the developed countries was adopted and called “Assigned Amounts”. The quantity of the initial assigned amount is denominated in individual units called Assigned Amount Units (AAU’s). Each one represents allowance to emit one metric ton of carbon dioxide from the atmosphere.

Since 2005, the Kyoto mechanism has been employed for carbon dioxide trading by all the countries within the European Union (EU) under its European Trading Scheme (ETS) with the European Commission (EC) as its validating authority. In line with the objectives of this study, calculation of vehicular carbon dioxide emissions at toll plazas should warrant a calculation of the monetary value that the country can place on its reduction. In terms of greenhouse gas emissions reduction, what comes to mind is Carbon Credits (Sharma & Prakash, 2013). Carbon credits or Certified Emission Reduction (CER) certificates are issued when there is a reduction of emissions of greenhouse gases (GHGs). Industries or firms with high levels of GHG emissions can undertake some conventional activities that will reduce emissions in order to offset emissions previously made by their industries. In

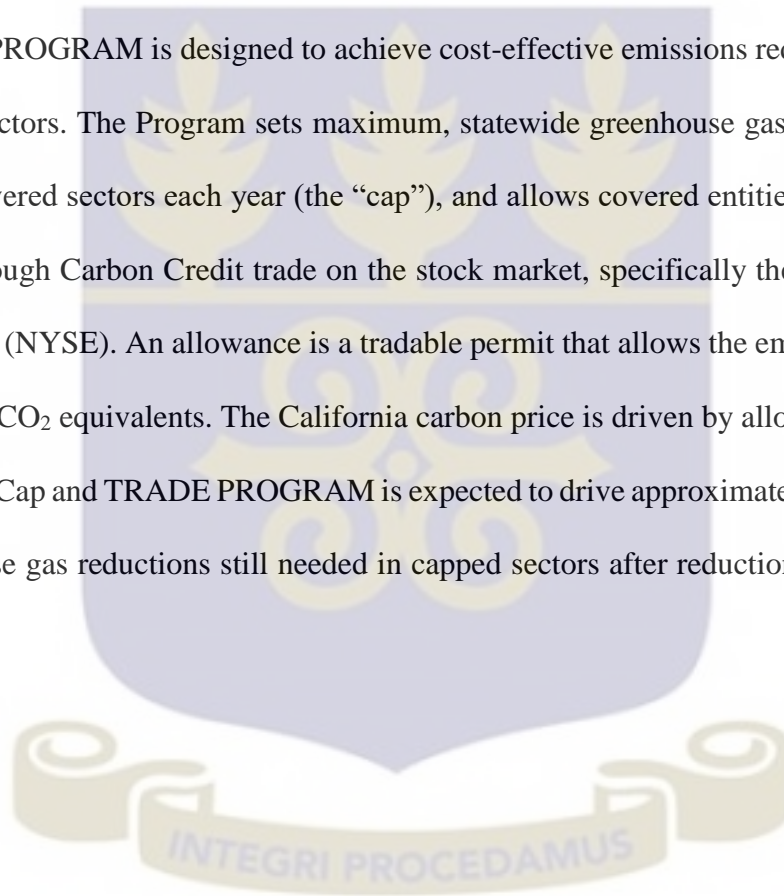
doing this these firms can trade the excesses they obtain through their emission reduction strategies. By convention, one ton of carbon dioxide (CO₂) equivalent corresponds to one carbon credit. This credit can be traded on the international market. The reduction of emissions of other gases which also contribute to the greenhouse may also be converted into carbon credits, using the concept of equivalent carbon.

According to the IMF (2008) the economic problem with climate change is that the emitters of greenhouse gases (GHGs) do not face the full cost implications of their actions. There are costs that emitters do face, for example the costs of the fuel being used, but there are other costs that are not necessarily included in the price of a good or service. These other costs are called external costs (Halsnæs, 2007). They are "external" because they are costs that the emitter does not face. External costs may affect the welfare of others. In the case of climate change, GHG emissions affect the welfare of people living in the future, as well as affecting the natural environment (Toth et al., 2001). These external costs can be estimated and converted into a common (monetary) unit. The argument for doing this is that these external costs can then be added to the private costs that the emitter faces. In doing this, the emitter faces the full (social) costs of their actions (IMF, 2008).

It is one type of emissions trading that basically targets carbon dioxide (calculated in tons of carbon dioxide equivalent or tCO₂e) and it currently constitutes the bulk of emissions trading. This form of permit trading is a common method most countries employ in order to meet their obligations specified by the Kyoto Protocol; namely the reduction of carbon emissions in an attempt to reduce (mitigate) future climate change (IPCC, 2007).

Emissions trading works by setting a quantitative limit on the emissions produced by emitters. The economic basis for emissions trading is linked to the concept of property rights as explained by Reid and Goldenberg (1995)

Carbon Credits are also being traded on the stock market and a typical example of this is done by the Climate Policy Initiative (2015) in the United States. The California Cap and TRADE PROGRAM is designed to achieve cost-effective emissions reductions across the capped sectors. The Program sets maximum, statewide greenhouse gas (GHG) emissions for all covered sectors each year (the “cap”), and allows covered entities to sell off allowances through Carbon Credit trade on the stock market, specifically the New York Stock Exchange (NYSE). An allowance is a tradable permit that allows the emission of one metric ton of CO₂ equivalents. The California carbon price is driven by allowance trading. By 2020, the Cap and TRADE PROGRAM is expected to drive approximately 22% of targeted greenhouse gas reductions still needed in capped sectors after reductions from mitigation policies.



CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the methodology used in the study. The chapter has two main sections. The first section focuses on the theoretical framework for the study, while the second section elaborates on the empirical estimation procedure. This will include the data type to be employed, specification of the model, explanation of variables as well as key assumptions. The estimation procedure will however be divided into two main sections. The first part consists of technical issues and will deal with estimating the volume of emissions by the different vehicular types per year. This involves evaluating energy consumption and total CO₂ emissions at the two toll plaza surveyed. The second section will comprise the valuation of CO₂ emissions at the toll plazas due to excess waiting time.

In the field of economics, environmental related problems such as pollution are seen as human behavioral issues related to the management of scarce resources that have alternative uses as Myers and Simon (1994) explain in their book. They continue that this is the reason why current research is focusing on how to solve environmental problems to improve living conditions. Pollution in all its forms can have damaging effects on individuals in terms of their efficiency and wellbeing as a whole (Pacione, 2003). It is evident that since the time of Adam Smith, economists understand that the economic development of a country is not measured only by per capita income, but includes other variables such as the

level of literacy of the citizens of the country, the equality of the distribution of income and the access to healthcare or life expectancy of individuals in that country all of which can be influenced by the level of pollution in the atmosphere. Duflo et al. (2008) as well as Bullinger (1989) sum this up by saying that, the effects of greenhouse gases can negatively affect economic development.

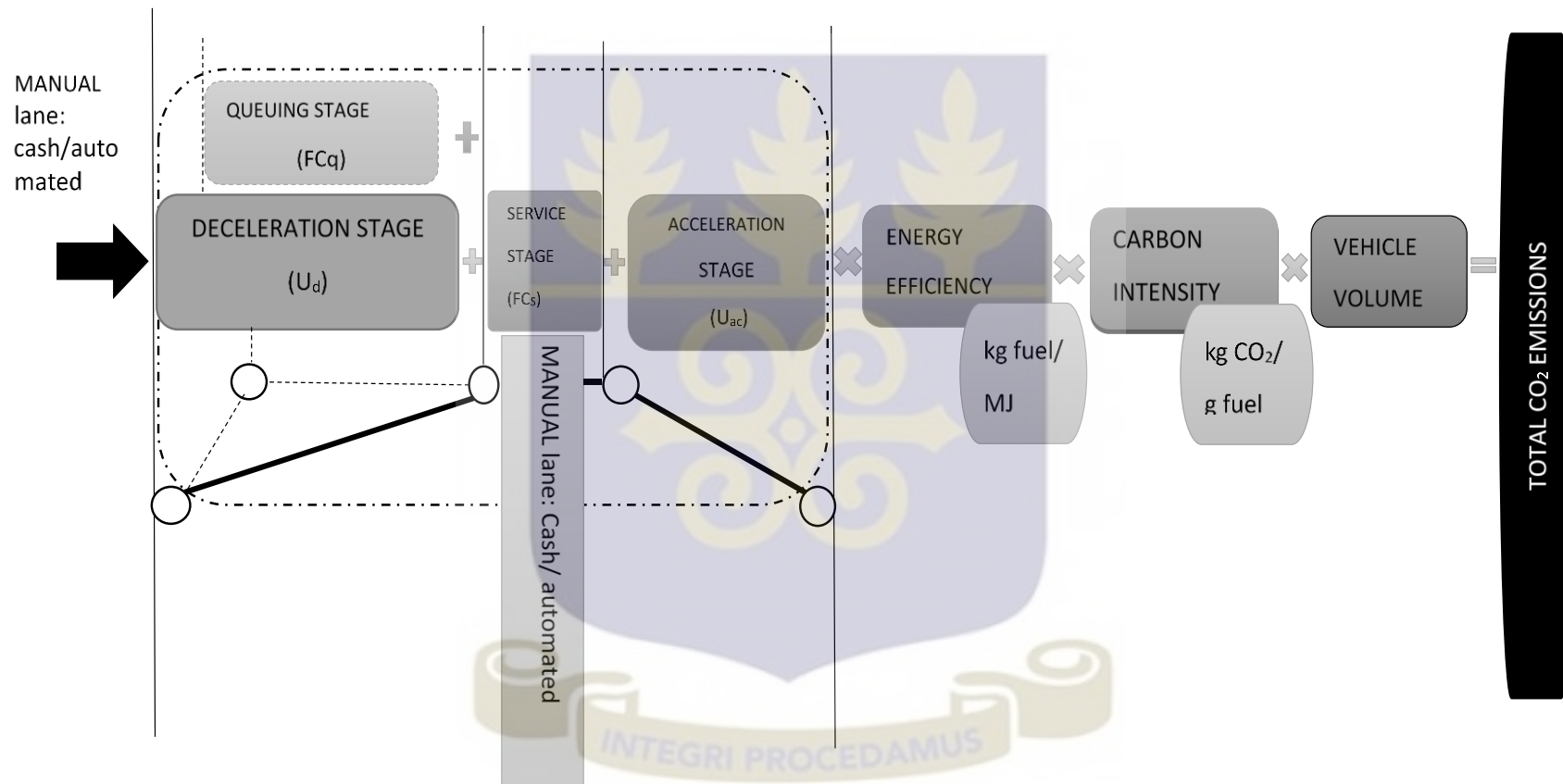
This is the reason why stylized models are being developed to measure all kinds of pollution especially those caused by the production of excess greenhouse gases in the atmosphere through transportation. Most of these models have been discussed in the previous chapter through the review of literature on the subject area. In this chapter however one of those models developed by Hernandez et al (2013) will be expanded upon and used to calculate the cost of emissions at specific toll plazas in Ghana. The procedure considered in this study will be in the form of a small case study of two toll plazas in the Greater Accra region of Ghana (Tema and Frafraha). The survey will then study vehicular characteristics and service time by employing a cross category analysis of vehicles moving through these toll booths. This will help ascertain whether the stages involved in paying the toll significantly contribute to excess CO₂ emissions. If this hypothesis holds, will a large scale reduction of these excess emission through effective and efficient measures enable Ghana obtain carbon credits to supplement the road fund?

3.2 Theoretical Framework

This section explains the theoretical model that will be used to estimate the total amount of CO₂ emissions at the toll plazas. The theoretical framework used to estimate CO₂ emissions at toll plazas by manual toll collection system can be illustrated below:



Figure 3.1: Framework for estimating CO₂ emissions at toll plazas by manual toll collection system.



Source : Hernandez et al. (2013)

The physical layout and operation of a toll booth in advanced countries sometimes offers an approaching vehicle different lanes to choose from, depending on the payment system selected. What normally happens at a Toll plaza as described by Opoku-Boahen et al (2013) and Blythe (2004) is that an approaching vehicle is offered three modes of payment to choose from. First is the Manual Toll Collection (MTC) system. In this case drivers pay cash to the attendant at the booth after which a ticket is given and access is granted to the vehicle. Second is the Electronic Toll Collection (ETC) which is basically for somewhat frequent users of the road. With ETC, drivers usually have a toll fare card on which the toll might have been paid for a week, or a maximum time period of a month. Drivers slot these cards at the Toll plaza and are allowed passage. The last is the Open Road Tolling (ORT) system. Usually vehicles that ply roads with ORT register with their various highway authorities after which they are given a sensor that corresponds to an apparatus at the toll plaza so that these vehicles are given immediate passage when they approach a toll booth.

In Ghana the most common payment system is that of the MTC system where as described above drivers pay the toll in cash. An integrated theoretical methodology developed by Pérez-Martinez et al (2011) and diagrammatically represented by Hernandez et al (2013) is being proposed to study the CO₂ emissions of vehicles at toll plazas. According to Pérez-Martinez et al (2011), a MTC lane has three stages, regardless of whether the payment is automated or made with cash. Figure 1.1 shows the three stages. First is the deceleration stage (U_d), comprising a phase where vehicles on approaching a toll plaza start to reduce speed to an appreciable level until the vehicle comes to a gradual stop where the toll is to be paid. During peak periods when traffic queue is long, a vehicle may spend more time before

it is attended to. This may also be due to slow personnel at toll booths. This situation creates a possible additional step within the deceleration stage; the queuing stage represented in Figure 1.1 as (FC_q). Another stage in the MTC system is the service stage, represented by (FC_s) in the Figure 1.1. During this stage vehicles literally stop with their engines running to pay the toll fare to the attendant in the booth or slot money in a vending machine, after which a receipt is given. The last stage that is the acceleration stage represented by (U_{ac}) in the Figure 1.1. This comprises the phase where vehicles after collecting their receipts speed off away from the toll booths. All the stages described above are summed up and known as the “Stop and Go” stage.

In order to calculate the total Carbon Dioxide (CO_2) emissions at a toll plaza, not only the stages listed and explained above will be considered. As shown in the framework factors like energy efficiency of the vehicle which look at the amount of CO_2 a particular vehicle category can emit based on the energy it uses are also considered. This is a stage where Carbon Emission Factors (CEF) play a vital role. Also, a factor like carbon intensity is considered in the model. The Carbon intensity depends on the vehicular characteristics such as type of vehicle, age, fuel use etc. and permits us to know how much CO_2 a vehicle can emit while stationary or in motion. The last factor to be considered is the vehicle volume at the toll plaza. This is the volume of traffic that go through the toll plaza over a period of time. In Figure 3.1, this is shown as final block that makes CO_2 emissions estimations at Toll plazas complete. The best way to find an approximate estimate for total emissions of a particular GHG is that one has to take into account the total number of emitters. In this study the number of emitters will be volume of vehicles that move through each toll plaza. This is

also known as the circulating fleet. The knowledge of vehicular volume is essential because after all calculations and estimations in an emissions model are done, the study can easily estimate total emissions at the specific toll plazas by multiplying total emissions by vehicle volume.

