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FUEL CONSUMPTION AND ENVIRONMENTAL IMPLICATIONS IN URBAN PASSENGER TRANSPORT IN KIGALI, RWANDA

By

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Declaration

I, the undersigned, declare that this Project is my original work, and has not been presented for a degree in University of Rwanda or any other universities. All sources of materials that will be used for the thesis work will have been fully acknowledged.

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Dedicated

To my and mother father

To my sister and brothers

To the memory of my brother

Abstract

Transport, particularly, road transport is very important to the society by its simplification of the movement of the people and goods, its supports on economic growth and play an important role in job creation. The positive facts are associated with the hazards to both human health and environment. The rapid growth of both population and urbanization accelerate the consequences caused by urban passenger transport when the application of policies is inadequate. During this study LEAP (long range energy alternative planning) model was used in fuel consumption and greenhouse gas emissions analysis for both public and private vehicles. In this analysis we used three scenarios which are: Business as usual (BAU), in scenario 1, we considered the gasoline and diesel driven vehicles to be 55% and 45% respectively whereas in scenario 2, we considered the number of public and private vehicles to be 60% and 40% respectively. By analysing each scenario, we saw that for the second scenario the fuel consumption was estimated at 151.4 million gallon (US) and the CO2 emissions equivalent from both private and public vehicles are 523.5 thousand Metric Tonnes with the contribution of 69.9% of emissions from private vehicles. These results show that in all three scenarios private vehicles contribute more in CO2 emissions equivalent.

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Key words

The key words are:

i. Road transport,
ii. Fuel consumption,
iii. Public transport,
iv. Private transport,
v. Greenhouse gas

List of symbols and acronyms

ACEESD	: African Centre of Excellence in Energy for Sustainable Development
BAU	: Business as usual
EIFTS	: Efficient Integrated Freight Transport System
EIFTS	: Efficient Integrated Freight Transport System
GWP	: Global warming potential
IEA	: International Energy Agency
MAED	: Modal of Analysis of Energy Demand
MINECOFIN	:Ministry of Finance and Economic Planning
MININFRA	: Ministry of Infrastructure
MRT	: Mass Rapid Transport
NAMA	: National Appropriate Mitigation Actions
NIRDA	: National Industrial Research and Development Agency
NISR	: National Institute of Statistics of Rwanda
ONATRACOM	: Office National de Transport en Commun
REM	: Rwanda Environment Management Authority
RRA	: Rwanda Revenue Authority
RURA	: Rwanda Utilities Regulatory Authority
tCO2e	: Tonne of CO2 Equivalent
UNFCCC	: United Nations Framework Convention on Climate Change
US.EPA	: United state Environmental Protection Agency
VKT	: Vehicle Kilometres Travelled

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CHAPTER I: GENERAL INTRODUCTION

1. INTRODUCTION

Transport, especially road transport is very important to the society. It simplifies the movement of the people and goods, it supports economic growth and play an important role in reducing unemployment. Unfortunately, these positive facts are associated with the hazards to the environment and human health caused by transport, particularly road transport (Dora,C., Phillips,M., 2000).We cannot ignore the concern about environmental problems caused by transportation systems, including rises in energy consumption and the emissions from the vehicles are being considered as the main contributors to those environmental problems. Some African countries are urbanizing at a high speed, and both large and intermediate cities are experiencing both rapid and often unplanned growth. Decision and policy makers face many challenges on the side of planning, development and management of the cities. However, most cities in African present low levels of accessibility and mobility, when measured against the needs of the populations (Stucki, 2015). With the growing population and accelerated urbanization, public transport system need to be well organized in order to meet the travel demand. A gap between service capacity and growing public transportation demand results to an increase of cost of travel, congestion and unreliable services there by creating economic loss and environmental degradation therefore it is of an important value that approaches for monitoring and assessing public transportation systems in order to ensure a better service provision. In developing countries, the transport system changes with respect to both the presence and the quality of road, railroad infrastructure and traffic, but both are not sufficient like in developed or industrialised countries. The current state of the transport system is explained by population growth and income/motorisation rates (Gwilliam, K., 2003). Developed countries have high motorisation rates but at the same time have mass rapid transport (MRT) systems while poor countries with fast population growth are less likely to have MRT systems. Mainly, dense and large cities, such as megacities, experience high levels of congestion and many environmental impacts. Developing cities differ from industrialised or developed cities in terms of four main characteristics; premature congestion, a deteriorating environment, low safety and security, and declining transport for the poor (Gwilliam, K., 2003).

Rwanda imports petroleum products requirements from abroad since there is no local production available. The consumption of petroleum in Rwanda stands at 23 million litres per month ,75% is used in transport. This constitutes about 20% of total national imports and has been steadily rising in the past five years, with an average annual increase of 12 per cent. The main policy objective for the sub-sector is to ensure safe, sufficient, reliable, sustainable and affordable supply of petroleum product (REG, 2020).

1.1. Background

Transportation plays an important support role for both social development and national economic development (Jian,C., Quan,Y., Shou,W., 2016). It is difficult for our life without transportation means within the country. Transport is an important driving economic and social development, by bringing significant opportunities for the poor and enabling economies to be more competitive. Infrastructures in transport connect people to their destinations; it enables the supply of goods and services around the world; and allows people to interact and generate the knowledge and solutions that foster long-term growth. The sector is very important in reducing poverty, boosting prosperity, and achieving the Sustainable Development Goals, as transport is at the heart of critical development challenges. On the climate change side transport contribute about 64% of global oil consumption, 27% of all energy use, and 23% of the world's energy-related CO_2 emissions and with motorization rates on the rise, the environmental impact of this sector is expected to grow dramatically (Azeredo, 2019). In 2050, cities are estimated to inhabited by 6.7 billion residents which is approximated to two thirds of the forecasted world population (Azeredo, 2019). The increase of population in the cities will be associated with the increase in number of vehicles on the road which will reach two billions in 2050. Air pollution from motorized road transport bring numerous health problems, without forgetting Cardiovascular, cancers and pulmonary diseases. Almost 185,000 deaths each year are counted and caused by pollution from vehicles (Azeredo, 2019).

Rwanda is a landlocked country with a hill landscape, the transportation of people and goods has been always important for the development of the country. The system of transport in Rwanda consists of three modes which are: road, air transport, and lake transport, where Kivu Lake is more used than other small internal lakes. Rwanda does not have the railway transport but it is committed to develop it as another way to increase socio economic development and welfare of the Rwandans as well as by reducing the transport cost (MININFRA, 2018). There is a clear need to improve appropriate public transport connections between the capital city of Kigali, other second cities and rural areas by reducing the travel times to urban markets and the isolation of the more remote areas (REMA, 2015) . As urbanization is at high growth rate in the developing countries, there is an opportunity to build safer, cleaner, more efficient and accessible transport systems that reduce congestion and pollution, facilitate mobility in general and contribute in lower transport energy consumption. In older or larger cities, technology and big data are helping better in drawing map travel patterns and needs, engaging citizens, and improving the quality and efficiency of transport solutions.