According to Pérez-Martinez et al. (2011) the calculation to obtain the total rate of CO₂ emissions in grams of CO₂ equivalent per vehicle-kilometer is found by multiplying the energy consumption of each vehicle category by its respective carbon emission factor (CEF) which is a constant that tells how much kgCO₂ is produced when one MJ of energy is burnt. According to The Environment and Energy Management Agency (2007) and the USEPA (2014), the grams (kilograms) of CO₂ emitted per mega-joule of energy (g CO₂/MJ) are 81 (0.081kg) for diesel engines and 86 (0.086kg) for petrol/gasoline engines, irrespective of the engine size. The UNFCCC defines emission factor as the average emission rate of a given GHG for a given source, relative to units of activity.

When a toll plaza is considered, additional calculations are required for the “Stop and Go” stage relating to emissions from deceleration, stop and acceleration. These additional calculations will be the resultant per minute emissions due to idle time at the toll plaza. The study sums this up as “waiting time” in the analysis then converts this to effective distance to estimate energy consumption and subsequent CO₂ emissions.

Bearing these factors in mind, total carbon emission rate of a vehicle category of type “i” and motor fuel type “j” (mostly petrol and diesel), is denoted as “ $N_{i,j}$ ” and expressed in kg of CO₂ equivalent per vehicle-kilometer (kgCO₂/veh-km) when assuming no toll plazas and also denoted as “ $M_{i,j}$ ” when assuming the presence of a toll plaza. The difference in “ $N_{i,j}$ ” and “ $M_{i,j}$ ” will result in excess CO₂ emissions rates due to waiting time at the toll plaza. “ $N_{i,j}$ ” and “ $M_{i,j}$ ” will be obtained considering two estimations. First, by multiplying the CEF and energy consumption rate when there is no toll plaza ($U_{i,j}$) and second by multiplying CEF and the energy consumption rate ($E_{i,j}$) which considers the waiting time when assuming the presence of a toll station. These are expressed in Equation 1.1a and 1.1b respectively as noted by Hernández et al. (2013) and Pérez-Martinez et al. (2011). Since CEF is a common factor among these equations, the rate of total excess CO₂ emissions of a vehicle type “i” with fuel type “j” due to waiting time at a toll plaza ($C_{i,j}$) can be obtained when CEF is multiplied by the difference in energy consumption rate denoted as $(E_{i,j} - U_{i,j})^4$. This is shown in equation 1.1c. The difference is attributed to the excess time taken to go through the toll booth which can be converted to distance using the assumptions by Fuzzi et al (2006)

In this study, we applied the rates of energy consumption per km and CO₂ emissions to the two road sections on the Oyibi/Frafraha and the Tema-bound highway to obtain actual excess CO₂ emissions caused by the toll plazas on these roads. This was done by multiplying the rate of CO₂ emissions per vehicle-km by the excess section length travelled due to the

⁴ Energy Consumption is higher when there is a toll plaza

excess time spent at the toll plaza. The fact is that, the total distance travelled is not considered since any motor vehicle will burn energy and emit when it is in motion. However, the excess time spent at the toll station that has been converted to distance is the most relevant in this study. The actual carbon emissions of a vehicle type “i” and fuel type “j” is computed using the expression in equation 1.1d where $(CT_{i,j})$ is excess emissions due to the excess time spent at a toll plaza and L_i is the excess section length of a vehicle type “i” due to the excess time spent at a toll plaza. Monthly vehicle volume and shift volume traffic data recorded at the two toll plazas studied is then applied to actual CO₂ emissions to obtain the total emissions at the two study sites.

After total excess CO₂ calculations are obtained, the resulting emissions estimate is multiplied by the current unit value of CO₂ denoted by “CC”, to obtain the value of CO₂ emission reduction if there was no toll plaza. The value $V_{i,j}$ is therefore the cost of excess CO₂ emissions of a vehicle type “i” with fuel type “j” at a toll as a result of the excess time spent at the toll station. This valuation can be described by Equation 1.1e.

$$N_{i,j} = U_{i,j} \times CEF_j \quad (1.1a)$$

$$M_{i,j} = E_{i,j} \times CEF_j \quad (1.1b)$$

$$C_{i,j} = (E_{i,j} - U_{i,j}) \times CEF_j \quad (1.1c)$$

$$CT_{i,j} = C_{i,j} \times L_i \quad (1.1d)$$

$$V_{i,j} = (CT_{i,j}) \times CC \quad (1.1e)$$

In order to calculate the unit energy consumption rate of a vehicle type i with motor fuel type j , a mechanical formula, expressed, in mega-joules per vehicle-kilometer (MJ/veh-km) is employed. The energy consumption model used here is in the form of work energy, and is the product of the distance traveled and the external force that opposes vehicle motion. The initial model consists of five groups of external forces used by Hernández, Monzon and Sobrino (2013) as shown in Equation 1.2:

$$U_k = U_g + U_i + U_r + U_a + U_c \quad (1.2)$$

Here U_k is the total energy consumption rate expressed in mega-joules per vehicle kilometer. It depends on the energy consumption due to gravitational losses, U_g , the consumption due to inertial acceleration/deceleration, U_i ; the consumption due to rolling resistance, U_r ; the consumption due to aerodynamic drag, U_a ; and the consumption due to cornering losses, U_c . The mechanical model can be fully expressed in mega-joules per vehicle-kilometer (MJ/veh-km) as shown in Equation 1.3:

$$U_{i,j} = L^{-1} \left[P \sin \theta d_g + C_i M_{fr} a d_i + C_r P \cos \theta d_r + 0.5 \rho C_d A_f v_r^2 d_a + \left(\frac{m^2 v^4}{R^2 C_{av}} \right) d_c \right] \left(\frac{1}{\eta_{motor}} \right) e_v \quad (1.3)$$

Where “L” is the section length travelled in km

“P” is the vehicle weight (kg m/s^2) of the various vehicular categories and is calculated as a product of the vehicle mass (kg) and acceleration due to gravity (g) (constant equal to 9.8 m/s^2). However, vehicle mass can be used if effect of gravity losses is assumed to be null

“ θ ” is the road gradient (m/m) on which the toll plaza is located.

“ C_i ” is the mass correction factor for rotational inertia acceleration

“ M_{fr} ” is the rotational mass of vehicle (kg-m^2) “a” is the rate of acceleration (m/s^2).

“ C_r ” is the rolling resistance.

“ ρ ” which is the density of air for average tropical temperatures of 30°C (1.164 kg/m^3).

“ C_d ” is the drag resistance of vehicles.

“ A_f ” is the frontal area of a vehicle (m^2).

“ v_r ” is the relative vehicle velocity taking into account the effect of wind (m/s) whereas “v” is the vehicle velocity (m/s).

“R” is the path radius from center of gravity (m).

“ C_{av} ” is defined as the cornering stiffness.

(e_v) defines the wind exposure factor and

(η_{motor}) defines the efficiency of the engine.

In Equation 1.3, the external forces that determine energy consumption are each multiplied by the total excess distances travelled in km. As seen from the equation, these excess distances are gravitational (d_g), inertial (d_i), rolling (d_r), aerodynamic (d_a) and curve (d_c). These distances are the excess time spent at the toll station as a result waiting time at the toll plaza which have been converted into distance.

Concerning the last part of the theoretical model (Figure 3.1) which is the vehicle volume, the Ghanaian fleet was classified into 5 categories based on the categorization by the Ghana Highway Authority (GHA) and the Driver Vehicle and Licensing Authority (DVLA). They are: saloon cars, pickup vans/4x4/SUV, mini bus/truck, large bus/truck and articulated/heavy trucks (trailers included). This form of categorization will be used in the study. In determining the category to place specific vehicles, the GHA uses the axle load of every vehicle. Also, various weights of each vehicle are also taken into consideration. The average weight of vehicles that fall in the same category are put in the same group. As required by the study objectives, knowledge of CO₂ emissions by specific vehicle category is paramount, therefore the characteristics of these classified vehicles for energy consumption and CO₂ emissions will be sought. Characteristics of vehicular data as well as driving conditions used and their sources is explained in the next section.

Equation 1.3 could not be used for the estimation of energy consumption. This is due to the fact that some variables were not relevant in the context of this study. Hence, the model was modified based on some assumptions. First, no cornering forces or gravitational losses shall

be considered based on the knowledge that the toll plazas considered in this study are straight sections of road with no significant gradient, hence the energy consumption due to cornering (U_c) and gravitational losses (U_g) have been considered null. Secondly in a tropical region such as Ghana, excessive wind action usually does not play a major role in driving condition as witnessed in temperate zones. Hence the wind exposure factor will be assumed as minimal where $e_v = 1$.

Based on these assumptions the final expression of the model as deduced is expressed in mega-joules per vehicle-kilometer (MJ/veh-km) as shown in Equation (1.4):

$$(E_{i,j} - U_{i,j}) = L^{-1} \left[(C_i \times M_{fr} \times a) d_i + (C_r \times P \times \cos \theta) d_r + \left((0.5) \times \rho \times C_d \times A_f \times v_r^2 \right) d_a \right] \times \left(\frac{1}{\eta_{motor}} \right) \times e_v \quad (1.4)$$

The difference in ($U_{i,j}$) and ($E_{i,j}$) is multiplied by CEF for each toll plaza studied. This results in the rate of CO₂ emissions measured in kg of CO₂ per vehicle kilometers (kgCO₂/veh-km) after which equation 1.1d is applied to obtain actual excess CO₂ emissions in kgCO₂. It should be noted that $(C_i M_{fr} a) = U_i$, $(C_r P \cos \theta) = U_r$ and $((0.5) \rho C_d A_f v_r^2) = U_a$ irrespective of the presence or absence of a toll station. The difference between $U_{i,j}$ and $E_{i,j}$ is the excess distances, d_i , d_r and d_a created as a result the waiting time.

Valuation is done as shown in equation 1.1e. For the purpose of this study the monetary unit that will be used to value the amount of CO₂ emissions will be U.S Dollars (\$). This unit will be used because it is the currency that Carbon Credit are valued in. Moreover due to the popularity and the ease at which this currency can be converted to any other currency, the study will not convert the cost of excess CO₂ emission into the local currency.

3.3 Data Types and Sources

Data used for the study can be grouped into three namely, data from literature, data from agencies and data from fieldwork.

Data from literature can be described as data the study obtained from scholarly articles and books and did not require the study to undertake extra effort to recalibrate values pertaining to such data. These data includes engine efficiency, rolling resistance, mass correction factors etc. most of which have been calculated according to literature. Specific variables such as the rotational mass of the vehicle (M_{fr}) has been calculated using the tyre rotational inertia, specifically the rim inertia. However, since all vehicle categories have different rim sizes, the variable here according to literature takes on different values for each vehicle category considered. Rolling resistance coefficient also assumes a constant value based on literature. This also applies to the Drag resistance coefficient which has already been estimated in literature and will be employed by the study. According to the International Union of Pure and Applied Chemistry (IUPAC) standard pressure and temperature measurements,

an average tropical temperature of 30°C will record an air density of 1.164, which was used in the calculations for energy consumption.

Data on engine efficiency is also obtained from literature and considers the average age of a vehicle which plays a vital role in determining vehicular CO₂ emissions. The average age of a vehicle can be determined by the mileage. This in turn provides an estimate for the engine efficiency. According to different studies by Dimopoulos et al (2007), Jahirul et al (2010) as well as Teng et al. (2006), the engine efficiency is 0.27 for petrol engines and 0.4 for diesel ones when considering vehicles that on the average have spent eight (8) years on road. The number of years specified (8 years) was chosen because, due to anecdotal evidence much more older vehicles above the age specified are found mostly in rural areas of which Tema and Frafraha do not form a part since these areas are considered as cities. Another reason for this average age is that the Driver and Vehicle Licensing Authority (DVLA) in Ghana registers vehicles that are above ten (10) years old at a penalty rate which serves as deterrent for individuals who wish to use such vehicles. Table 3.1 summarizes data obtained from literature and their sources used for the energy consumption model.

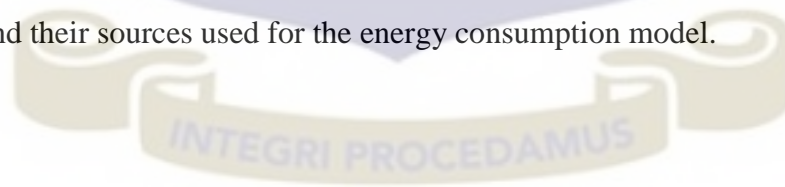


Table 3. 1: Data from Literature with their Sources

Parameter	Notation	Units	Value	Source/assumptions
Rolling resistance coefficient	C_r	-	0.01	(Lutsey & Sperling, 2005)
Rotational mass of vehicle	M_{fr}	kg-m ²	Saloon: 43.15 Pick-up:93.94 Mini-bus: 200.50 Large bus:611.42 Heavy Truck:1677.40	(HPWIZARD, 2014)
Drag resistance coefficient	C_d	-	0.35	(Lutsey & Sperling, 2005)
Mass correction factor for rotational inertia acceleration	C_i	-	1.05	(Burgess & Choi, 2003)
Engine efficiency	η_{motor}	m	Diesel Engine: 0.40 Petrol Engine: 0.27	(Dimopoulos, Rechsteiner, Soltic, Laemmle, & Boulouchos, 2007), (Jahirul, et al., 2010)
Air density	ρ	kg/m ³	1.164	(IUPAC, 2015)

Data sourced from agencies can be defined as data the study obtained from agencies and firms. This data includes vehicular volume, fleet characteristics and tolling which was sourced from the Ghana Highway Authority (GHA), one of the four departments under the Ministry of Roads and Highways. Also, vehicle specifications were obtained from car makers. Variables such as vehicle mass and vehicle frontal area were obtained from car makers as well as dealers such as VOLVO, Mercedes Benz and Volkswagen, HONDA Palace, Stallion Ghana, Metro Mass Transit Accra and Kumasi among others. These variables take on

different values depending on the vehicle category being considered due to the fact that vehicles come in different shapes and sizes.

Table 3.2 summarizes data obtained from agencies and their sources used for the energy consumption model.

Table 3. 2: Data from Agencies with their Sources

Parameter	Notation	Units	Value	Source/assumptions
Vehicle mass	m	kg	Saloon:2100 Pick-up:3,500 Mini-bus: 8,000 Large bus:18,000 Heavy Truck:65,000	(Mercedes-benz, 2014; Volkswagen, 2014)
Frontal area	A_f	m^2	Saloon:2.52 Pick-up:5.13 Mini-bus: 6.02 Large bus:8.67 Heavy Truck:8.62	(Mercedes-benz, 2014; VOLVO(a), 2014)

Data from fieldwork is that type of data that the researcher gathered from field observations. Variables such as section length of road, excess distances considered as a result of waiting time, velocity, rates of acceleration and deceleration, and service/waiting times was obtained from the fieldwork. The study used primary data comprising daily vehicular volume and

driving conditions for the year 2014. The year 2014 was chosen because it was the most recent year and data required was available and sourced from the Ghana Highway Authority (GHA). In the next sections, we discuss the project site description as well as the primary data collection process.

3.4 Project Site Selection and Description

In the attempt to select a study area, all toll plazas in the country were considered. However due to constraints on time, money and personnel, two toll plazas were randomly selected and studied. This is because most of the toll stations in the country share similar characteristics as explained in the next paragraphs, hence biases or skewness can be assumed away in results obtained.

The argument for the random selection is that most toll plazas in Ghana are strategically located as connective links to other regions. Moreover they usually link the regional capitals not only to the industrial and maritime sections of the country but also to other important towns and communities. It will be possible to assume that vehicles that ply these tolled roads will on average be the same and will also share similar characteristics like type of vehicle, age, and fuel use. The major difference observed among toll plazas is that, they can be on single carriage or dual carriage roads. This may form a base for comparing the size of a toll station and emission levels as the study sought to select two toll plazas for small case studies. Due to these similarities among toll plazas, the study randomly selected two toll plazas not

on any significant reason based on literature but on the number of booths per toll plaza as well as vehicular volume per booth. The steps for the random selection are explained below.

A survey of toll plazas in the country and a brief interview with the Director of Tolls at the Ghana Highway Authority revealed that the Tema motorway toll plaza and the Kasoa toll plaza are the busiest in the country. Those plazas were mentioned not only because of their location but also a look at the number of vehicles that went through each hour was extremely high. According to the Director, on average between 19,500 and 20,000 vehicles went through these toll plazas each day. Hence the researcher in the process of randomly choosing a big toll plaza chose the Tema-motorway toll stations to be studied. However, the study specifically used the vehicular traffic at the Accra end toll plaza i.e. the Tema-bound toll plaza for the analysis since in-bound and out-bound traffic could not be recorded at the same time due to the dual carriage nature of the motorway and the position of the toll plaza. From preliminary surveys at both in-bound and out-bound toll plazas on the motorway and interaction with the tolls manager at GHA, the researcher realized that vehicular volume did not show any significant difference. From this observation the researcher randomly selected the Tema bound (Accra end) toll plaza with the idea of making generalizations applicable to the Accra bound toll plaza i.e. the Tema end toll plaza.

After the choice was made to select the big plaza, investigations were undertaken to locate a relatively smaller toll plaza with significant vehicular volume where driving conditions will not be different from the relatively big plaza identified. The parameters were that, this

toll plaza should be on single carriage road and have not more than two booths in order to be regarded as “small”. A number of suggestions were made to the Director of Toll after which he suggested the Oyibi/Frafraha bound and Atimpoku toll plazas. The researcher randomly selected the Oyibi/Frafraha bound toll plaza to study as the small toll station. For this toll plaza both in-bound and out-bound vehicles were considered since the toll plaza was located in the middle of the road serving both in-bound and out-bound traffic.

After both toll station were chosen, we realised the biases that could arise since the vehicular volume for Frafraha toll plaza considered both traffic directions (in and out-bound traffic) while the vehicular volume for the Tema-bound toll plaza only considered one traffic direction (in-bound). Using the notion discussed that vehicular volume at the Accra end and Tema end toll plazas did not show any significant differences, study solved this directional bias by multiplying all the excess emissions and cost results that were obtained at the Tema-bound toll plaza by two (2). This enabled the study capture the excess emissions caused by excess waiting time for the toll plazas at both ends of the Tema motorway

Although randomly chosen, the researcher considered regional balance in an effort to choose the two study areas. As Stock and Watson (2007) describe generalization as regards to the law of large numbers, samples must be independently and identically distributed. Therefore the study wanted to sample vehicles in the same region. It is assumed that vehicles

in the same vicinity will have similar characteristics which will reduce errors in measurement as regards to GHG emissions. A pictorial view of the Oyibi/Frafraha bound and Tema bound Toll plazas are shown in Figure 2.1 and 2.2 respectively:

Figure 3.2: Oyibi/Frafraha bound Toll Plaza



Source: Author, 2015

Figure 3.3: Tema bound Toll Plaza



Source: Author, 2015

3.5 Field Data Collection

This section states the data obtained from the field and explains the processes the study went through to obtain the required data and also how some field data assumptions were made.

Prior to the commencement of the study, visits were paid to the two study sites, the Accra toll plaza and the Frafraha toll booth in the Greater Accra region to establish initial contacts. Also, the needed rapport with the management staff at the head office of the Ghana Highway Authority (GHA) was also established since this office is in charge of all toll plazas in the country hence permission needed to be sought from the office. In the process, the consent of the Ghana Police Service was also sought for the use of the Lidar⁵ speed gun in order to measure the speed of the various category of vehicles in order to calculate acceleration rates, deceleration rates and also velocities.

During the study an officer from the Ghana Police Service assisted in obtaining values for average deceleration and acceleration rates. A controlled experiment was conducted at each chosen toll plaza and in the process the research obtained the results needed. In the experiment the police officer aims the LiDAR "cross-hairs" specifically on the license plate of the target vehicle through a fitted telescope. This allows the police officer to see the target vehicle before the target vehicle operator sees the police officer generally at a distance of between 305 meters and up to 1,200 meters. To operate the device, the police officer presses

⁵ LIDAR or LiDAR is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflecting light. The term was created as a portmanteau for "light" and "radar"

the trigger of the LiDAR gun and it emits very short LiDAR laser pulses with a pulse width (duration of pulse) of 30 nanoseconds or less. The laser pulse "flies" towards the target and hits the target vehicle license plate. At the same time the pulse is released into flight. The LiDAR hence measures time-in-flight of each pulse and requires only 2 pulses over a period of time of as little as 3 milliseconds (theoretically) to determine the velocity of a vehicle. Table 3.3 shows data obtained from fieldwork using the LiDAR gun and a timer.

Table 3. 3: Data from Fieldwork with their Sources

Parameter	Notation	Units	Value	Source/as- sumptions
Relative vehicle velocity	v_r	m/s	Saloon: 13.8 Pick-up:13.5 Mini-bus: 12.5 Large bus:10.6 Heavy Truck: 9.8	LiDAR gun
Rate of deceleration/acceleration	a	m/s^2	Saloon: 2.3 Pick-up: 2.2 Mini-bus: 2.1 Large bus: 2 Heavy Truck: 1.5	LiDAR gun

Also, a brief review of service operations at toll booths and how it affects toll collection activities at the two toll plazas considered was carried out together with supervisors in order

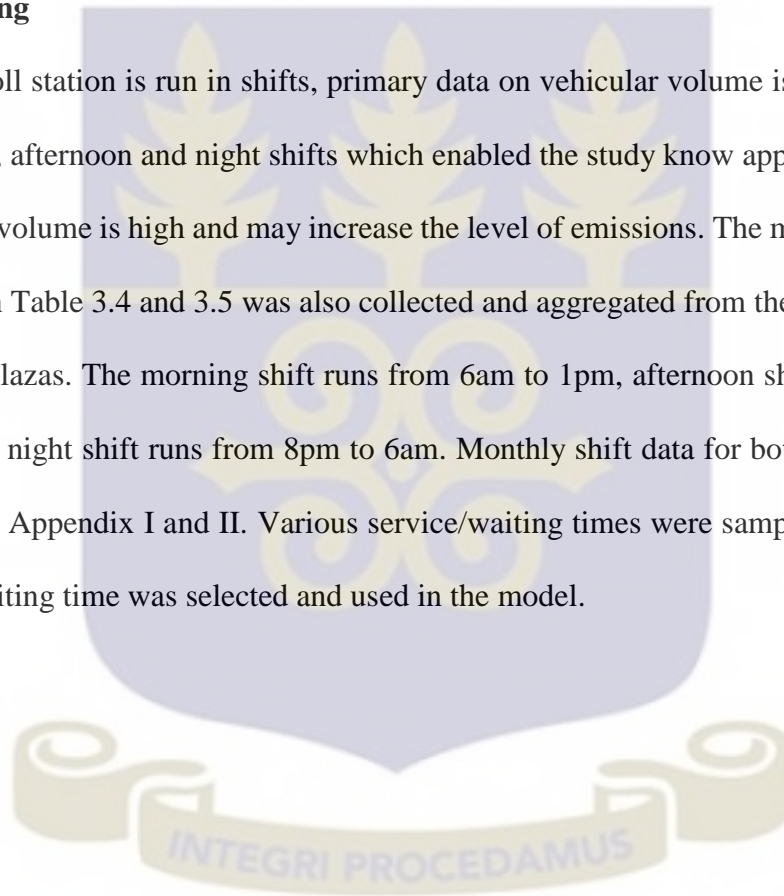
to have a fair idea of service times at the various booths. In doing this, the study sampled in addition to service time, waiting time which included processes during the ‘Stop and Go’ stage. The study observed traffic volume around the two study sites considering various deceleration, stop and acceleration periods for each vehicular category using a timer. This was done for a period after which the specific periods were averaged and summed up as waiting time. This excess time was then converted to distance and used to calculate the energy consumption rates and subsequent CO₂ emission rates.

On the field, the study also chose specific start and end point on both trunk roads where the toll plazas were found. These are the two points on the trunk road before and after the Tema-bound and Oyibi/Frafraha toll. This was done in order to obtain accurate emission levels of sampled vehicles, first when they are in motion and second when they come to a gradual stop at the toll plaza. The assumption behind this is that toll plazas are seen as barriers to vehicular movement. Without the toll plaza there will be no stoppage and vehicles will not emit excess CO₂ due to idle time at the toll station. On the Tema motorway, the start point was 150 meters to the Tema-bound toll station and the end point was 150 meters after the same toll plaza, making up a section length of 300 meters. On the Frafraha-Dodowa motorway the start point was from the Christian University College junction which is 150 meters to the toll plaza with the end point being 150 meters after the toll plaza, a section length of 300 meters.

Lastly the study also collected data on vehicular volume. The GHA provided daily and shift volume data for the Tema-bound and the Oyibi/Frafraha bound toll plazas from which the researcher aggregated to obtain monthly traffic volume. However, this data from GHA did not have hourly vehicular traffic which could cater for peak and off peak periods.

3.6 Sampling

Since the toll station is run in shifts, primary data on vehicular volume is sampled in terms of morning, afternoon and night shifts which enabled the study know approximately the period where volume is high and may increase the level of emissions. The monthly traffic data as shown in Table 3.4 and 3.5 was also collected and aggregated from the various shifts run at the toll plazas. The morning shift runs from 6am to 1pm, afternoon shift runs from 1pm to 8pm and night shift runs from 8pm to 6am. Monthly shift data for both case studies can be found in Appendix I and II. Various service/waiting times were sampled after which an average waiting time was selected and used in the model.



**Table 3. 4: Monthly Vehicular Traffic on Tema bound Toll plaza by Vehicle Category
2014**

Month	Saloon cars	Mini bus/Mum wagon	Large bus/truck (tourist coaches)	pick-up vans/4x4/ SUV	Articulated trucks (trailer included)
January	296,478	203,723	41,463	55,960	25,041
February	278,127	188,054	35,767	50,394	22,577
March	303,676	179,409	48,703	55,954	22,810
April	276,675	191,816	40,339	56,693	23,032
May	278,404	189,941	45,246	54,039	25,036
June	301,577	216,029	48,534	66,414	33,831
July	300,279	208,349	48,694	57,077	25,093
August	294,548	203,122	46,144	59,275	21,594
September	291,848	208,295	44,683	54,219	22,369
October	312,816	213,867	48,510	58,657	25,039
November	293,520	192,003	47,874	59,210	21,016
December	299,936	195,932	55,295	64,520	22,201
TOTAL	3,527,884	2,390,540	551,252	692,412	289,639

Source: Compiled with data on daily traffic from GHA, 2015

Table 3. 5: Monthly Vehicular Traffic on Oyibi-Dodowa Motorway by Vehicle Category, 2014.

Month	Saloon cars	Mini bus/Mum wagon	Large bus/truck (tourist coaches)	pick-up vans/4x4 SUV	Articulated trucks (trailer included)
January	104,998	49,499	4,087	42,868	2,132
February	97,069	46,898	4,449	40,128	1,646
March	105,004	51,120	5,170	44,821	2,447
April	97,951	45,876	4,413	39,864	1,767
May	104,489	50,569	4,844	42,777	1,033
June	91,661	46,439	4,314	41,462	749
July	99,722	50,007	3,715	42,267	1,357
August	100,406	49,996	3,469	43,962	1,283
September	98,223	49,414	3,929	44,016	1,231
October	99,122	50,032	3,953	42,849	1,730
November	98,867	48,618	3,707	41,903	2,057
December	102,281	50,663	3,739	43,934	2,366
TOTAL	1,199,793	589,131	49,789	510,851	19,798

Source: Compiled with data on daily traffic from GHA, 2015

3.7 Empirical Estimations

This section deals with the empirical estimations of excess CO₂ emissions at toll plazas. The estimations that will be discussed here are the vehicular energy consumption and total CO₂ emission. In both cases, estimations will explain calculations that apply to the Tema bound and the Oyibi/Frafraha bound toll plazas

Energy Consumption rates ($E_{i,j} - U_{i,j}$) for a specific vehicle category “i” with fuel type “j” due to excess waiting time at a toll plaza, were calculated for all the different vehicular categories using Equation 1.4. In employing this model, specific variables corresponding to specific vehicular categories were used. This enabled the study obtain the different energy consumption rates for specific vehicle categories.

Based on the work by Fuzzi et al. (2006) on Italian Highways, if a car stopped for 3 min at a toll plaza with its engine running it pollutes and consumes the equivalent of 1 km route. This idea was used to estimate energy consumption when there was a toll plaza. For the goal of this study to calculate actual excess emissions in kilograms of CO₂ (kgCO₂) due to waiting time at toll plazas to be achieved, we multiply the rate of excess CO₂ emission by the excess section length due to the additional time caused by the presence of a toll plaza for each vehicle category. Monthly vehicular volumes are applied to per unit excess CO₂ emissions to obtain total excess CO₂ emissions for the year 2014.

3.8 Valuation of CO₂ Emissions

This section explains how the study deals with valuing the cost of emissions at toll plazas considered by this study by using the Carbon Credits approach.

Concerns over global warming have led to proposals for the establishment of markets for greenhouse gas emission reductions. Although formal markets are now being recognized, a number of international exchanges have occurred, whereby power companies and other energy-intensive industries have invested in 'green' projects, to partially offset their emissions of carbon dioxide (CO₂) and other greenhouse gases (Hassall and Associates, 1999). This is known as Carbon Finance which is done through the sale of Carbon Credits. Studies have shown that there are significant CO₂ emission levels around toll plazas and by investing in some 'green project' to reduce carbon emissions caused by toll booth operation, the country could benefit from the monetary value of these credits.

The main gases that are considered when calculating Carbon Credits are: Carbon Dioxide (CO₂) of which 1 ton is equivalent to a Carbon Credit (CC) and Methane CH₄ of which 1 ton is equivalent to 21 Carbon Credits (TopoGeo, 2014). Climate Change mitigation by taking CO₂ out of the atmosphere through carbon sequestration by trees is also considered when calculating Carbon Credits. In such cases the hectares of plantations are considered.