The transport sector in Rwanda is expected to undergo substantial growth in the future and change based on national level planning. This assessment estimates a baseline or BAU scenario of annual GHG emissions from the transport sector in Rwanda will increase from 526,000 tCO_2 e in 2012; to 1,597,000 tCO_2e in 2020; to 3,124,600 tCO_2e in 2030, this represents an almost six-fold increase. The assessment identified that two high impacting components in the transport sector are expected to be the freight and bus sub-sectors, and that alternative emission scenarios for NAMAs can focus on these two. The first NAMA applicable alternative emissions scenario is for Efficient Integrated Freight Transport System (EIFTS), which is a multi-activity effort potentially leading up to 50% reductions in GHGs during 2016-2030 amounting to an estimated 3,200,000 tCO_2e. The second alternative emission scenario is for a Bus Rapid Transit (BRT) System for Kigali where a multi-activity effort is potentially leading up to 50% reductions in GHGs during 2016-2030 amounting to an estimated 1,260,000 tCO_2e (REMA, 2015).

1.1.1. Passenger transport in the City of Kigali

After the independence in 1962, there was evolution in terms of transport day in, day out so the greenhouse emission of CO_2 started to increase at a small growth rate. There were too many unpaved roads with potholes that obstructed vehicles to reach at their destination without a delay. This issue augmented too the CO_2 because vehicles at that time consumed too much fuel. Even paved roads had one lane in one direction means two lanes of both directions, this issue too contributed to air pollution because such kind of roads were not enough to vehicles. Many non-paved roads propelled vehicles to the untimely dysfunction mode that emitted too much greenhouse gases in the atmosphere. Different mode of transport especial road transport in Kigali has been the main cause of air pollution. For instance, before genocide perpetrated against Tutsi in Rwanda there were no many vehicles in Rwanda even the population in Kigali was not at high level. So, at time they used to use different passenger vehicles like buses, minibuses, pickups, motorcycles, bicycles, and so on. In 2010 there were 41 individual companies and one public company, ONATRACOM that used for public. ONATRACOM serves Kigali (about 15% of services), major provincial towns (57%) and rural routes (28%). In principle, ONATRACOM has the obligation of serving routes that are unattractive to the private sector providers and often withdraws from those that are over-supplied with private sector operators. Both services, however, share some characteristics such as operating without timetables, running uncoordinated services and having no prescribed passenger service levels. ONATRACOM will continue to play the role of connecting remote areas until such a time that these areas become profitable to the private sector (African Development Bank Group, 2013), they had different buses that used to carry passengers from and to different provinces. Because there were no more vehicles at that time one car used to carry a bunch of many people and there was no limit of number of persons to carry. At that time there was a low CO_2 emission that tainted the air.

After genocide in 1994 that devastated the economy and infrastructure of the country at unprecedented level that caused the high decrease in number of vehicles of course it is even understandable that the emissions of greenhouse gases from vehicles were at small level. The country started again to recover from this tragedy, there was evolution of economy and of course there was an increase of number of vehicles. Even passenger's vehicles increased, they used minibuses in public transport with a limited of 18 passengers. Because of this limited number of passengers per one vehicle caused the increase of such kind of vehicles at a significant level. To bypass this issue, the authorities of the city of Kigali took the decision to create too many tarmac roads even they put in place two lanes roads of one direction in different parts of the city. Even they replaced those 18 passenger's cars with new buses that can carry between 32 and 70 passengers. This reduced the number of vehicles in public transport within the city of Kigali of course there was a reduction of the quantity of greenhouse gases. Back in 2019 there was a game changer way of reducing emissions from the transport sector at a significant level by introducing the use of electric vehicles from Volkswagen company in its pilot stage.

1.2. Statement of the problem

The road transport is used in all areas of Rwanda. In this transport, private and public vehicles are used for the movement of people and greenhouse gas are emitted. These emissions are more significant in urban than rural areas because of the presence of big number of vehicles due to the mass mobility. In Rwanda the only urban area is the city of Kigali which has an intra city transport where emissions and fuel consumption were not counted for the projection of the future and this is an issue because the number of vehicles is increasing day by day, this increase is accompanied by a quantity of emissions which is to be accounted and at the end different policies can be applied when the issue is severe. The vision 2050 of Rwanda is to be in the middle income countries (MINECOFIN, 2018), this will raise the vehicle ownership which lead to increase in emissions. In our country there is a lack of emission accounting for current and coming years. In 2012, over three million premature deaths globally were approximated and caused by poor ambient air quality. Approximately 87% of these deaths occurred in low and middle-income countries. In the same period, Rwanda recorded 2,227 deaths attributed to ambient air pollution (REMA, 2018). A few studies propose an increased incidence of lung cancer in people with long-term exposure to transport-related air pollution and other studies suggest that it also causes adverse outcomes in pregnancy, such as premature birth and low birth weight, but the available evidence is inconsistent (WHO, 2005).

1.3. Objectives

1.3.1. Main objective

This study aims to analyse the in environmental implication of fuel consumption in road transport.

1.3.2. The Specific objectives

i. To identify the correlation between fuel consumption and air pollution in road transport.
ii. To forecast the fuel consumption and emission in road transport sector in the City of Kigali.
iii. To identify the potential policies to be made for a significant reduction of emissions from the road transport.

1.4. Scope of the study

The main focus of this study is to account and forecast emissions from road transport in the City of Kigali, this City was selected depending on its transport structure compared to the rest of the country. This city has an intra city transport of passengers. In this study the accent was put on the urban side by considering private and public transport without including motorcycles. Fuel and emissions from road transport in the City of Kigali were analysed using LEAP model.

1.5. Expected Outcomes and significance of study

1.5.1. Expected Outcomes

At the end of this study we expect to get a useful information on fuel consumption and emissions from road transport in the City of Kigali. Without the introduction of policies that can be applied in reducing emissions, we expect a significant increase of emissions in coming years and this has a negative effect on both environment and health side. we give scenarios which can be applied so that fuel consumption and emissions do not increase comparing to a business as usual scenario. These expected results regarding the decrease of fuel consumption and greenhouse gas emission will be reached after introducing different policies

1.5.2. Significance of the study

This study is important because was carried out in the capital of Rwanda which contains a significant number of population and basing on estimate done by the City of Kigali indicating 70% of vehicles of the country were in the City of Kigali (Ishimwe.T, Niyibizi.A, 2015) and as registered vehicles changed in increasing rate from 2015 where in 2018 Rwanda counted 216,204 Cumulative number of registered vehicle (NISR, 2018), this means that environmental problems and health risks from road transportation due to fuel consumption may continue to raise and to be severe in the City of Kigali. This study will help decision and policy maker to use scenarios that bring good contribution in choosing the appropriate policy facilitating the reduction in environment and health problems from road transport in the City of Kigali.

CHAPTER II: LITERATURE REVIEW

Various studies regarding road transportation have been carried. With increasing demands especially for light-duty vehicles, freight, and aviation, global transport CO_2 emissions are expected to double by 2050 (IEA, 2014), among the pollutants that affect human health most, the solid particles, known as PM particles, are also present in the atmosphere. Long-term and high exposure to these pollutants can cause problems in the respiratory system and thus premature death. Around 90% of the urban population in Europe is exposed to the pollution with PM particles the concentration of which is higher than the acceptable ambient air quality laid down by the EU. It is easy to think that the sustainability of transport is just an environmental problem .The study conducted by (Shashank B, Sudheer B, Rohit, Munish, 2016) shows that there is a major role played by congestion in increasing fuel consumption and emission levels and the emission of CO_2 in Mumbai Metropolitan Region for the year 2014 was found that CO_2 emission produced per day using fuel consumption based method was greater than one found using VKT method.