Carbon Credits, just as any other commodity (gold, cocoa, cotton, foreign currency etc.) is traded on the stocks, options and futures market and does not have a constant price. Its price

also depends on market forces. The state of California in the United States being the world's fourteenth largest emitter according to the California Carbon Dashboard (Climate Policy Initiative, 2015), in its efforts to reduce excess emissions and gain some revenue trades its emissions reductions using Carbon Credit prices quoted by the New York Stock Exchange (NYSE).

In this study, after total excess CO₂ emissions has been estimated as described, this estimated value will be converted into Carbon Credits using the current price as quoted by the NYSE after which the actual cost in monetary terms will be obtained as shown in Equation 1.1d. The monetary value would be the current cost of excess emissions at Toll plazas due to inefficiencies or congestion but would be a gain to the country if these Toll plazas are removed or managed efficiently.

To obtain the exact per unit emission earnings in monetary terms that Ghana can obtain by managing CO₂ emissions through efficient measures, the study will convert the kilograms of CO₂ emitted (kg CO₂) for a single vehicle in each category as obtained using the methodology into tons (Long ton) of CO₂ (tCO₂), which will then be multiplied by the current rate of Carbon Credit as quoted by the NYSE. Finally, monthly vehicular volumes are applied to per unit earnings to obtain total excess CO₂ emission for the year 2014.

CHAPTER FOUR

ESTIMATION AND DISCUSSION OF RESULTS

4.1 Introduction

In this chapter, we present the analysis of the influence of Toll Plazas on the level of CO₂ emissions. There will be a discussion of the results of the estimations. This chapter will have four sections. The first section will discuss of the distribution and summary statistics of vehicle count at the toll plazas considered. The second section will discuss the types of data that were employed in the various toll plaza scenarios considered for the estimations. The third section will entail the actual presentation of how total vehicular energy consumption and CO₂ emission rates were obtained and converted to actual emissions for each vehicle category. The fourth section will then deal with the value calculation of CO₂ emissions through the Carbon Credit approach. In these discussion the particular results of each section will be discussed in the process.

4.2 Distribution of Vehicular Count

Aggregated values of vehicular traffic forming the primary data for the survey was analyzed in terms of the categories they fell into. In the survey it was observed that 7,451,727 vehicles comprising the five vehicle categories passed through the Tema bound (one direction) toll plaza in the year 2014. The Oyibi/Frafraha bound toll booth (both directions) recorded a total value of 2,369,362 vehicles for that same year. As discussed in chapter three vehicular data was collected in relation to the shifts run at each toll plaza. This enabled vehicle counts to be aggregated in terms of the morning, afternoon and night shifts and also ascertain the shift

that will reveal the highest level of emissions. Tables 4.1a and 4.1b show the total vehicle volume for the Tema-Bound Toll and Oyibi/Frafraha bound toll Plaza in Shifts⁶ for the various vehicular categories. The monthly breakdown for each vehicle category for the two study sites is found in tables 3.4 and 3.5 in chapter three.

Table 4. 1a: Total Vehicle Volume in Shifts at the Tema bound Toll Plaza, 2014

SHIFT	Saloon Cars	Mini Bus/Mum Wagon	Large Bus/ Large Truck	Pick-up/ 4X4/ SUV	Articulator/Heavy Trucks	Total Shift Volume
Morning	1,365,397	990,166	236,478	276,344	103,785	2,972,170
Afternoon	1,403,388	932,609	235,484	269,184	135,354	2,976,019
Night	765,099	468,263	79,290	146,884	48,920	1,508,456
Total Yearly Volume	3,533,884	2,391,038	551,252	692,412	288,059	7,456,645

Source: Compiled with data on daily traffic from GHA, 2015.

Table 4.1b: Total Vehicle Volume in Shifts at the Oyibi/Frafraha bound Toll Plaza, 2014

SHIFT	Saloon Cars	Mini Bus/Mummy Wagon	Large Bus/ Large Truck	Pick-up/ 4X4/ SUV	Articulator/Heavy Trucks	Total Shift Volume
Morning	505,173	261,983	21,672	229,054	10,509	1,028,391
Afternoon	526,934	262,298	22,104	231,251	7,291	1,049,878

⁶ Morning: 6am-1pm, Afternoon: 1pm-8pm and Night: 8pm-6am

Night	167,686	64,850	6,013	50,546	1,998	291,093
Total Yearly Volume	1,199,793	589,131	49,789	510,851	19,798	2,369,362

Source: Compiled with data on daily traffic from GHA, 2015

As regards to vehicular traffic at the Tema bound Toll plaza in the year 2014, the morning shift recorded a total morning shift figure of 2,972,170 with the Saloon/Passenger vehicle category recording the highest number of vehicles (1,365,397) and the Articulated/Heavy Trucks recording the lowest number of vehicles (103,785). The afternoon shift in the same regard following closely recorded approximately 2,976,019 vehicles going through the toll plaza with the same vehicle categories recording the highest (1,403,388) and lowest (135,354) vehicle count as observed in the morning shift. The night shifts also recorded a total vehicular count of 1,508,456 with the same category of vehicles as observed above recording the highest (765,099) and lowest (48,920) vehicle counts respectively. It was also observed that the total count observed for the afternoon count was the highest in terms of vehicular traffic at the Tema bound toll plaza followed by the morning with the night shifts recording the lowest vehicular volume among the shifts. Specific breakdowns of monthly vehicular category count in terms of the various shifts at the Tema-bound toll plaza can be found in the Appendix I.

As regards to vehicular traffic at the Oyibi/Frafraha bound Toll booth, the afternoon shift recorded a total shift figure of 1,049,878 with the Saloon/Passenger vehicle category recording the highest number of vehicles (526,934) and the Articulated/Heavy Trucks recording the lowest number of vehicles (7,291). The morning shift however recorded approximately 1,028,391 vehicles going through the toll booth with the same vehicle categories recording the highest (505,173) and lowest (10,509) vehicle count as observed in the morning shift. The night shifts then recorded a total vehicular count of 291,093 with the same category of vehicles as observed in the two other shifts recording the highest (167,686) and lowest (1,998) vehicle counts respectively. It was also observed in this case that the total vehicle volume count observed for the afternoon shift was the highest in terms of vehicular traffic at the toll booth followed by the morning and then the night shift. Monthly totals of the different vehicular categories not mentioned above but obtained for the various shifts at the Oyibi/Frafraha bound toll plaza can also be found in the Appendix II.

4.3 Results from Toll Scenarios

One objective of this paper was to estimate the volume of emissions resulting from vehicular idle time using specific toll plazas as case studies. To reach this objective, different case scenarios relating to different contributing factors of idleness were set in order to make concrete conclusions. For all the scenarios, the area of modeling included a 300 m road section which included the tolling station roughly located in the mid-section of the road considered. The study considers two cases using a Saloon car at the two toll plazas. This has been described as scenario “A” and “B” in Table 4.2. Scenario A shows there is a free flow of traffic without any obstruction such as a toll plaza and the vehicle does not totally stop at the toll

station and scenario B, where there is a pause to pay the toll and communicate with the toll staff. Information on vehicular driving conditions at the tolls was obtained with the help of a LiDAR gun.

Table 4. 2: Scenarios of different toll systems and driving conditions for both Case Studies.

Scenario/toll system	Description	Driving condition			
Scenario A	Free flow: vehicles pass toll without stop	Constant velocity: 13.8 m/s (Oyibi) 13.8 m/s (Tema) Distance travelled: 300 m (Both)			
Scenario B	Traditional toll: Vehicles pass toll, there are three steps of the procedure: deceleration (dec) – stop – acceleration (acc)		Deceleration	Acceleration	Units
		dec/acc	1.8	2.3	m/s ²
		Initial Velocity	13.8	0.0	m/s
		Final velocity	0.0	13.8	m/s
		Distance travelled	150	150	m

Source: Authors Computations using results from LiDAR Gun, 2015

It was observed in scenario ‘A’ that when there was no toll plaza, all the vehicles travelled the 300 m section at the Tema bound and the Oyibi bound toll plazas with a constant velocity of 13.8 m/s since the distance being travelled is the same. In scenario B however, due to the

stop and go processes present at the toll plaza, values observed were different. In this scenario, vehicles travelled 100m then decelerated while approaching the toll plaza to pay the toll which covered 100m, then proceeded to accelerate 100m after toll payment. The deceleration and acceleration rates at the Tema bound and Oyibi/Frafraha bound toll plazas were 1.8 m/s^2 and 2.3 m/s^2 respectively. Observed data for initial and final velocity in the above case did not differ from constant velocities observed scenario “A”.

4.4 Average Waiting Time

Average waiting time in a toll plaza plays a vital role in transportation emissions as stated by Beevers and Carslaw (2005) as well as Smit et al. (2008). In this study throughput/service period measured the volume of traffic per unit time departing from each of the toll plaza surveyed. As a result of this assertion, efforts were made to know exactly how long it takes for each vehicle category to move through a toll booth at the two study sites. This analysis for waiting time deals with the “Stop and Go” stage comprising deceleration, queuing, service and finally acceleration. Service time and throughput data were collected for MTC toll-booths during morning, afternoon and night shifts over a one week period to obtain accurate average waiting times for both study sites

It should be noted that according to Fuzzi et al. (2006) a vehicle that is stationary with its engine running for 3 minutes pollutes and consumes the equivalent of 1km. Table 4.3 and Table 4.4 shows the breakdown of average waiting time at the Oyibi/Frafraha and the Tema-bound toll plazas respectively for all the vehicle categories considered with their excess distances calculated in km for energy consumption calculations.

Table 4. 3: Average waiting Time At the Oyibi/Frafraha Toll Plazas with Excess Distance

	SALOON CARS (Secs)	MINI BUS,MUM WAGON (Secs)	LARGE BUS, LIGHT TRUCK (Secs)	PICK UP, VANS, 4X4, SUV's (Secs)	ARTICULATED TRUCK (Secs)
Deceleration (U_d)	10	10	25	10	35
Queuing (FC_q)	125	125	125	125	125
Service Stage (FC_s)	6	6	10	6	15
Acceleration (U_{ac})	9	9	20	9	35
Total Waiting Time (Secs)	150	150	180	150	210
Total Excess Distance (km)	0.833	0.833	1	0.833	1.167

Source: Authors Computations using measurements from fieldwork, 2015

Table 4. 4: Average waiting Time At the Tema-bound Toll Plazas with Excess Distance

	SALOON CARS (Secs)	MINI BUS,MUM WAGON (Secs)	LARGE BUS, LIGHT TRUCK (Secs)	PICK UP, VANS, 4X4, SUV's (Secs)	ARTICULATE D TRUCK (Secs)
Deceleration (U_d)	15	15	15	15	20
Queuing (FC_q)	60	60	60	60	60
Service Stage (FC_s)	6	6	10	6	15
Acceleration (U_{ac})	9	9	20	9	25
Total Waiting Time (Secs)	90	90	105	90	120
Total Excess Distance (km)	0.5	0.5	0.583	0.5	0.667

Source: Authors Computations using data from Fieldwork, 2015

These waiting periods for each vehicle category was obtained by means of averaging the processes observed at every 15 minutes vehicular flow during the survey period of the toll-booths as done by Padayhag and Sigua (2003) in the Philippines. This mode of measurement records the representative processing time at the tollbooth in a way that calculation is applicable to different modes of toll payment namely: manual scheme, mixed-modes and the dedicated Electronic-pass lane.

From the tables above tables, service stage time for Large buses and Articulator was observed to be higher than normal because of the nature of such vehicles similar to average service time results obtained by Padayhag and Sigua (2003) in Manila (Philippines). The sizes of such vehicles prevent the drivers from easy access to the toll attendants for payment. Usually both attendant and driver have to stretch their hands for money/receipt exchange. Also there are instances of some load carrying articulated vehicles hitting the booths and scratching against the medians in an attempt to use the toll lanes. Acceleration and Deceleration times of the heavier vehicles are also greater than the lighter vehicles. All this contributes to increased waiting time for heavy vehicles as compared to lighter ones.

4.5 Results for Energy Consumption Rates

The Table 4.5 shows the parameters for each vehicle category used to calculate energy consumption based on the scenarios discussed.

Table 4.5: Specific Vehicle Category Parameters Used For Energy Consumption Calculations for Both Case Studies

Parameter	Notation	Units	Saloon Cars	Mini Bus/Mum Wagon	Large bus/ Large truck	Pickup/ 4x4/ SUV	Articulated/ Heavy Truck
Rotational mass of vehicle	M_{fr}	kg/m ²	43.15	200.5	611.42	93.94	1677.4
Frontal area	A_f	m ²	2.52	6.02	8.67	5.13	8.62
Relative vehicle velocity	v_r	m/s	13.8	12.5	10.6	13.5	9.8
Rate of acceleration	a	m/s ²	2.3	2.1	2	2.2	1.5
Engine Efficiency	η_{motor}		0.27	0.4	0.4	0.4	0.4
Vehicle Mass	m	kg	2,100	8,000	18,000	3,500	40,000
Air density	ρ	kg/m ³	1.164	1.164	1.164	1.164	1.164
Slope/Gradient	θ	rad	0	0	0	0	0
Actual Section Length	L	km	0.3	0.3	0.3	0.3	0.3
Excess Distance (Oyibi)	$d_i, d_r,$ and d_a	km	0.833	0.833	1	0.833	1.167
Excess Distance (Tema)	$d_i, d_r,$ and d_a	km	0.467	0.467	0.583	0.467	0.667

Source: Authors computations using data from LiDAR and Fieldwork, 2015

From the mechanical model in Equation 1.4 energy consumption rates were obtained for each vehicle category “i” with fuel type “j”. For Saloon cars the result obtained for energy consumption at the Oyibi/Frafraha bound and the Tema bound toll plaza is calculated using Equations 2.1 and 2.2 respectively. As revealed by field observations, driving conditions

relating to speed did not vary at the two study sites when measured by the LiDAR gun but service time and queuing time which make up waiting time at the two toll plazas varied. The difference in the two equations are the excess distance travelled which is the waiting time converted to distance. Like equations 2.1 and 2.2, all subsequent equations of this form are based on Equation 1.4 for the Oyibi/Frafraha-bound and the Tema-bound plazas respectively.

$$\begin{aligned}
 (E_{ij} - U_{ij})_{Oyibi} &= 0.3^{-1}[(1.05 \times 43.15 \times 2.3)0.833 + (0.01 \times 2100 \times \cos 0)0.833 + \\
 &\quad (0.5 \times 1.164 \times 0.35 \times 2.52 \times (13.8)^2)0.833] \times \frac{1}{0.27} \times 1.0 \quad (2.1) \\
 &= 2,292.95768
 \end{aligned}$$

$$\begin{aligned}
 (E_{ij} - U_{ij})_{Tema} &= 0.3^{-1}[(1.05 \times 43.15 \times 2.3)0.467 + (0.01 \times 2100 \times \cos 0)0.467 + \\
 &\quad (0.5 \times 1.164 \times 0.35 \times 2.52 \times (13.8)^2)0.467] \times \frac{1}{0.27} \times 1.0 \quad (2.2) \\
 &= 1,285.487680
 \end{aligned}$$

Calculations show that excess energy consumption rate for saloon cars on the Oyibi/Frafraha toll plaza is 2,293 MJ/veh-km and excess energy consumption rate is 1,285 MJ/veh-km on the Tema bound toll plaza for the same vehicle category.