2.1 Studies on transportation and energy consumption

Computer applications such as the Long Range Energy Alternative Planning (LEAP) has been developed to facilitate computational procedures. Consequently, to analyze road transport energy consumption and CO2 emissions several studies (Bose, 1996) **,** (Dhakal, 2003), (Shabbir, 2010) have used the LEAP model. Under different scenarios, application of the LEAP model in transport sector, (Bose, 1996) examined the energy demand and environmental implications of urban passenger transport in Delhi, India for a base year of 1990 and for future years up and including the year 2010. **,** (Dhakal, 2003) used the LEAP model to examine the transport sector energy demand and greenhouse gas emissions in Rawalpindi and Islamabad (Pakistan), the study focused on the impact of some policy initiatives in reducing transport sector greenhouse gas emissions by applying four scenarios namely business-as-usual, reduction in population, introduction of more efficient public transport and introduction of natural gas vehicles. The study done by (Dakal, 2003) shows the implications of transport policies on energy and environment in Kathmandu Valley, Nepal, this study present future projections on energy demand and emissions using different scenarios. Greenhouse gas emissions from transport sector depends on the type of fuel consumed, studies indicate that a diesel-powered vehicle emits 10-20% less greenhouse gas than comparable gasoline vehicle (Thompson, 2005)

(Ma,Z., Wang,Y., Duan, H., Wang,E., 2012) , (Yan, X., Crookes, J., 2010)**,** (Sadri, 2014) are other studies that have used LEAP for transport sector energy demand and emissions analysis. The study of (Emodi, V., Murthy,G., 2017) focused on Nigeria and used the LEAP model to different sectors. The intention of this study is to focus on a smaller geographic area (Lagos) and on the transport sector only so as to carry out more detailed analyses. (Yang, 2007) studied the energy consumption and demand of different transportation modes, including railway, road, water, air, and predict the energy consumption by these modes in 2010 and 2020, by using history data such as freight turnover volume, passenger turn volume, and energy consumption of these modes and studying future development.

(Jalas, M., Juntunen, J., 2015) stated that because the lifestyles of the population change historically, the profiles of energy consumption vary and affect the generation of greenhouse gases. These implications have been investigated taking into account the habits of users in the past and their future changes. As the tool of choice for this study, LEAP was decided to be used for the reason that it facilitate to analyze vehicular emissions as well as other transport indicators like energy consumption. Road transport brings huge contribution to a different types of pollutants and to suspended particulate matter (PM) of different sizes and composition. Emissions of primary particles from road transport contributes up to 30% of fine PM (less than 2.5 µm in aerodynamic diameter or $PM_{2.5}$) in urban areas (WHO, 2005).

(Shekarrizfard M., Faghih-Imani A., Tétreault L, Yasmin S., Reynaud F., 2017) established a useful model for the quantification of emissions related to transport in an urban area case. (Hukkalainen, M., Virtanen,M., Paiho,S., Airaksinen,M., 2017) Analyzed a methodology to evaluate the impact of urban planning considering small agglomerations, in terms of energy consumption and emissions with transport planning included. Emission from private and public vehicles are not the same, (Transportation, U.S. Department of, 2010) stated that in U.S national averages demonstrate that public transportation produces significantly lower greenhouse gas emissions than private vehicles. Providing reliable, accessible public transport infrastructure (relevant to people's needs) can drive significant numbers of people to switch from driving to taking the tram, train or bus. Rail based transport is known to have the greatest impact on reducing car use (McIntosh, J., Trubka, R, Kenworthy,J., Newman, P., 2014).

The interaction between travel and land use was studied by (Mindali O, 2004) and it is a general view that urban density is strongly and negatively correlated to energy consumption. energy consumption will be reduced by a higher density. A Co-Plot technique was used in order to analyze the relationship between urban density and energy use, and refuted immediate impact of the entire urban density. (Cooper, 2001) studied the relationship between the environmentally sustainable development, transport, and space planning, as well as rational use of energy. They combined the generic transport model, housing supply, and energy evaluation methods were combined to provide a common stand to evaluate energy use. (Lu, 2004) analyzed how the percentage of transportation energy consumption had changed, and how the energy had been consumed by different urban transportation modes in China. The advice is to optimize the structure and system of urban transportation, energy consumption should be included and analyzed in the model system.

(Wu, 2005) briefed the energy consumption of USA and Japan. Through comparison of the energy consumption by transportation, industries, residents, and service sectors between China and the two countries, they figured out that the energy consumed by transportation would significantly affect China's overall energy consumption in the future, and adjusting the industrial structure would be one of the major approaches for China to build an economical society and minimize energy consumption.

(Dmurger.S, 2001) states that the principal role of transport is to provide access between partially separated locations for the business and household sectors, for both freight and passengers movements. For the business sector, this contains connections between businesses and their involvement sources. For the household sector, it facilitates people to reach their workplaces, education facilities, shops, social, recreational, community and medical facilities. Transport is considered as an important sector of the economy in its own right: transport infrastructure provision and transport operations together account for about five percent of GDP.

2.2 Energy demand in transportation

The transport sector contributes to the growing share of emissions (Ong, C., Mahlia, T., 2012). According to Key World Energy Statistics (IEA, 2014) , the aggregate energy demand of the global transport system increased from 23% in 1973 to 28% in 2012. The World Energy Outlook (IEA, 2012) reported that the transportation sector will account for 30% of the growth in petroleum consumption between 2004 and 2030.

The increasing petroleum energy demand problem has become a major issue all over the world and the prerequisite to address this problem has become mandatory (NEPC, 2012). In many region of the world the rising of the impacts of climate change has been experienced. Data show that transportation sector contributes more in greenhouse gas emissions. with this issue, many cities in developing countries have taken innovative initiatives to create sustainable urban mobility ,among others, uplifting the role of their public transport systems (Dirgahayani, 2013).The correlation between energy and transport is positive and direct although the extent of the fossil fuel dependency varies with particular transportation mode. For the social economic development of a give nation the transportation sector plays an essential role through nation's energy consumption. The globalization has also intensified transport activities and that transportation sector is accounting for the growing share of amount of energy spend for daily human activities (Schipper, 2009).

The idea continues that the energy consumption has a positive correlation with the level of economic development and that among the developed countries, the land transport sector accounts for the great majority of energy consumption. The average of 85% of the total energy used by the transport sector in developed countries is consumed in road transport. This trend is not constant within the land transportation sector itself, as road transportation is almost the sole mode responsible for additional energy demands over the last 25 years (Rodrigue, 2020).

The demand for fuel is increasing almost in every day basis in City of Kigali and the ownership of private vehicles has increased over last five years and this influences underlying the fuel consumption in transport sector.

From these previous studies, authors did not focus on predicting the greenhouse gas emissions for coming years which is a big problem for planners and decision makers to apply different policies allowing the adequate transport system.

Table 1. Cumulative number of vehicles registered by category in Rwanda.

Category	Cumulative up to 31-12-2015	Cumulative up to 31-12-2016	Cumulative up to 31-12-2017	Cumulative up to 31-12-2018
Caterpillar	103	124	140	145
Bus	1,060	1,265	1,465	1,576
Trucks	4,933	6,022	6,851	7,694
Pick-up	16,372	17,213	17,940	18,618
Special Engine	1,186	1,719	2,249	2,856
Jeeps	20,191	22,188	24,344	26,715
Microbus	267	556	1,032	1,466
Minibus	6,154	6,275	6,336	6,411
Cars	30,214	33,063	35,060	36,951
Motors	85,239	94,038	101,829	112,404
Trailers	886	919	934	976
Semi-trailers	217	231	277	316
Tricycle	73	73	73	73
Unknown	1	2	3	3
Total	**166,896**	**183,688**	**198,533**	**216,204**

Source: RRA

From the table 1 there is a significant increase in registered vehicles, this will affect the emissions from the road.