For the Mini bus/Mummy wagon category Equations 3.1 and 3.2 describe the equations employed to obtain energy consumption values at the Oyibi/Frafraha and the Tema bound toll plazas respectively.

$$\begin{aligned}
 (E_{ij} - U_{ij})_{Oyibi} &= 0.3^{-1}[(1.05 \times 200.5 \times 2.1)0.833 + (0.01 \times 8,000 \times \cos 0)0.833 + \\
 &\quad (0.5 \times 1.164 \times 0.35 \times 6.02 \times (12.5)^2)0.833] \times \frac{1}{0.4} \times 1.0 \quad (3.1) \\
 &= 4,954.321732
 \end{aligned}$$

$$\begin{aligned}
 (E_{ij} - U_{ij})_{Tema} &= 0.3^{-1}[(1.05 \times 200.5 \times 2.1)0.467 + (0.01 \times 8,000 \times \cos 0)0.467 + \\
 &\quad (0.5 \times 1.164 \times 0.35 \times 6.02 \times (12.5)^2)0.467] \times \frac{1}{0.4} \times 1.0 \quad (3.2) \\
 &= 2,777.512904
 \end{aligned}$$

Calculations show that excess energy consumption rate is 4,954 MJ/veh-km for mini bus/mummy wagons on the Oyibi/Frafraha toll plaza while excess energy consumption rate is 2,778 MJ/veh-km on the Tema bound toll plaza for the same vehicle category.

For the next vehicle categories i.e. Large bus/Light truck, pick-up/4x4/SUV and Articulated/Heavy truck, Equations 4.1 through to 6.3 are employed respectively to calculate energy consumption values for these vehicle categories for the two toll plazas considered.

$$\begin{aligned}
 (E_{ij} - U_{ij})_{Oyibi} &= 0.3^{-1}[(1.05 \times 611.42 \times 2.0)1.0 + (0.01 \times 18,000 \times \cos 0)1.0 + \\
 &\quad (0.5 \times 1.164 \times 0.35 \times 8.67 \times (10.6)^2)1.0] \times \frac{1}{0.4} \times 1.0 \quad (4.1) \\
 &= 13,853.489
 \end{aligned}$$

$$\begin{aligned}
 (E_{ij} - U_{ij})_{Tema} &= 0.3^{-1}[(1.05 \times 611.42 \times 2.0)0.583 + (0.01 \times 18,000 \cos 0) 0.583 + \\
 &\quad (0.5 \times 1.164 \times 0.35 \times 8.67 \times (10.6)^2)0.583)] \times \frac{1}{0.4} \times 1.0 \quad (4.2) \\
 &= 8,076.5838
 \end{aligned}$$

Calculations show that excess energy consumption rate is 13,853 MJ/veh-km for Large bus/Light trucks at the Oyibi/Frafraha toll plaza and excess energy consumption rate is 8,077 MJ/veh-km on the Tema bound toll plaza for the same vehicle category.

$$\begin{aligned}
 (E_{ij} - U_{ij})_{Oyibi} &= 0.3^{-1}[(1.05 \times 93.94 \times 2.2)0.833 + (0.01 \times 3,500 \times \cos 0)0.833 + \\
 &\quad (0.5 \times 1.164 \times 0.35 \times 5.13 \times (13.5)^2)0.83)] \times \frac{1}{0.4} \times 1.0 \quad (5.1) \\
 &= 3,071.33477
 \end{aligned}$$

$$\begin{aligned}
 (E_{ij} - U_{ij})_{Tema} &= 0.3^{-1}[(1.05 \times 93.94 \times 2.2)0.467 + (0.01 \times 3,500 \times \cos 0)0.467 + \\
 &\quad (0.5 \times 1.164 \times 0.35 \times 5.13 \times (13.5)^2)0.467)] \times \frac{1}{0.4} \times 1.0 \quad (5.2) \\
 &= 1,721.86475
 \end{aligned}$$

Calculations show that excess energy consumption rate is 3,071 MJ/veh-km for Pick up vans/4x4's on the Oyibi/Frafraha toll plaza and excess energy consumption rate is 1,722 MJ/veh-km for the Tema bound toll plaza regarding the same vehicle category.

$$\begin{aligned}
 (E_{ij} - U_{ij})_{Oyibi} &= 0.3^{-1}[(1.05 \times 1677.4 \times 1.5)1.167 + (0.01 \times 40,000 \times \\
 &\cos 0)1.167 + (0.5 \times 1.164 \times 0.35 \times 8.62 \times (9.8)^2)1.167] \times \frac{1}{0.4} \times 1.0 \quad (6.1) \\
 &= 31,222.5118
 \end{aligned}$$

$$\begin{aligned}
 (E_{ij} - U_{ij})_{Tema} &= 0.3^{-1}[(1.05 \times 1677.4 \times 1.5)0.667 + (0.01 \times 40,000 \times \\
 &\cos 0)0.667 + (0.5 \times 1.164 \times 0.35 \times 8.62 \times (9.8)^2)0.667] \times \frac{1}{0.4} \times 1.0 \quad (6.2) \\
 &= 17,845.25739
 \end{aligned}$$

Calculations show that excess energy consumption rate for Articulator/Heavy trucks on the Oyibi/Frafraha bound toll plaza is 31,223MJ/veh-km while excess energy consumption rate is 17,845 MJ/veh-km for this same category on the Tema-bound toll plaza

From the above it can be concluded that in all the different types of energy consumption estimated for the two toll different toll plazas the Articulator/Heavy truck category has the highest level of energy consumption rate followed by the Large bus/Light truck category, Mini vans/ Mummy wagons, Pick-up/Vans/4x4/SUV category, and the Saloon Car category.

4.6 Results for Vehicular CO₂ Emission

After the estimations for energy consumption, Equations 1.1c was applied to obtain the rate of total excess CO₂ emissions. Table 4.6a shows how energy consumption rates obtained at

the two toll plazas and Carbon Emissions Factors (CEF) were multiplied to obtain per vehicle excess CO₂ emissions rates in kilograms of CO₂ (kg CO₂/veh-km) for each vehicle category at the two study sites. Since this excess CO₂ value obtained is a rate, Table 4.6b goes ahead to multiply this rate by the excess section length travelled by each vehicle category at both toll plazas to obtain actual CO₂ emissions as shown in Equation 1.1d. This is then converted to tons⁷ (long ton) for valuation purposes.

Table 4.6a: Calculation for CO₂ Emission Rates in kgCO₂/veh-km at the two toll plazas

Vehicle Type	Energy Consumption at Frafraha ($E_{i,j} - U_{i,j}$) _{oyibi} MJ/veh-km	Energy Consumption at Tema ($E_{i,j} - U_{i,j}$) _{tema} MJ/veh-km	Carbon Emission Factor (CEF) kgCO ₂ /MJ	Rate of CO ₂ Emissions at Frafraha ($E_{i,j} - U_{i,j}$) _{oyibi} (CEF) kgCO ₂ /veh km	Rate of CO ₂ Emissions at Tema ($E_{i,j} - U_{i,j}$) _{tema} (CEF) kgCO ₂ /veh km
Saloon Car	2,292.957682	1,285.48768	0.086	197.19	110.55
Mini bus	4,954.321732	2,777.51290	0.081	401.30	224.98
Large bus	13,853.4886	8,076.58388	0.081	1,122.13	654.20
Pick up/4x4	3,071.334775	1,721.864754	0.081	248.78	139.47
Heavy truck	31,222.51181	17,845.25739	0.081	2,529.02	1,445.47

Source: Authors Computations, 2015

These total excess emissions in tCO₂ for a single vehicle in each vehicle category were multiplied by the monthly vehicular traffic volume to obtain the total monthly CO₂ emissions

⁷ 1kg=0.00098tons

for the two toll plazas considered. The same was done for shift vehicular volume to obtain shift emissions. Tables for monthly CO₂ emissions for the year 2014 at the two toll plazas studied using volume data obtained from GHA (Tables 3.4 and 3.5) can be found in the Appendix V. Total yearly and shift emissions for the vehicular categories at the Accra/Tema bound and the Oyibi/Frafraha bound toll plazas is summarized in Tables 4.7a and 4.7b respectively. It should however be noted that, since vehicle traffic data obtained from GHA for the Tema bound toll plaza was for one way traffic, the study obtained excess emissions for two-way traffic by multiplying excess emissions calculated from Table 4.1a by 2 to obtain the approximate shift emissions due to excess waiting time at the two toll plazas located on the Tema motorway as shown in Table 4.7b.

It can be observed that the Articulator/Heavy truck category records the highest level of excess emissions at the Oyibi/Frafraha bound toll plaza followed by the Large bus/Light truck vehicle category, Mini bus/Mummy wagon category, the Pick-up/Van/SUV category and least being the Saloon car category. With regards to excess CO₂ emissions at the Tema bound toll plaza the Articulator/Heavy truck category still records the highest level of emissions followed by the Large bus/Large truck category, the Mini bus/Mummy wagon category, the Pick-up/Van/SUV category and finally the Saloon car category.

These excess emissions are high as compared to studies by Hernández, Monzon and Sobrino (2013) as well as Pérez-Martinez et al. (2011). This is due to the fact that in those studies, research considers queuing and service time only, and aggregates these processes as ‘waiting

time'. Moreover, Opoku-Boahen, Adams, & Salifu (2013) also consider waiting time as the difference between a specific vehicles arrival and departure time at a toll plaza. In so doing waiting time is relatively smaller as a result of the bias that only two stages are observed at a toll plaza. In this study however, additional processes such as deceleration and the initial acceleration of vehicles witnessed as a result of the presence of a toll station are included in the calculation of 'waiting time'.



Table 4.6b: Excess CO₂ Emissions in kgCO₂ and tCO₂ Due To the Presence of Toll Plazas at the Two Study Sites

Vehicle Type	Rate of CO ₂ Emissions at Frafraha (C _{i,j}) _{Oyibi} kgCO₂/km	Rate of CO ₂ Emissions at Tema (C _{i,j}) _{Tema} kgCO₂/km	Excess Section Length at Frafraha (L _i) _{Oyibi} km	Excess Section Length at Tema (L _i) _{Tema} km	Actual CO ₂ Emissions at Frafraha Toll (C _{i,j} × L _i) _{Oyibi} kgCO₂	Actual CO ₂ Emissions at Tema Toll (C _{i,j} × L _i) _{Tema} kgCO₂	Actual CO ₂ Emissions at Frafraha Toll (CT _{i,j}) _{Oyibi} tCO₂	Actual CO ₂ Emissions at Tema Toll (CT _{i,j}) _{Tema} tCO₂
Saloon Car	197.19	110.55	0.833	0.5	164.26	55.28	0.162	0.054
Mini bus	401.30	224.98	0.833	0.5	334.28	112.49	0.329	0.111
Large bus	1,122.13	654.20	1	0.58	1,122.13	379.44	1.104	0.373
Pickup/4x4	248.78	139.47	0.833	0.5	207.23	69.74	0.204	0.069
Heavy truck	2,529.02	1,445.47	1.167	0.67	2,951.37	968.46	2.905	0.953

Source: Authors Computations, 2015

Table 4.7a: Total Vehicular CO₂ emissions (tCO₂) by vehicle category in Shifts at the Oyibi/Frafraha bound Toll Plaza, 2014

SHIFT	Saloon Cars	Mini Bus/Mum Wagon	Large Bus/ Large Truck	Pick-up/ 4X4/ SUV	Articulator/Heavy Trucks	Total Shift Emissions
Morning	81,838	86,192	23,926	46,727	30,529	269,212
Afternoon	85,363	86,296	24,403	47,175	21,180	264,418
Night	27,165	21,336	6,638	10,311	5,804	71,255
Total Yearly Emissions	194,366	193,824	54,967	104,214	57,513	604,884

Source: Authors Computations using data from Fieldwork and GHA, 2015

Table 4.7b: Total Vehicular CO₂ Emissions (tCO₂) by vehicle category in Shifts at the Accra and Tema bound Toll Plazas, 2014

SHIFT	Saloon Cars	Mini Bus/Mum Wagon	Large Bus/ Large Truck	Pick-up/ 4X4/ SUV	Articulator/Heavy Trucks	Total Shift Emissions
Morning	147,463	219,817	176,413	38,135	197,814	779,642
Afternoon	151,566	207,039	175,671	37,147	257,985	829,408
Night	82,631	103,954	59,150	20,270	93,242	359,247
Total Yearly Emissions	381,659	530,810	411,234	95,553	549,040	1,968,297

Source: Authors Computations using data from Fieldwork and GHA, 2015

At the Oyibi/Frafraha bound toll plaza, the Saloon car category recorded the highest annual excess emissions of 194,366 tCO₂ whereas the Large bus/Light truck category recorded the least of 54,967 tCO₂ at the same toll plaza. On the Tema motorway it is seen that the Articulator/Heavy truck category recorded the highest annual excess emissions of 549,040 tCO₂ while the Pick-up/4x4/SUV category recorded the least annual excess emissions of 95,553 tCO₂.

4.7 Results for Carbon Credit Allocation (Valuation)

The valuation of cost for CO₂ emissions is done by employing the Carbon Credit (CC) approach as discussed in chapter three. As the excess total emissions is known, the study goes ahead to calculate how much Carbon Credit can be accessed from avoidance of the excess CO₂ emissions obtained through efficient tolling such as the introduction of the Electronic Toll Collection (ETC) systems. This gives the study the opportunity to estimate in monetary terms how much the country can make from managing toll plaza efficiently. As at 30th June 2015, the current price of Carbon Credit as listed by the New York Stock Exchange (NYSE) was \$12.72 (Climate Policy Initiative, 2015) and was used to calculate the cost of excess emissions at the study sites.

Excess CO₂ emissions calculated for the two study sites for each vehicle category is multiplied by the current price of a ton of CO₂ to obtain the earning that can be realised if waiting time is avoided at the toll plaza. Table 4.8 summarizes the valuation of excess CO₂ per vehicle category in Carbon Credits for the two study sites based on Equation 1.1e.

Table 4.8: Valuation of CO₂ in Carbon Credits (CC) by Vehicle Categories

Vehicle Type	Actual CO ₂ Emissions at Frafraha Toll ($CT_{i,j}$) _{Oyibi}	Actual CO ₂ Emissions at Tema Toll ($CT_{i,j}$) _{Tema}	Value of Carbon Credit per tCO ₂ (\$CC)	Value of Excess CO ₂ at Frafraha (US\$) ($CT_{i,j}$) _{Oyibi} (CC)	Value of Excess CO ₂ at Tema (US\$) ($CT_{i,j}$) _{Tema} (CC)
Saloon Car	0.162	0.054	12.72	2.06	0.69
Mini bus	0.329	0.111	12.72	4.19	1.41
Large bus	1.104	0.373	12.72	14.04	4.75
Pick up/4x4	0.204	0.069	12.72	2.60	0.88
Heavy truck	2.905	0.953	12.72	36.95	12.12

Source: Authors Computations using data from fieldwork, 2015

From Table 4.8, it is seen that for the Saloon car category it is estimated that Ghana can earn about \$2.06 on a single vehicle in this category at the Oyibi/Frafraha bound toll station if waiting time is avoided and \$ 0.69 on this same vehicle category at the Tema bound toll plaza. For the Mini bus/mummy wagon vehicle category it is estimated that Ghana can earn about \$ 4.19 on a single vehicle in this category at the Oyibi/Frafraha bound toll station if waiting time is avoided and \$ 1.41 on this same vehicle category at the Tema bound toll plaza if the same measures are taken. Also, for the Large bus/Large truck category it is estimated that if waiting time is avoided the country can earn \$14.04 on a single vehicle in this category at the Oyibi/Frafraha bound toll station if waiting time is avoided whereas the presence of the Tema bound toll station creates excess emissions worth \$ 4.75 in Carbon Credits if waiting time at this toll station is avoided. For the Pick-up/vans/SUV category it is also estimated that Ghana can earn about \$2.60 on a single vehicle in this category at the Oyibi/Frafraha bound toll station if waiting time is avoided whereas \$0.88 on this same vehicle category can be earned at the Tema-bound toll plaza if waiting time is avoided.

Lastly, the country can earn \$36.95 on a single vehicle in the Articulator/Heavy truck category by avoiding the excess emissions caused by waiting time at the Oyibi/Frafraha bound toll plaza. Also, an amount of \$12.12 can be earned from Carbon Credits from a single vehicle in the same category when waiting time is avoided at the Tema-bound toll plaza.

Knowledge on the amount the country can earn on each vehicle category can help deduce the average monthly CO₂ emission earnings from Carbon Credits for the Tema-bound toll plaza (Big plaza) and the Oyibi/Frafraha toll plaza (Small plaza) using volume data from GHA. The monthly earnings on total shift emissions is found in Appendix VI and VII while total monthly vehicular traffic excess emissions at the same study sites can be found in Appendix VII. The study wanted to ascertain the total shift earnings from traffic emission for the year 2014 based on GHA data at the two study sites if average waiting time (idle time) exacerbating excess CO₂ is reduced. In doing this total average shift vehicular CO₂ emissions from Tables 4.7a and 4.7b were multiplied by the CC value per vehicle category from Table 4.8 depending on the study site. Tables 4.9a and 4.9b summarize the calculations for these Carbon Credit earning for the Accra/Tema bound and the Oyibi/Frafraha bound Toll plazas respectively for the shift periods.

Table 4.9a: Total CC Earnings (US\$) for Shift Periods at the Oyibi/Frafraha bound Toll Plaza in 2014

SHIFT	Saloon Cars	Mini Bus/Mum Wagon	Large Bus/ Large Truck	Pick-up/ 4X4/ SUV	Articulator/Heavy Trucks	Total Earnings
Morning	168,586	361,146	335,919	121,490	1,128,033	2,115,176
Afternoon	175,848	361,580	342,616	122,656	782,614	1,785,314
Night	55,960	89,396	93,202	26,810	214,465	479,833
Total Yearly Earnings	400,395	812,123	771,737	270,955	2,125,112	4,380,323

Source: Authors Computation using data from fieldwork and GHA, 2015

Table 4.9b: Total CC Earnings (US\$) for Shift Periods at the Accra and Tema-bound Toll Plazas in 2014

SHIFT	Saloon Cars	Mini Bus/Mum Wagon	Large Bus/ Large Truck	Pick-up/ 4X4/ SUV	Articulator/Heavy Trucks	Total Earnings
Morning	101,749	309,942	837,960	33,559	2,397,508	2,842,759
Afternoon	104,580	291,925	834,438	32,690	3,126,775	3,555,970
Night	57,015	146,576	280,964	17,838	1,130,087	1,351,516
Total Yearly Earnings	263,345	748,443	1,953,361	84,087	6,654,370	7,750,245

Source: Authors Computation using data from fieldwork and GHA, 2015

Total annual earnings from the Tema bound toll plaza show that if toll plazas are removed the country can earn about \$4,946,719 while a total annual earning of \$4,824,132 can be earned if the Oyibi/Frafraha toll plaza is removed. The combined earning from the removal of the two toll plazas located on the Tema motorway can earn the country about \$7,750,245. Emissions earnings from shifts also revealed that for the Tema toll plazas the afternoon shift earns the highest in Carbon Credits. For the Oyibi/Frafraha toll plaza the morning shifts recorded the highest earnings. Monthly earnings in the three shifts can be found in the Appendix VI and VII.

4.8 Conclusions

The study found that at the Oyibi/Frafraha toll plaza, lighter vehicles wait an average of 150 seconds from deceleration, queuing, service time (toll payment) to acceleration whereas heavy vehicles wait an average of between 180 and 210 seconds. At the Tema-bound toll plaza, waiting time for light vehicles was 90 seconds from deceleration, queuing, service time (toll payment) to acceleration and also between 105 and 120 seconds for heavy vehicles for the same stages. This can be attributed to the fact that bigger toll plazas like the Tema bound toll plaza have more booths compared to smaller toll plazas like the Oyibi/Frafraha bound toll plaza that have just a single booth attending to vehicles from all directions. Also, at the Oyibi/Frafraha toll plaza, the study observed that the presence of a Police barrier close to the toll plaza also contributed to the increase in waiting time there. Since these waiting times are converted to excess distances that affect CO₂ emissions, the study confirms the fact based on the above results that, the presence of a toll station can result in excess emissions when there is waiting time.

As similar to results obtained by Pérez-Martinez et al. (2011) in Spain, this study also concluded that the Articulator/Heavy truck category records the highest level of per vehicle excess emissions at the Tema-bound toll plaza followed by the Large bus/Light truck vehicle category, Mini bus/Mummy wagon category, the Pick-up/Van/SUV category and least being the Saloon car category. With regards to excess emissions at the Oyibi/Frafraha bound toll plaza, the Articulator/Heavy truck category still records the highest level of emissions followed by the Large bus/Large truck category, the Mini bus/Mummy wagon category, the Pick-up/Van/SUV category and finally the Saloon car category. Case studies also showed that energy consumption and CO₂ emissions were directly related to vehicle mass, engine efficiency, acceleration rate and the amount of waiting time. As was seen in the analysis, when these variables increased, energy consumption and CO₂ emissions also increased

Although the Articulator/Heavy truck vehicle tops in terms of individual emissions, this is not the case in terms of results for the total emissions per vehicle going through the Oyibi/Frafraha bound toll plazas. As GHA vehicular volume confirmed, Saloon cars are the most common at this toll plaza, hence that category records the highest amount of total emissions followed by Mini buses/mummy wagons, Pick-up/Vans/SUV's, Large buses/truck and the least volume recorded being the Articulator/Heavy trucks. As a result of the small nature of the toll plaza, heavy trucks are not very frequent at this toll plaza, making the aggregation of total emissions lower as compared to the other categories. As regards to the Tema bound toll plaza although GHA data also confirms the Saloon car

category as the most common, total CO₂ emissions recorded at this toll plaza showed that the Articulator/Heavy truck records the highest amount total emissions followed by Mini buses/mummy wagons, the Large buses/truck, Saloon cars and the Pick-up/Vans/SUV category. This is mainly because the Tema-bound toll plaza is a major connective link to one of the industrial cities in the country. As a result most heavy and articulated trucks carrying loads to the port use this toll plaza.

Conclusions also drawn for revenue creation through excess emission costs at small toll stations such as the Oyibi/Frafraha toll station differed so much to the conclusions for CO₂ emission costs at big toll plazas such as the Tema toll plazas in terms of the amount of Carbon Credits that can be generated. The cost of emissions at the Oyibi/Frafraha bound toll station was \$4,824,132 while that of the combined Tema toll plazas was \$7,750,245. A big difference of \$2,926,113 although waiting time at the Accra and Tema bound toll plazas was lower than that of the Oyibi/Frafraha bound toll plaza. This is because total excess emissions generated at a toll plaza depends significantly on the waiting time at the particular toll plaza and also the vehicular traffic. The Accra/Tema bound toll plaza has significant vehicular traffic but a lower waiting time since there are more booths and personnel to cater for the volume. The Oyibi/Frafraha bound toll plaza on the other hand has lower vehicular volume but a higher waiting time. Total emissions and subsequent valuation shows that each of the toll plazas studied has either vehicular volume or waiting time being higher, hence the disparity in Carbon Credit revenue.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Introduction

This chapter concludes the research by providing a summary of the entire study. Moreover, the findings of the entire research are also summarized in this chapter. The major conclusions on findings that were made while estimating the cost of emissions at the toll plazas used are also discussed in this chapter. These conclusions serve as a basis on which recommendations have been made for policy makers to consider.

5.2 Summary and Conclusions

A central implication of Climate Change is that, the amount of greenhouse gases in the atmosphere is increasing of which there is a vast body of studies that attest to this fact. Although there is no overall consensus among researchers on the varying amounts and magnitudes of GHG's currently in the atmosphere in fields such as Agriculture, Transport and Industry; none dispute the fact that the amount of GHG emissions are increasing.

Despite these enormous studies, there still remains a gap to be filled because studies aimed at estimating CO₂, a greenhouse gas, at specific areas in the fields mentioned above is lacking. For instance the contribution of toll plazas to overall transport emissions in Ghana or Sub Saharan Africa can be said to be a grey area to researchers. Although these toll

stations have been found to be significant hubs for excess CO₂ generation the exact quantity has eluded research.

Hence the necessity of this study to estimate and value the level of vehicular CO₂ emissions resulting from vehicular idle time at toll plazas and ascertain if the reduction in excess CO₂ emissions through efficient management could earn Ghana some Carbon Credits to supplement the road fund. This was done in three major steps, first calculating the energy consumption values for each vehicle category, second calculating total CO₂ emissions by multiplying energy consumption by Carbon Emission Factors (CEF) depending on fuel type and thirdly valuing the amount of emissions using the going rate for a ton of CO₂ in Carbon Credit terms.

The relevant theoretical literature reviewed showed that the transport sector produces significant amounts of pollutants that are global in nature. Meaning that the impacts of one ton of carbon dioxide emissions are the same no matter where it is emitted. Moreover narrowing the review to Ghana, literature also showed that the most abundant greenhouse gas produced and emitted in Ghana is CO₂. This has necessitated the development of a variety of definitions and procedures for the calculation of transport carbon footprints. Literature further showed that car use, road, freight and aviation are the principal contributors to greenhouse gas emissions from the transport sector. It continues to state that the increasing temperatures observed in recent years is very likely due to the increase in man-made greenhouse gas concentrations coming from the transport sector.

Empirical reviews also concluded that there is potential positive effect of the introduction of Intelligent Transport System (ITS) technologies on the environmental impacts of toll plazas and how its introduction can reduce GHG emissions. Through this, the study sought to investigate another dimension of revenue generation through Carbon Finance from the reduction in transport emissions at toll plazas.

As a result the study's specific objectives was to ascertain the vehicle category in Ghana that contributes most to CO₂ emissions at toll booths, identify the average waiting time at Ghanaian Toll Plazas, ascertain how much will Ghana earn in carbon Credits if waiting time is reduced and finally advice policy makers on changing the current manual toll collection to more fast and efficient tolling systems.

To achieve the above objectives, the study randomly selected one big (Tema-bound toll plaza) and one small (Oyibi/Frafraha bound) toll plaza based on the criteria explained. After, the study with the help of GHA vehicle classifications, grouped vehicles that went through these toll plazas for the year 2014 into categories. This helped the study obtain results desired by the study objectives in terms of energy consumption, CO₂ emissions and Carbon Credit allocation. After a vehicular cross category analysis based on model variables obtained from literature, fieldwork and agencies was done, some concrete conclusions were drawn in terms of how toll plazas affect CO₂ emissions. The mechanical model used

to calculate energy consumption rates revealed that in per vehicle terms, the Articulator/Heavy truck has the highest level of energy consumption followed by the Large bus/Light truck category, Mini vans/ Mummy wagons category, Pick-up/Vans/SUV category and the Saloon car category for both the Tema-bound toll plaza and the Oyibi/Frafraha bound toll plazas.

This rate was then applied to the CEF to obtain total CO₂ emissions rates at the two study sites. However, since the study wanted to know the effect on emissions as a result of idle/waiting time at these toll plazas, the study went further to collect information on average waiting time. This excess time spent at the toll stations was converted to distance and multiplied by the CO₂ emission rates to obtain actual CO₂ emissions per vehicle due to the presence of the toll plaza. Finally excess per vehicle CO₂ emissions was applied to vehicular traffic data on the Frafraha and the Tema toll plazas to obtain total annual vehicular excess CO₂ emissions for the year 2014.

One of the major additions of this study to literature stems from the idea of revenue creation through a reduction of the CO₂ emissions from toll plazas estimated in the study. The study confirms the fact based on the results obtained that if waiting time is removed completely through efficient measure at the toll booths, the country can earn some amount of revenue from Carbon Credits by selling the reduced cost of CO₂ emissions to supplement the Road Fund. On a monthly as well as shift basis, Ghana can earn huge amounts of revenue in

Carbon Credits at both toll plazas studied by reducing average waiting time of all vehicle categories that pass through such toll stations.

5.3 Recommendations for Policy and Future research

This study which aimed at valuating CO₂ emissions at toll plazas using case studies of the Tema and Oyibi/Frafraha toll plazas has shown results that are similar to related studies and predictions of certain theories. Based on the findings of the study the following recommendations are offered:

Due to the nature of vehicular volume sampled in the year 2014 as well as methodological procedures, this study which sought to value the amount of vehicular emissions at two toll plazas as other studies have done found that, toll plazas are significant niches for excess CO₂ generation. This casts no doubt on the application of efficient measures such as Intelligent Transport Systems (ITS) discussed in the next paragraphs to remedy the situation and in the long run reduce Climate Change as stated by Chapman (2007). Therefore Ghana should also employ efficient and effective means of toll collection that reduce excess humans interaction to ensure reduction in vehicular emissions in order to tap into the monetary gains shown by the study.

This can be done by employing some modern means of revenue collection at toll plazas. As research by Saka et al. (2001) and Teng et al. (2006) have shown, the employment of a modern system such as Electronic Toll Collection (ETC) can greatly reduce toll transaction

time, human interaction and thereby increase service capacity. With this system human interaction at the toll plaza is minimal due to the fact that drivers would need just prepaid cards known in some countries like Singapore as “Cash Cards”. The driver swipes the card at a vending machine when at a toll booth and is allowed passage. In this case there is no need engaging the toll attendants to change bigger denominations which increase idle time.

Another modern measure the country can adopt to ensure efficiency and a reduction in excess emissions at toll plazas is the adoption of the Open Road Tolling (ORT). ORT is a kind of toll collection system where service time is zero and this has been proven by Klondzinski et al. (2012) and also Lin and Yu (2009) to be better than ETC when comparing air quality where these two systems are used. The country can adopt this system with the help of the DVLA. Vehicles, while undergoing yearly registration can be mandated to pay in addition to Road Worthiness some amount of money as Road Fund to serve as a toll fare. The drivers can be supplied with stickers to be pasted on their windscreens after payment. In such a scenario toll plazas will not serve as revenue collection points but as check points to ensure that each vehicle going through has paid through the recognition of the stickers given to them. This can greatly reduce emissions due to avoidance of deceleration and service time.