2.3 CO_2 emission in transport sector

The multiplicity of different factors can influence the level of CO2 emission from passenger road transport such us fuel efficiency and fuel economy, emission standard of the fuel, passenger travelled distance and chosen mode of transport (Tim, S., David, B., Jillian, A., 2012). To date the policy efforts have struggled to target both the above categories in order to reduce the CO_2 emission resulted from vehicular road transport mode.

Despite the technological improvement, numerous studies are found that CO_2 emissions from personnel road transport are increasing and which are driven by the change in travel behavior including high private car dependence, declining levels of the private cars occupancy, increase in per capita trips rate and longer motorized trip distance (Vehicle Kilometers Travelled−VKT) .As shown in Table 2, gas emissions recorded in City of Kigali are increasingly compared to the rest of the country. Baseline or BAU scenario from the assessment states that annual GHG emissions from the transport sector in Rwanda will increase from 526,000 tCO_2e in 2012; to 1,597,000 tCO_2e in 2020; to 3,124,600 tCO_2e in 2030, this represents an almost six-fold increase (REMA, 2015)

Table 2. Emissions from vehicles in City of Kigali from 2012 to 2013

Vehicle & Fuel type	Gas emissions per each type of vehicle and fuel			Total emissions (tons/year or m^3/year)
	Chemical component	Vehicles from Kigali City	Vehicles from outside Kigali	
Petrol vehicles	CO_2 (tons/year)	146,500.0	3,767.1	150,267.1
	CO (tons/year)	13,163.0	338.5	13,501.5
	HC (m^3)	346,068.0	8,899.0	354,967.0
Diesel vehicles	CO_2 (tons/year)	366,632.0	9428.0	376,060.0
	CO (tons/year)	4,781.0	123.0	4,904.0
Overall total gas emission	CO_2 (tons/year)		526,327.1	
	CO (tons/year)		18,405.5	
	HC (m^3/year)		354,967.0	

Source NIRDA

The table 2. Shows that from 2012 to 2013, vehicles from the City of Kigali and outside of the city of Kigali, diesel vehicles emitted a significant quantity of CO_2 compared to ones from petrol vehicles while CO emitted from Petrol are more significant compared to ones from diesel vehicles.

CHAPTER III: METHODOLOGY

There are various models used in modelling transportation sector like: EMME (Equilibre Multi modal/Multi modal equilibrium) focuses on shortest total travel time and then considers other lines with respect to maximum waiting time (Hlidbrand, C., Hortin, S., 2014), Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE) is a dynamic linear energy model generator developed by the International Atomic Energy Agency (IAEA), it is designed to formulate and evaluate alternative energy supply strategies consonant with user defined constraints on new investment, market penetration rates for new technologies, fuel availability, and environmental emissions (Lukáš, 2013). In this study, the analysis of fuel consumption emissions from transport is carried out using LEAP (long-range energy alternatives planning) model.

In this model the set of dependent variables includes emissions and fuel consumption from private and public vehicles, whereas the fuel consumption acted also as new input because it affects the emission and the total number of vehicles was used as independent variable, emission factor for gasoline and diesel was used as a parameter.

3.1 Data and sample characteristics

The sample encompasses the total number of registered vehicles in urban passenger transport in City of Kigali, these vehicles are light and heavy duties which are private and public that only consume petroleum products especially diesel and gasoline. The data for total number of registered vehicles entail the yearly data from 2011 to 2018.

The data for fuel energy consumption were taken as total percentage of petroleum products imported in Rwanda to be used in transport sector especially in City of Kigali from 2011 to 2018. The table 3 shows a number of public and private and public in the City of Kigali from 2011 to 2018.

Table 3. Number of public and private vehicles in the City of Kigali from 2011 to 2018

Year	2011	2012	2013	2014	2015	2016	2017	2018
Private vehicles	23,100	24,024	24,985	25,984	27,024	28,105	29,229	30,398
Public vehicles	14,600	15,300	15,900	11,600	12,122	12,667	13,238	13,833

Source: RRA

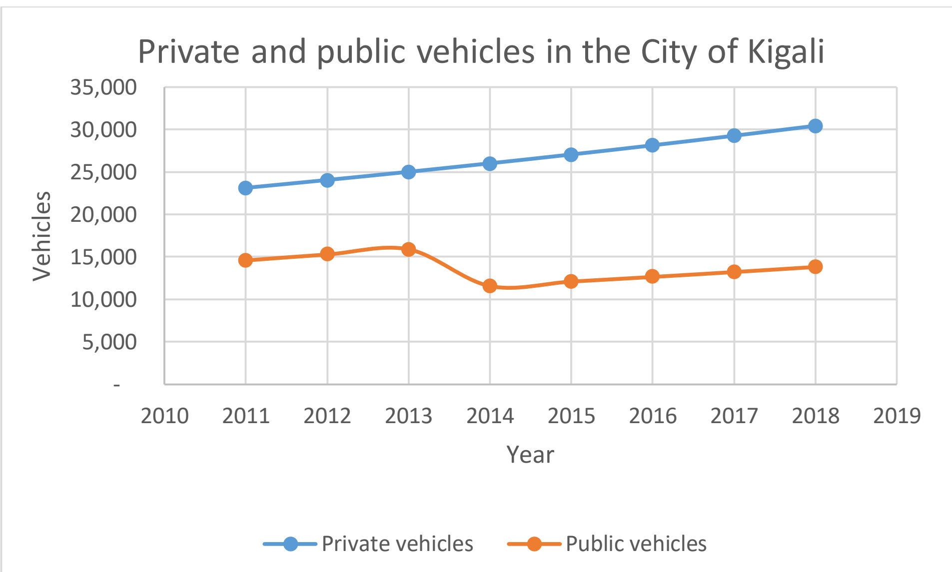

Figure 1. Number of registered private and public vehicles in City of Kigali.

From the figure 1, there is a reduction in number of public vehicles in 2014 due to decision taken by authorities of the City of Kigali banning all minibuses performing the public transport within this city.

Table 4. Fuel consumption from road transportation in the City of Kigali (2011–2018)

Year	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
diesel consumption (million gallon (US))	12.400	12.900	13.400	13.936	14.493	15.073	15.676	16.303
gasoline consumption (million gallon (US))	7.600	8.200	8.800	9.460	10.170	10.932	11.752	12.634

Source: RRA

Potentiality impact of greenhouse gases were used in this study to find Metric ton of CO_2 emission equivalences; values are shown in the Table 5.

Table 5. Potentiality impact of greenhouse gases

Effect	**Category**	**Unit**	**GWP (100 yr: TCO2e/T)**
Carbon Dioxide	Major GHGs	Metric Ton	1
carbon monoxide	Major GHGs	Metric Ton	1
Methane	Major GHGs	Kilogram	21
Nitrous Oxide	Major GHGs	Kilogram	310

Source: US.EPA (2018)

3.2 Introduction to LEAP model

It was decided to use LEAP because it is an integrated, scenario based modelling tool that can be used to track both energy consumption, and greenhouse gases (GHG)emission. The LEAP tool was used to calculate the energy demand and greenhouse gas emissions in road transport sectors of Kigali up to the years 2050 considering 2010 as base year. The evaluation of national or regional energy planning policies are computerized by LEAP. The system is designed to help energy planners and decision makers in the identification and quantification of future energy consumption pattern and the associated problems, and also the likely impact of different policies

The most used software tool for climate change mitigation assessment and energy policy analysis was LEAP, the Long Range Energy Alternatives Planning System, that was built by the Stockholm Environment Institute. The model has been used by a lot of organizations in worldwide. The model users comprise some of non-governmental organizations, consulting companies, energy utilities, academics and government agencies. The software has been used within many various level of ranging from regional and global, cities and states to national usage. The LEAP model is now becoming the ordinary for nations commissioning greenhouse gas mitigation assessments and integrated resource planning, more specifically in the developing countries at great pace. United Nations lately presented that over 85 nations have preferred LEAP model in preparing their report towards the U.N. Framework Convention on Climate Change (UNFCCC). LEAP model is modelling tool which is integrated and can be used for tracking resource extraction, energy production and consumption in all economic sectors. The model can also be applied for considering both non-energy sector and energy sector greenhouse gas (GHG) emission sinks and sources. Additionally, to pursuing GHGs, LEAP software can also be applied to examine emissions of regional and local air contaminants, making it suitable for studies related to the climate co-benefits of national air pollution lessening. The LEAP model has developed a better repute in between its users for portraying complex analysis related to energy concepts in intuitive way and a clear manner. Even though the LEAP model is flexible enough for wide ranging expert users: from designing polices leading global experts and show their benefits to trainers and decision makers who are in need of building capacity amongst young analysts who are embarking on understanding the complexity of energy systems challenge.

3.2.1 Model approach

The model approach used for emission analysis and fuel consumption in transport sector is summarized in the figure 2

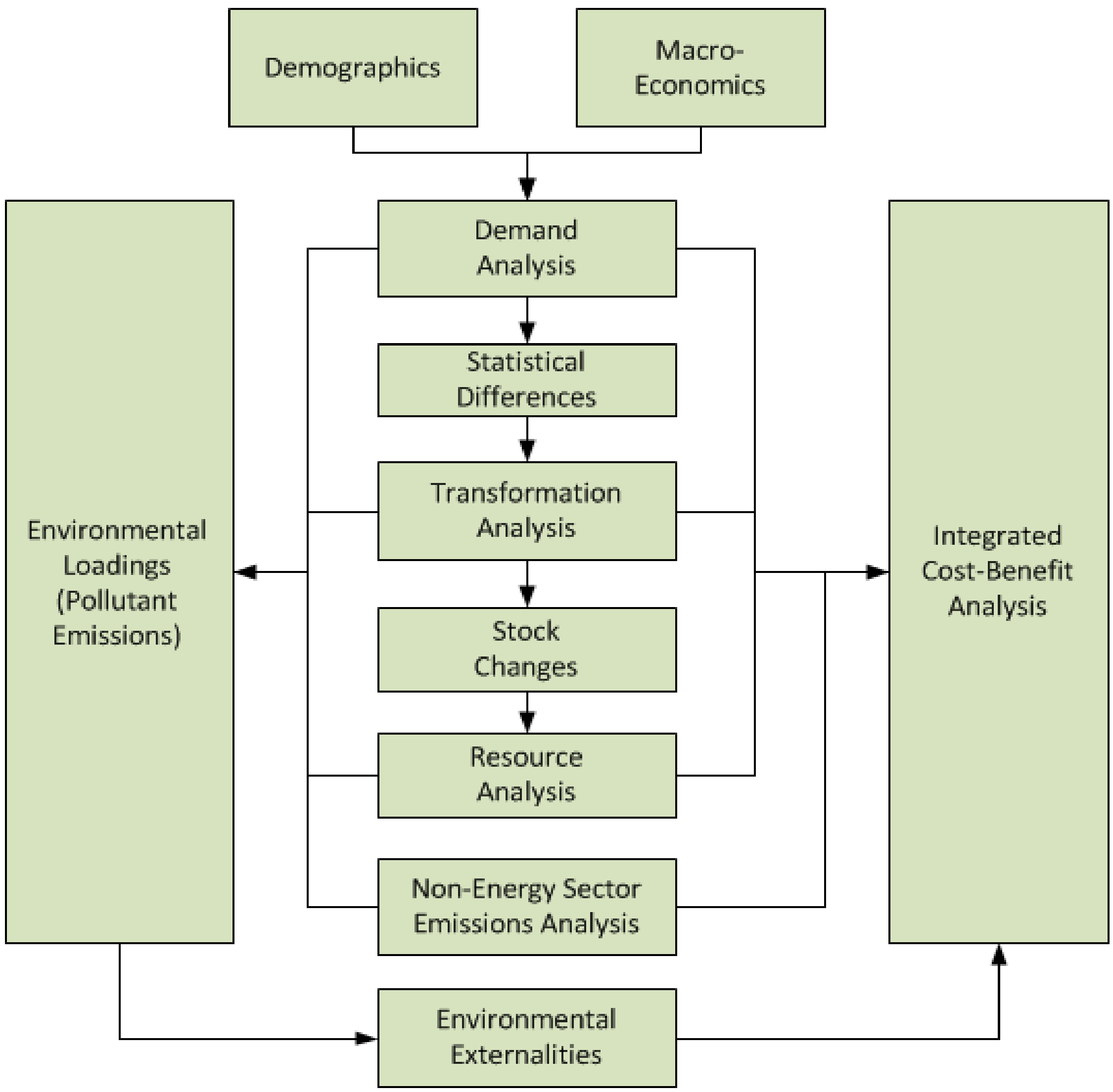

Figure 2. Model approach

Source: LEAP model

3.3 Empirical strategies

3.3.1 Energy consumption

Energy consumption from the road transport sector in Rwanda in this study is calculated in two steps. First, the total travel demand and energy intensity are estimated. Travel demand is calculated in terms of passenger kilometres (pass-km), while energy intensity is calculated in terms of litres per passenger kilometre (litres/pass-km).

$$TD = \sum V_i(t) * VKT_i(t) * VO_i(t) \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where TD is the travel demand (pass-km), V is the total number of vehicles of category i,VKTis the average annual vehicle kilometre travelled (mileage) of vehicle category i (kilometre) and VO is the vehicle occupancy rate of the vehicle i (passenger kilometre/vehicle kilometre) in year t

$$EI = \sum \frac{1}{\{FE_{ij}(t) * VO_i(t)\}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Where EI is Energy Intensity (litres/pass-km), TD is the travel demand (pass-km), FE is the fuel economy of fuel category j under vehicle category i (vehicle kilometre/litre) and VO is the vehicle occupancy rate of the vehicle i (passenger kilometre /vehicle kilometre) in year t .

Finally,

$$EC = \sum TD_i(t) * EI_{ij}(t) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Where EC is Energy consumption, TD is the travel demand (pass-km) of vehicle category i and EI is the energy intensity per fuel category j under vehicle category i (litres/ pass-km) in year t.

Emissions are estimated using the following method:

$$E = \sum EC_j(t) * EF_{jk}(t) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

Where E is emission, EC is the energy consumption of fuel category j and EF is the emission factor of pollutant type k under fuel category i in year t .

In this study Greenhouse gas emissions which were estimated are Carbon dioxide, Methane and Nitrous Oxide because they have a high contribution in Diesel and gasoline emissions.

CHAPTER IV: RESULTS AND DISCUSSION

In this chapter we present the results found and discussions depend on three scenarios namely business as usual (BUA), scenario 1 and 2. LEAP model was used in doing analysis. The figure 3 shows the simplified model description that is used in our study.