If the above recommendations are farfetched, then the country should improve on efficient management strategies at the toll stations. Toll stations should be expanded to have about ten (10) booths on each side of the road as explained by Opoku-Boahen et al. (2013) in an

effort to reduce waiting time at smaller toll plazas. They explain that although this approach might be expensive it is a sure way of vehicular emissions reduction since a lot of vehicles can be served at once reducing waiting time. Moreover he suggests that if the proportion of manual lane usage is not reduced substantially in the short term then additional manual lanes would have to be provided to improve the level of service. These additional lanes could be retrofitted into ETC zone lanes in the future. This can be applied to small toll plaza that have a single booth on the truck road serving vehicles from both directions.

Also in relation to the Tema toll plaza efforts should be made to increase the proportion of E-zone lanes usage through attractive packages such as discounts per a number of trips, while some days and hours with very low traffic volume could have no toll charges at all. Though the E-zone lane is an improvement over the manual lanes, the fact that it uses a barrier for enforcement reduces its capacity, much lower waiting/queuing periods could be obtained if the barriers were removed and a system of cameras, backed by appropriate legal framework, were used for the enforcement of toll collection. The Police barrier at the Oyibi/Frafraha toll plaza should also be replaced by the measures explained above.

One other efficient toll management strategy is the creation of Truck only Toll (TOT) lanes where on approaching toll plazas, vehicles in the Articulator/Heavy truck category will have some toll booths designated for only such vehicles so as to be served separately. Based on the study it was concluded that Articulated/Heavy trucks have the highest level of emissions compared to other vehicle categories due to size and service time. Special lanes with

special booths can be designed for the truck to facilitate their movement through the toll plaza so as to reduce emissions from these types of vehicles. Studies done in Atlanta, USA have verified this and shown that emissions can be reduced from such a strategy.

Lastly it should be noted that if some or most of all these management strategies are employed the country can go ahead to access the monetary benefits that go with it to supplement the Road Fund. This is the Carbon Credits Ghana can earn as a result of significantly reducing CO₂ emissions generated at toll plazas. It is advised that policy makers pursue Environmental Plans such as these that go a long way to reduce Climate Change impacts. Also in doing so the country will be ensuring its commitment to the environmental pacts and protocols it has appended its name to.

Future research on transport emissions should be expanded to look for other niches of excess CO₂ generation such as stop lights and very heavily congested traffic. Research should focus on these areas to find out the exact amounts in these CO₂ generation areas and also how to significantly reduce them. Moreover, research should also investigate other efficient toll management measures that are less expensive but can equally meet the goal of reducing CO₂ emissions. Measures like expanding the number of toll station can reduce waiting time but may incur costs to the government. Hence more cost friendly measures should be sought. Lastly future research should also concentrate on the analysis on vehicle volume variation during peak and non-peak periods since waiting time greatly varies according to these periods. Such studies will enable policy makers gain in-depth knowledge on how

peak and non-peak period influence CO₂ emissions at toll plazas and how to work assiduously to minimize such transport emissions.



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APPENDICES

Appendix I: Vehicle Volume for Tema-Bound Toll Plaza in Shifts

Vehicular Count for Morning Shift (TEMA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	112,984	89,355	18,866	23,568	8,754	
February	115,432	68,885	15,923	19,548	7,352	
March	113,861	73,689	17,830	22,158	8,672	
April	111,322	67,938	19,025	26,516	8,354	
May	116,427	83,286	18,309	23,864	9,201	
June	114,732	90,009	20,136	25,068	10,462	
July	113,745	88,362	21,057	23,216	9,210	
August	109,342	95,426	19,953	18,568	8,720	
September	115,321	80,675	17,469	22,954	8,813	
October	115,432	90,289	23,589	26,294	8,671	
November	113,923	78,598	19,753	23,012	7,347	
December	112,876	83,654	24,568	21,578	8,229	
Total	1,365,397	990,166	236,478	276,344	103,785	
Vehicular Count for Afternoon Shift (TEMA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	110,733	77,361	18,785	23,698	11,462	
February	102,468	74,985	14,922	20,567	10,247	
March	126,384	70,417	23,639	20,932	9,766	
April	101,755	89,439	15,579	19,522	11,254	
May	110,648	67,841	21,355	18,954	11,925	
June	132,697	78,442	19,675	26,598	19,477	
July	123,678	80,628	20,419	18,471	12,237	
August	121,483	76,201	19,496	25,987	8,513	
September	113,646	83,568	21,556	17,823	9,578	
October	124,127	86,047	16,684	22,148	13,058	
November	108,722	70,152	19,615	25,691	8,710	
December	127,047	77,528	23,759	28,793	9,127	
Total	1,403,388	932,609	235,484	269,184	135,354	
Vehicular Count for Night Shift (TEMA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	72,761	37,007	3,812	8,694	4,825	
February	60,227	44,184	4,922	10,279	3,497	
March	63,431	35,803	7,234	12,864	4,372	
April	63,598	34,438	5,735	10,655	3,424	
May	51,329	38,814	5,582	11,221	3,910	
June	60,148	47,578	8,723	14,748	3,892	
July	62,856	39,358	7,218	15,390	3,646	
August	63,723	31,495	6,695	14,720	4,361	
September	62,881	44,052	5,658	13,442	3,978	
October	73,257	37,531	8,237	10,215	3,310	
November	70,875	43,253	8,506	10,507	4,959	
December	60,013	34,750	6,968	14,149	4,746	
Total	765,099	468,263	79,290	146,884	48,920	

Appendix II: Vehicle Volume for Oyibi/Frafraha-Bound Toll Plaza in Shifts

Vehicular Count for Morning Shift (FRAFRAHA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	44,037	22,206	1,781	18,793	1,199	
February	40,903	20,274	1,979	17,723	980	
March	43,092	22,475	2,180	19,733	1,392	
April	41,136	20,940	1,895	18,594	999	
May	44,717	22,760	2,118	19,144	645	
June	39,572	20,735	1,848	18,909	435	
July	43,159	22,519	1,580	19,476	466	
August	41,360	22,440	1,495	19,533	451	
September	41,495	22,440	1,643	20,100	611	
October	42,021	22,122	1,741	18,934	968	
November	41,231	21,188	1,751	18,477	1,067	
December	42,450	21,884	1,661	19,638	1,296	
Total	505,173	261,983	21,672	229,054	10,509	
Vehicular Count for Afternoon Shift (FRAFRAHA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	46,917	21,772	1,803	19,806	870	
February	42,787	21,105	1,965	18,219	612	
March	46,589	22,839	2,249	20,715	932	
April	42,808	19,872	1,958	17,233	704	
May	45,663	22,466	2,180	19,589	326	
June	39,684	20,780	2,034	18,593	274	
July	44,249	22,202	1,698	18,565	523	
August	45,658	22,588	1,566	20,256	505	
September	43,790	21,915	1,855	19,935	415	
October	42,413	22,158	1,735	19,586	587	
November	43,065	22,054	1,517	19,175	772	
December	43,311	22,547	1,544	19,579	771	
Total	526,934	262,298	22,104	231,251	7,291	
Vehicular Count for Night Shift (FRAFRAHA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	14,044	5,521	503	4,269	63	
February	13,379	5,519	505	4,186	54	
March	15,323	5,806	741	4,373	123	
April	14,007	5,064	560	4,037	64	
May	14,109	5,343	546	4,044	62	
June	12,405	4,924	432	3,960	40	
July	12,314	5,286	437	4,226	368	
August	13,388	4,968	408	4,173	327	
September	12,938	5,059	431	3,981	205	
October	14,688	5,752	477	4,329	175	
November	14,571	5,376	439	4,251	218	
December	16,520	6,232	534	4,717	299	
Total	167,686	64,850	6,013	50,546	1,998	

Appendix III: Total Vehicular Monthly Emissions (tCO₂) For Tema-bound Shift Periods

		Total Monthly Emissions for Morning Shift (TEMA)				
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	6,101.14	9,918.41	7,037.02	1,626.19	8,342.56	
February	6,233.33	7,646.24	5,939.28	1,348.81	7,006.46	
March	6,148.49	8,179.48	6,650.59	1,528.90	8,264.42	
April	6,011.39	7,541.12	7,096.33	1,829.60	7,961.36	
May	6,287.06	9,244.75	6,829.26	1,646.62	8,768.55	
June	6,195.53	9,991.00	7,510.73	1,729.69	9,970.29	
July	6,142.23	9,808.18	7,854.26	1,601.90	8,777.13	
August	5,904.47	10,592.29	7,442.47	1,281.19	8,310.16	
September	6,227.33	8,954.93	6,515.94	1,583.83	8,398.79	
October	6,233.33	10,022.08	8,798.70	1,814.29	8,263.46	
November	6,151.84	8,724.38	7,367.87	1,587.83	7,001.69	
December	6,095.30	9,285.59	9,163.86	1,488.88	7,842.24	
Total	73,731.44	109,908.43	88,206.29	19,067.74	98,907.11	
		Total Monthly Emissions for Afternoon Shift (TEMA)				
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	5,979.58	8,587.07	7,006.81	1,635.16	10,923.29	
February	5,533.27	8,323.34	5,565.91	1,419.12	9,765.39	
March	6,824.74	7,816.29	8,817.35	1,444.31	9,307.00	
April	5,494.77	9,927.73	5,810.97	1,347.02	10,725.06	
May	5,974.99	7,530.35	7,965.42	1,307.83	11,364.53	
June	7,165.64	8,707.06	7,338.78	1,835.26	18,561.58	
July	6,678.61	8,949.71	7,616.29	1,274.50	11,661.86	
August	6,560.08	8,458.31	7,272.01	1,793.10	8,112.89	
September	6,136.88	9,276.05	8,040.39	1,229.79	9,127.83	
October	6,702.86	9,551.22	6,223.13	1,528.21	12,444.27	
November	5,870.99	7,786.87	7,316.40	1,772.68	8,300.63	
December	6,860.54	8,605.61	8,862.11	1,986.72	8,698.03	
Total	75,782.95	103,519.60	87,835.53	18,573.70	128,992.36	
		Total Monthly Emissions for Night Shift (TEMA)				
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	3,929.09	4,107.78	1,421.88	599.89	4,598.23	
February	3,252.26	4,904.42	1,835.91	709.25	3,332.64	
March	3,425.27	3,974.13	2,698.28	887.62	4,166.52	
April	3,434.29	3,822.62	2,139.16	735.20	3,263.07	
May	2,771.77	4,308.35	2,082.09	774.25	3,726.23	
June	3,247.99	5,281.16	3,253.68	1,017.61	3,709.08	
July	3,394.22	4,368.74	2,692.31	1,061.91	3,474.64	
August	3,441.04	3,495.95	2,497.24	1,015.68	4,156.03	
September	3,395.57	4,889.77	2,110.43	927.50	3,791.03	
October	3,955.88	4,165.94	3,072.40	704.84	3,154.43	
November	3,827.25	4,801.08	3,172.74	724.98	4,725.93	
December	3,240.70	3,857.25	2,599.06	976.28	4,522.94	
Total	41,315.35	51,977.19	29,575.17	10,135.00	46,620.76	

Appendix IV: Total Vehicular Monthly Emissions (t/CO₂) for Oyibi/Frafraha Shift Periods

Total Monthly Emissions for Morning Shift (FRAFRAHA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	7,133.99	7,305.77	1,966.22	3,833.77	3,483.10	
February	6,626.29	6,670.15	2,184.82	3,615.49	2,846.90	
March	6,980.90	7,394.28	2,406.72	4,025.53	4,043.76	
April	6,664.03	6,889.26	2,092.08	3,793.18	2,902.10	
May	7,244.15	7,488.04	2,338.27	3,905.38	1,873.73	
June	6,410.66	6,821.82	2,040.19	3,857.44	1,263.68	
July	6,991.76	7,408.75	1,744.32	3,973.10	1,353.73	
August	6,700.32	7,382.76	1,650.48	3,984.73	1,310.16	
September	6,722.19	7,382.76	1,813.87	4,100.40	1,774.96	
October	6,807.40	7,278.14	1,922.06	3,862.54	2,812.04	
November	6,679.42	6,970.85	1,933.10	3,769.31	3,099.64	
December	6,876.90	7,199.84	1,833.74	4,006.15	3,764.88	
Total	81,838.03	86,192.41	23,925.89	46,727.02	30,528.65	
Total Monthly Emissions for Afternoon Shift (FRAFRAHA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	7,600.55	7,162.99	1,990.51	4,040.42	2,527.35	
February	6,931.49	6,943.55	2,169.36	3,716.68	1,777.86	
March	7,547.42	7,514.03	2,482.90	4,225.86	2,707.46	
April	6,934.90	6,537.89	2,161.63	3,515.53	2,045.12	
May	7,397.41	7,391.31	2,406.72	3,996.16	947.03	
June	6,428.81	6,836.62	2,245.54	3,792.97	795.97	
July	7,168.34	7,304.46	1,874.59	3,787.26	1,519.32	
August	7,396.60	7,431.45	1,728.86	4,132.22	1,467.03	
September	7,093.98	7,210.04	2,047.92	4,066.74	1,205.58	
October	6,870.91	7,289.98	1,915.44	3,995.54	1,705.24	
November	6,976.53	7,255.77	1,674.77	3,911.70	2,242.66	
December	7,016.38	7,417.96	1,704.58	3,994.12	2,239.76	
Total	85,363.31	86,296.04	24,402.82	47,175.20	21,180.36	
Total Monthly Emissions for Night Shift (FRAFRAHA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	2,275.13	1,816.41	555.31	870.88	183.02	
February	2,167.40	1,815.75	557.52	853.94	156.87	
March	2,482.33	1,910.17	818.06	892.09	357.32	
April	2,269.13	1,666.06	618.24	823.55	185.92	
May	2,285.66	1,757.85	602.78	824.98	180.11	
June	2,009.61	1,620.00	476.93	807.84	116.20	
July	1,994.87	1,739.09	482.45	862.10	1,069.04	
August	2,168.86	1,634.47	450.43	851.29	949.94	
September	2,095.96	1,664.41	475.82	812.12	595.53	
October	2,379.46	1,892.41	526.61	883.12	508.38	
November	2,360.50	1,768.70	484.66	867.20	633.29	
December	2,676.24	2,050.33	589.54	962.27	868.60	
Total	27,165.13	21,335.65	6,638.35	10,311.38	5,804.19	