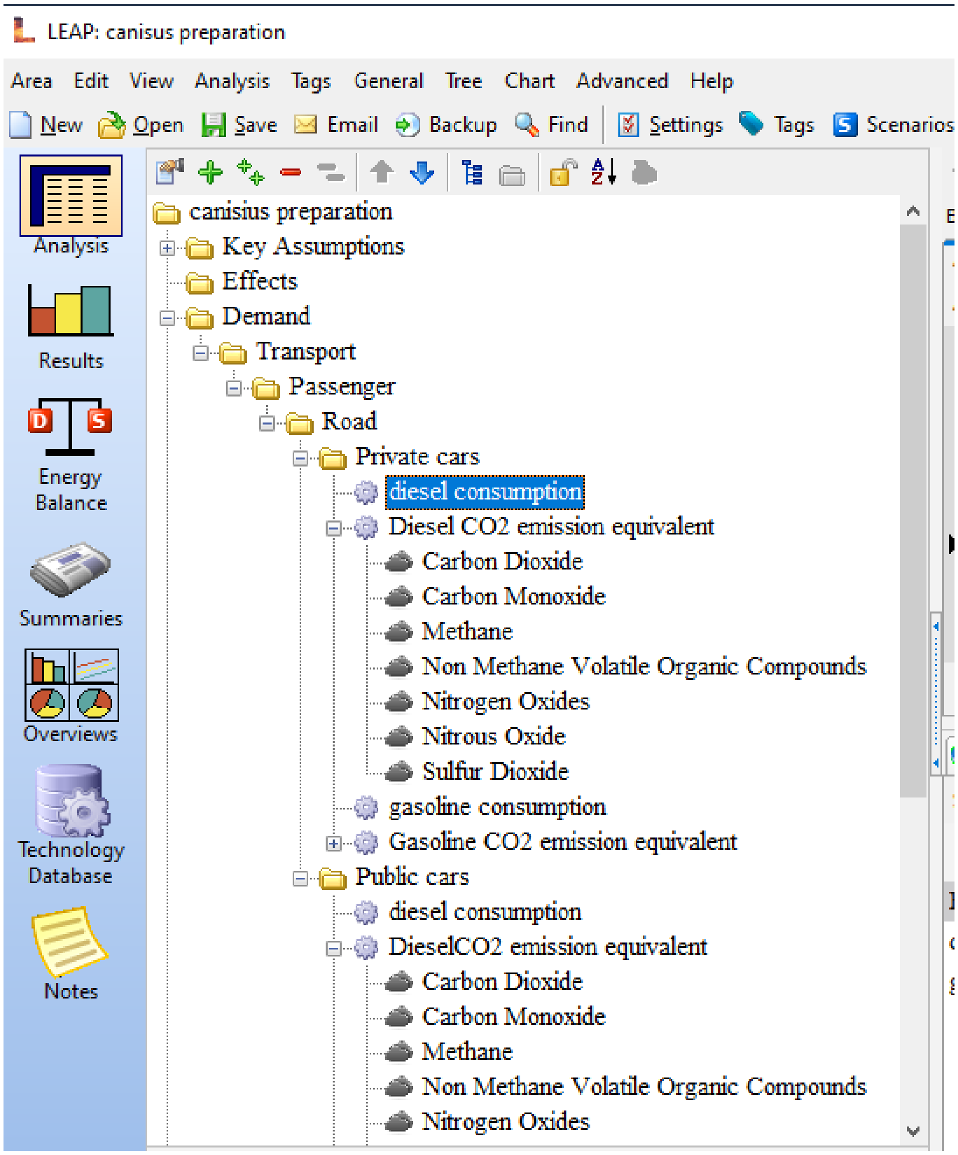

Figure 3. Simplified model description

(Source: Author's design)

The figure 3 shows the diesel and gasoline emission model which was used in this study, this is one part of our LEAP model.

4.1 Fuel consumption from passenger transport in the City of Kigali

The fuel consumption results from urban passenger transport in City of Kigali were obtained by applying the formula (3) to both private and public vehicles, the results have been standardized in energy units (Gallon US) which is approximated to 3.8 litres, the forecasted fuel consumption is shown in both figure 4 and figure 5. From the following figures we see that many times from 2010 to 2011 there is a decrease because the data of the year 2011 are less than the value of 2010 set by default in our model.

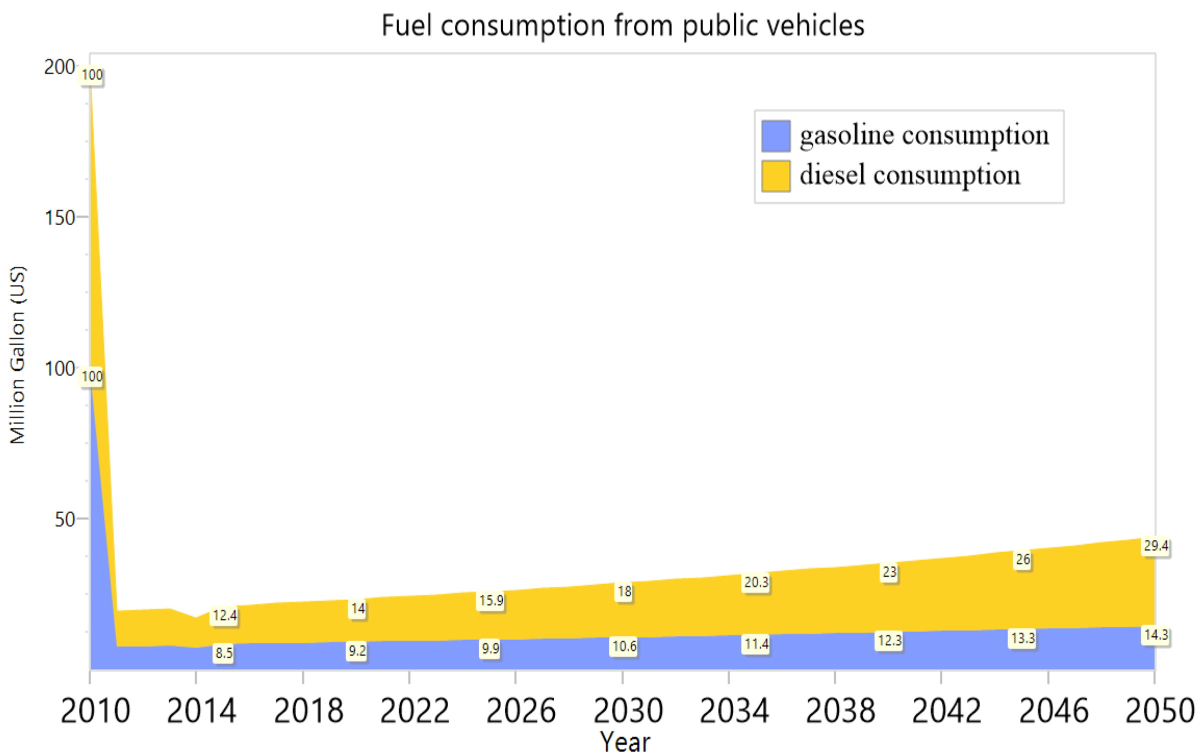

Figure 4. Fuel consumption from public vehicles in City of Kigali

From the above figure 4 the year 2010 was taken as business as usual for the analysis and set by default in the model, it is shown that the total fossil fuel consumption in public vehicles is projected to raise approximately from 20.1 million gallons (US) in 2011 to 43.7 million gallons(US) in 2050, separately for the diesel fuel consumption is to increase from 11.8 million gallons (US) in 2011 to 29.4 million gallons (US) in 2050, while the gasoline fuel consumption is to increase from 7.4 million gallons(US)in 2011 to 14.3 million gallons(US) in 2050 as shown in the Figure 4.

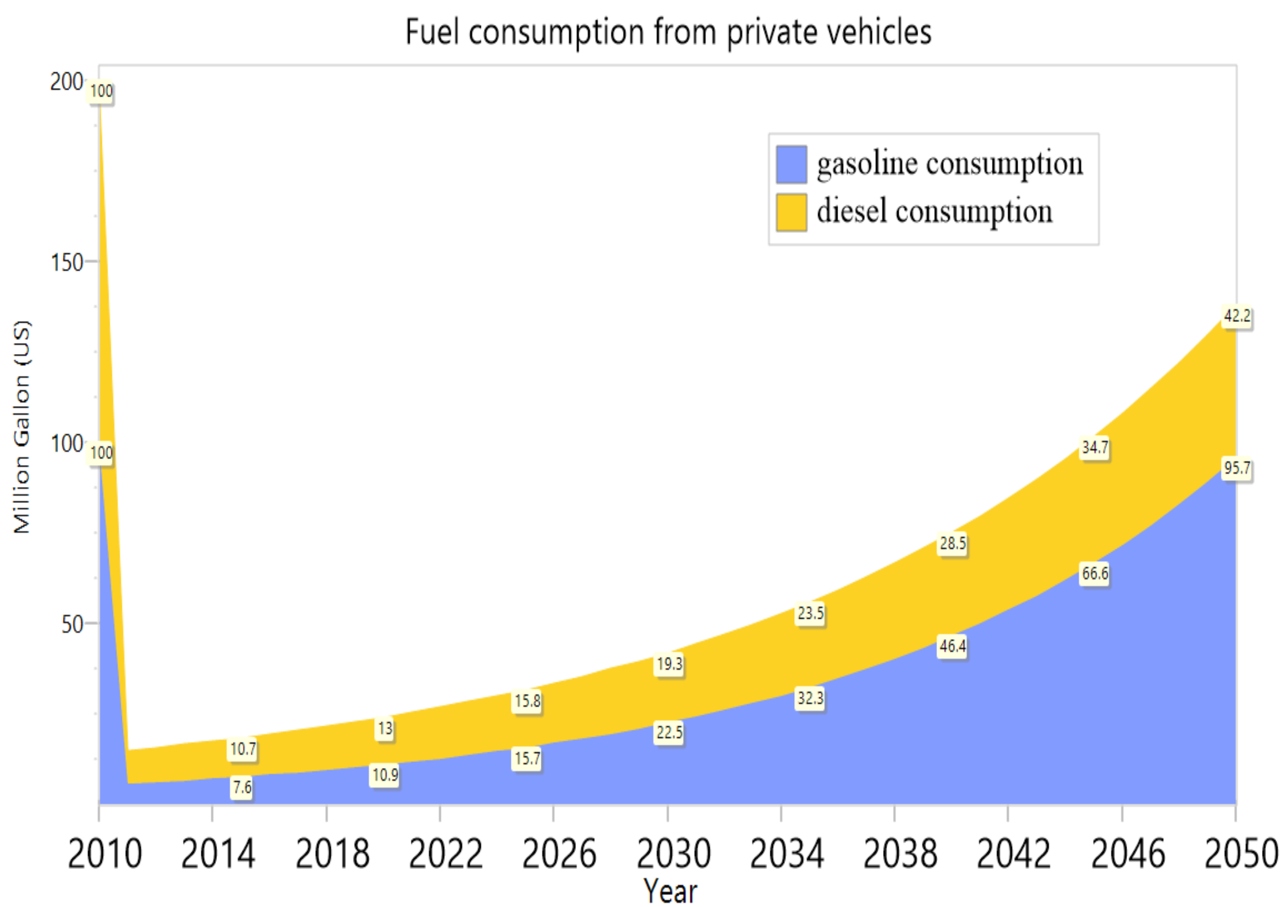

Figure 5.Fuel consumption from private vehicles in City of Kigali

In the figure 5, the year 2010 was taken as base year for the analysis and set by default in the model ,the total fossil fuel consumption in private vehicles is projected to increase approximately to 137.9 million gallons(US) in 2050 from 14.9 million gallons (US) in 2011, for the diesel fuel consumption is to increase to 42.2 million gallons(US) in 2050 from 9.2 million gallons(US) in 2011 while the gasoline fuel consumption is to increase to 95.7 million gallons(US) in 2050 from 5.7 million gallons(US)in 2011.

From the above two figures 4and 5, the private vehicles the fuel consumption is predicted to raise to 137.9 million gallons(US) with diesel fuel consumption to 42.2 million gallons and gasoline consumption to 95.7 million gallons(US) in 2050, while for the public vehicles the fossil fuel consumption is predicted to uplift to 43.7 million gallons(US) with diesel fuel consumption to 29.4 million gallons(US) and gasoline fuel consumption to 14.3 million gallons(US) in 2050.