Appendix V: Total Monthly Vehicular Emissions (t/CO₂) For Both Toll Stations

		TEMA-BOUND MONTHLY EMISSIONS			
SALOON CARS	MINI BUS/MUM WAGON	LARGE BUS/LIGHT TRUCK	PICKUP/VANS/4X4/MED BUS	ARTICULATED TRUCK	
16,009.81	22,613.25	15,465.70	3,861.24	23,864.07	
15,018.86	20,873.99	13,341.09	3,477.19	21,515.88	
16,398.50	19,914.40	18,166.22	3,860.83	21,737.93	
14,940.45	21,291.58	15,046.45	3,911.82	21,949.50	
15,033.82	21,083.45	16,876.76	3,728.69	23,859.31	
16,285.16	23,979.22	18,103.18	4,582.57	32,240.94	
16,215.07	23,126.74	18,162.86	3,938.31	23,913.63	
15,905.59	22,546.54	17,211.71	4,089.98	20,579.08	
15,759.79	23,120.75	16,666.76	3,741.11	21,317.66	
16,892.06	23,739.24	18,094.23	4,047.33	23,862.17	
15,850.08	21,312.33	17,857.00	4,085.49	20,028.25	
16,196.54	21,748.45	20,625.04	4,451.88	21,157.55	
190,505.74	265,349.94	205,617.00	47,776.43	276,025.97	

		FRAFRAHA MONTHLY EMISSIONS				
	SALOON CARS	MINI BUS/MUM WAGON	LARGE BUS/LIGHT TRUC	PICKUP/VANS/4X4/MED BUS	ARTICULATED TRUCK	
January	17009.68	16285.17	4512.05	8745.07	6193.46	
February	15725.18	15429.44	4911.70	8186.11	4781.63	
March	17010.65	16818.48	5707.68	9143.48	7108.54	
April	15868.06	15093.20	4871.95	8132.26	5133.14	
May	16927.22	16637.20	5347.78	8726.51	3000.87	
June	14849.08	15278.43	4762.66	8458.25	2175.85	
July	16154.96	16452.30	4101.36	8622.47	3942.09	
August	16265.77	16448.68	3829.78	8968.25	3727.12	
September	15912.13	16257.21	4337.62	8979.26	3576.06	
October	16057.76	16460.53	4364.11	8741.20	5025.65	
November	16016.45	15995.32	4092.53	8548.21	5975.59	
December	16569.52	16668.13	4127.86	8962.54	6873.23	
TOTAL	194366.47	193824.10	54967.06	104213.60	57513.19	

VI. Total Monthly Shift Carbon Credit Earnings (US\$) at the Tema Bound Toll Plaza

Total Monthly Earnings for Morning Shift (TEMA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	\$ 4,209.78	\$ 13,984.95	\$ 33,425.84	\$ 1,431.05	\$ 101,111.85	
February	\$ 4,301.00	\$ 10,781.19	\$ 28,211.58	\$ 1,186.95	\$ 84,918.25	
March	\$ 4,242.46	\$ 11,533.07	\$ 31,590.30	\$ 1,345.43	\$ 100,164.72	
April	\$ 4,147.86	\$ 10,632.98	\$ 33,707.54	\$ 1,610.05	\$ 96,491.71	
May	\$ 4,338.07	\$ 13,035.09	\$ 32,438.97	\$ 1,449.02	\$ 106,274.86	
June	\$ 4,274.91	\$ 14,087.31	\$ 35,675.96	\$ 1,522.13	\$ 120,839.87	
July	\$ 4,238.14	\$ 13,829.54	\$ 37,307.74	\$ 1,409.68	\$ 106,378.82	
August	\$ 4,074.08	\$ 14,935.12	\$ 35,351.73	\$ 1,127.45	\$ 100,719.14	
September	\$ 4,296.86	\$ 12,626.44	\$ 30,950.70	\$ 1,393.77	\$ 101,793.32	
October	\$ 4,301.00	\$ 14,131.13	\$ 41,793.81	\$ 1,596.57	\$ 100,153.17	
November	\$ 4,244.77	\$ 12,301.37	\$ 34,997.38	\$ 1,397.29	\$ 84,860.49	
December	\$ 4,205.76	\$ 13,092.69	\$ 43,528.35	\$ 1,310.22	\$ 95,047.91	
Total	\$ 50,874.69	\$ 154,970.88	\$ 418,979.90	\$ 16,779.61	\$ 1,198,754.11	
Total Monthly Earnings for Afternoon Shift (TEMA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	\$ 4,125.91	\$ 12,107.77	\$ 33,282.32	\$ 1,438.94	\$ 132,390.23	
February	\$ 3,817.96	\$ 11,735.90	\$ 26,438.05	\$ 1,248.83	\$ 118,356.54	
March	\$ 4,709.07	\$ 11,020.96	\$ 41,882.40	\$ 1,270.99	\$ 112,800.82	
April	\$ 3,791.39	\$ 13,998.10	\$ 27,602.09	\$ 1,185.38	\$ 129,987.75	
May	\$ 4,122.74	\$ 10,617.79	\$ 37,835.72	\$ 1,150.89	\$ 137,738.04	
June	\$ 4,944.29	\$ 12,276.96	\$ 34,859.18	\$ 1,615.03	\$ 224,966.36	
July	\$ 4,608.24	\$ 12,619.09	\$ 36,177.36	\$ 1,121.56	\$ 141,341.76	
August	\$ 4,526.46	\$ 11,926.22	\$ 34,542.04	\$ 1,577.93	\$ 98,328.21	
September	\$ 4,234.45	\$ 13,079.23	\$ 38,191.84	\$ 1,082.21	\$ 110,629.35	
October	\$ 4,624.97	\$ 13,467.22	\$ 29,559.88	\$ 1,344.83	\$ 150,824.60	
November	\$ 4,050.98	\$ 10,979.49	\$ 34,752.88	\$ 1,559.96	\$ 100,603.64	
December	\$ 4,733.77	\$ 12,133.91	\$ 42,095.01	\$ 1,748.31	\$ 105,420.14	
Total	\$ 52,290.24	\$ 145,962.63	\$ 417,218.78	\$ 16,344.85	\$ 1,563,387.43	
Total Monthly Earnings for Night Shift (TEMA)						
	SALOON CARS	MINI BUS,MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK	
January	\$ 2,711.07	\$ 5,791.97	\$ 6,753.91	\$ 527.90	\$ 55,730.49	
February	\$ 2,244.06	\$ 6,915.24	\$ 8,720.55	\$ 624.14	\$ 40,391.61	
March	\$ 2,363.44	\$ 5,603.53	\$ 12,816.84	\$ 781.10	\$ 50,498.17	
April	\$ 2,369.66	\$ 5,389.89	\$ 10,160.99	\$ 646.97	\$ 39,548.43	
May	\$ 1,912.52	\$ 6,074.78	\$ 9,889.91	\$ 681.34	\$ 45,161.91	
June	\$ 2,241.11	\$ 7,446.43	\$ 15,454.98	\$ 895.50	\$ 44,954.00	
July	\$ 2,342.01	\$ 6,159.92	\$ 12,788.49	\$ 934.48	\$ 42,112.61	
August	\$ 2,374.32	\$ 4,929.28	\$ 11,861.87	\$ 893.80	\$ 50,371.12	
September	\$ 2,342.95	\$ 6,894.58	\$ 10,024.56	\$ 816.20	\$ 45,947.33	
October	\$ 2,729.56	\$ 5,873.98	\$ 14,593.90	\$ 620.25	\$ 38,231.69	
November	\$ 2,640.80	\$ 6,769.53	\$ 15,070.51	\$ 637.99	\$ 57,278.24	
December	\$ 2,236.08	\$ 5,438.72	\$ 12,345.55	\$ 859.13	\$ 54,818.01	
Total	\$ 28,507.59	\$ 73,287.84	\$ 140,482.06	\$ 8,918.80	\$ 565,043.61	

Appendix VII: Total Monthly Carbon Credit Earnings (US\$) at the Oyibi/Frafraha Bound Toll Plaza

Total Monthly Emissions for Morning Shift (FRAFRAHA)					
	SALOON CARS	MINI BUS, MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK
January	90,716.22	93,043.14	25,005.24	48,861.80	44,303.05
February	84,260.18	84,948.06	27,785.16	46,079.80	36,211.00
March	88,769.52	94,170.25	30,607.20	51,305.80	51,434.40
April	84,740.16	87,738.60	26,605.80	48,344.40	36,913.05
May	92,117.02	95,364.40	29,736.72	49,774.40	23,832.75
June	81,518.32	86,879.65	25,945.92	49,163.40	16,073.25
July	88,907.54	94,354.61	22,183.20	50,637.60	17,218.70
August	85,201.60	94,023.60	20,989.80	50,785.80	16,664.45
September	85,479.70	94,023.60	23,067.72	52,260.00	22,576.45
October	86,563.26	92,691.18	24,443.64	49,228.40	35,767.60
November	84,935.86	88,777.72	24,584.04	48,040.20	39,425.65
December	87,447.00	91,693.96	23,320.44	51,058.80	47,887.20
Total	1,040,656.38	1,097,708.77	304,274.88	595,540.40	388,307.55
Total Monthly Emissions for Afternoon Shift (FRAFRAHA)					
	SALOON CARS	MINI BUS, MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK
January	96,649.02	91,224.68	25,314.12	51,495.60	32,146.50
February	88,141.22	88,429.95	27,588.60	47,369.40	22,613.40
March	95,973.34	95,695.41	31,575.96	53,859.00	34,437.40
April	88,184.48	83,263.68	27,490.32	44,805.80	26,012.80
May	94,065.78	94,132.54	30,607.20	50,931.40	12,045.70
June	81,749.04	87,068.20	28,557.36	48,341.80	10,124.30
July	91,152.94	93,026.38	23,839.92	48,269.00	19,324.85
August	94,055.48	94,643.72	21,986.64	52,665.60	18,659.75
September	90,207.40	91,823.85	26,044.20	51,831.00	15,334.25
October	87,370.78	92,842.02	24,359.40	50,923.60	21,689.65
November	88,713.90	92,406.26	21,298.68	49,855.00	28,525.40
December	89,220.66	94,471.93	21,677.76	50,905.40	28,488.45
Total	1,085,484.04	1,099,028.62	310,340.16	601,252.60	269,402.45
Total Monthly Emissions for Night Shift (FRAFRAHA)					
	SALOON CARS	MINI BUS, MUM WAGON	LARGE BUS, LIGHT TRUCK	PICK UP, VANS, 4X4, MED BUS	ARTICULATED TRUCK
January	28,930.64	23,132.99	7,062.12	11,099.40	2,327.85
February	27,560.74	23,124.61	7,090.20	10,883.60	1,995.30
March	31,565.38	24,327.14	10,403.64	11,369.80	4,544.85
April	28,854.42	21,218.16	7,862.40	10,496.20	2,364.80
May	29,064.54	22,387.17	7,665.84	10,514.40	2,290.90
June	25,554.30	20,631.56	6,065.28	10,296.00	1,478.00
July	25,366.84	22,148.34	6,135.48	10,987.60	13,597.60
August	27,579.28	20,815.92	5,728.32	10,849.80	12,082.65
September	26,652.28	21,197.21	6,051.24	10,350.60	7,574.75
October	30,257.28	24,100.88	6,697.08	11,255.40	6,466.25
November	30,016.26	22,525.44	6,163.56	11,052.60	8,055.10
December	34,031.20	26,112.08	7,497.36	12,264.20	11,048.05
Total	345,433.16	271,721.50	84,422.52	131,419.60	73,826.10

Appendix VIII: Total Monthly Vehicular Earnings (US\$) For the Tema-bound and the Oyibi/Frafraha Toll Stations

	TEMA MONTHLY EARNINGS				
	SALOON CARS	MINI BUS/MUM WAGON	LARGE BUS/LIGHT TRUCK	PICKUP/VANS/4X4/MED BUS	ARTICULATED TRUCK
January	\$ 11,046.77	\$ 31,884.69	\$ 73,462.07	\$ 3,397.89	\$ 289,232.56
February	\$ 10,363.01	\$ 29,432.33	\$ 63,370.18	\$ 3,059.92	\$ 260,772.48
March	\$ 11,314.97	\$ 28,079.30	\$ 86,289.54	\$ 3,397.53	\$ 263,463.71
April	\$ 10,308.91	\$ 30,021.12	\$ 71,470.62	\$ 3,442.40	\$ 266,027.89
May	\$ 10,373.33	\$ 29,727.67	\$ 80,164.60	\$ 3,281.25	\$ 289,174.81
June	\$ 11,236.76	\$ 33,810.70	\$ 85,990.11	\$ 4,032.66	\$ 390,760.23
July	\$ 11,188.40	\$ 32,608.70	\$ 86,273.59	\$ 3,465.72	\$ 289,833.18
August	\$ 10,974.86	\$ 31,790.62	\$ 81,755.63	\$ 3,599.18	\$ 249,418.47
September	\$ 10,874.26	\$ 32,600.25	\$ 79,167.11	\$ 3,292.18	\$ 258,370.00
October	\$ 11,655.52	\$ 33,472.32	\$ 85,947.59	\$ 3,561.65	\$ 289,209.46
November	\$ 10,936.56	\$ 30,050.39	\$ 84,820.76	\$ 3,595.23	\$ 242,742.37
December	\$ 11,175.62	\$ 30,665.32	\$ 97,968.92	\$ 3,917.65	\$ 256,429.54
TOTAL	\$ 131,448.96	\$ 374,143.42	\$ 976,680.73	\$ 42,043.26	\$ 3,345,434.72

	FRAFRAHA MONTHLY EARNINGS				
	SALOON CARS	MINI BUS/MUM WAGON	LARGE BUS/LIGHT TRUC	PICKUP/VANS/4X4/MED BUS	ARTICULATED TRUCK
January	\$ 35,039.93	\$ 68,234.87	\$ 63,349.15	\$ 22,737.19	\$ 228,848.35
February	\$ 32,393.87	\$ 64,649.36	\$ 68,960.21	\$ 21,283.89	\$ 176,681.23
March	\$ 35,041.93	\$ 70,469.43	\$ 80,135.83	\$ 23,773.06	\$ 262,660.37
April	\$ 32,688.21	\$ 63,240.52	\$ 68,402.21	\$ 21,143.87	\$ 189,669.34
May	\$ 34,870.07	\$ 69,709.87	\$ 75,082.78	\$ 22,688.92	\$ 110,881.96
June	\$ 30,589.11	\$ 64,016.63	\$ 66,867.69	\$ 21,991.44	\$ 80,397.47
July	\$ 33,279.23	\$ 68,935.15	\$ 57,583.09	\$ 22,418.42	\$ 145,660.04
August	\$ 33,507.49	\$ 68,919.99	\$ 53,770.06	\$ 23,317.44	\$ 137,716.90
September	\$ 32,778.98	\$ 68,117.69	\$ 60,900.13	\$ 23,346.09	\$ 132,135.23
October	\$ 33,078.99	\$ 68,969.61	\$ 61,272.13	\$ 22,727.11	\$ 185,697.77
November	\$ 32,993.90	\$ 67,020.40	\$ 57,459.09	\$ 22,225.35	\$ 220,797.87
December	\$ 34,133.22	\$ 69,839.45	\$ 57,955.10	\$ 23,302.59	\$ 253,965.85
TOTAL	\$ 400,394.92	\$ 812,122.97	\$ 771,737.47	\$ 270,955.37	\$ 2,125,112.37