4.2 CO2 emission equivalent from road transport in the city of Kigali

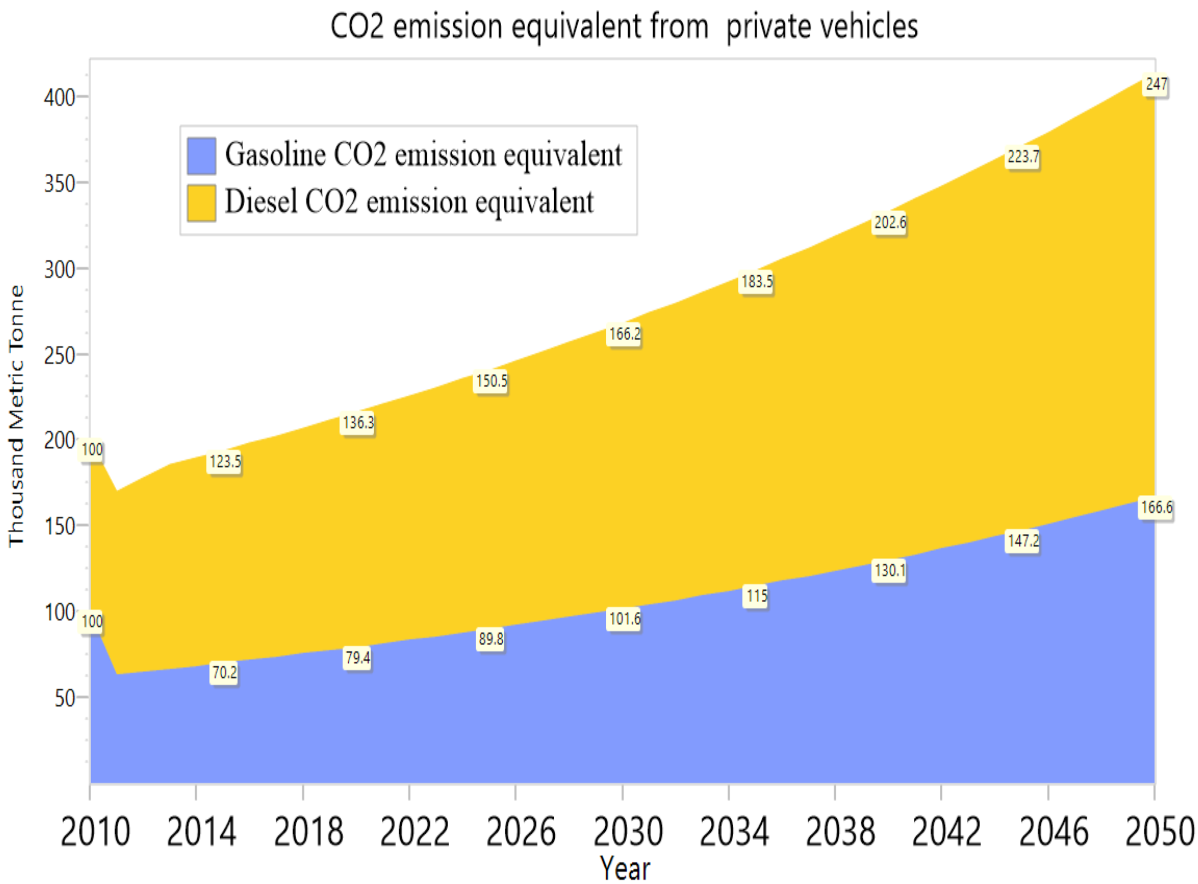

Figure 6. CO_2 *emission equivalent from private vehicles in the city of Kigali*

From the figure 6, year 2010 was taken base year for the analysis and was set by default in the model. From the greenhouse gases' global warming potentials 1,1,310 and 21 for CO2, CO, NOX and CH4 respectively were used to estimate the quantity of CO2 emissions equivalent, here The total CO2 emission equivalent from the private vehicles is forecasted to 413.6 thousand Metric Tonnes in 2050 from 194.9 thousand Metric Tonnes in 2011.

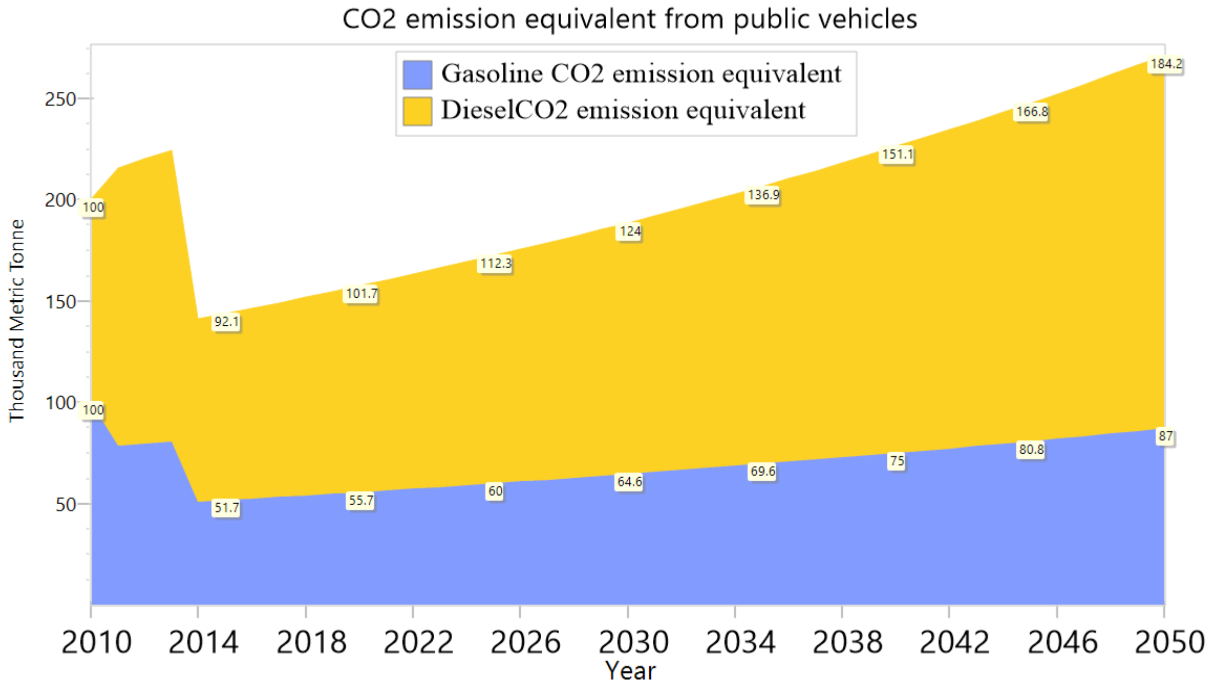

Figure 7. CO_2 *emission equivalent from public vehicles in the city of Kigali*

From the greenhouse gases' global warming potentials 1, 1, 310 and 21 for CO_2, CO, NOX and CH_4 respectively were used to estimate the quantity of CO_2 emissions equivalent in the figure 7, here the total CO_2 emission equivalent from the public vehicles is estimated to 271.2 thousand Metric Tonnes in 2050. The year 2010 was taken as business as usual for the analysis and set by default in the model. From the figure 7 we see that from 2010 to 2011 there is a decrease because the data of the year 2011 are less than the value of base year 2010 set by default in our LEAP model.

From figure 6 and figure 7, estimated values of CO_2 emission equivalent show that one from private vehicles is much greater than one predicted from public vehicles in 2050

4.3 Scenarios analysis

Table 6. Scenarios analysis

	BAU (2050)	2020	Scenario1 (2050)	Scenario 2 (2050)
Private vehicles				
Diesel consumption (Million gallon(US))	42.2	13	57.2	37.6
Gasoline consumption (Million gallon(US))	95.7	10.9	127.8	84.2
Diesel CO2 emission equivalent (thousand metric tonne)	247	136.3	205.5	218
Gasoline CO2 emission equivalent (thousand metric tonne)	166.7	79.4	138.7	148
Public vehicles				
Diesel consumption(Million gallon(US))	29.4	14.0	14.7	20.2
Gasoline consumption (Million gallon(US))	14.3	9.2	17.8	9.4
Diesel CO2 emission equivalent (thousand metric tonne)	184.2	101.7	130	100.9
GasolineCO2 emission equivalent (thousand metric tonne)	87	55.7	104.9	56.6

Source: author’s calculation

From the table 6., three scenarios namely business as usual (BAU), scenario 1 and scenario 2 were used forecast fuel consumption and emissions up to year 2050, this year was chosen because the government of Rwanda has the vision 2050 to be in middle income countries (MINECOFIN, 2018). In the BAU private vehicles represent 55% and public vehicles represent 45% (MININFRA, 2012). In Scenario 1 we considered the gasoline and diesel driven vehicles to be 55% and 45% respectively while in scenario 2 we considered the number of public and private vehicles to be 60% and 40 respectively

The fuel consumption from private and public vehicles in each scenario are presented in the table 6, in the BAU the overall fuel consumption was estimate at 181.6 million gallon (US), for the first scenario the overall consumption was estimated at 217.5 million gallon (US) whereas for the second scenario it was estimate at 151.4 million gallon (US). This shows that the scenario 2 experienced a low fuel consumption compared the remaining two scenarios, this was caused by decreasing number of private vehicles.

By analysing each scenario, we see that in the BAU scenario, the CO_2 emissions equivalent from both private and public vehicles which are environmental implication of fuel consumption are 684.9 thousand Metric Tonnes, this shows that private vehicles are higher contributors to the environmental implication with CO_2 emissions equivalent 60.4% of the total emission from vehicular road transport. Considering the scenario 1, results show that CO_2 emissions equivalent from both private and public vehicles are 579.1 thousand Metric Tonnes, these private vehicles contribute in emission at 59.4%. From the scenario 2, the CO_2 emissions equivalent from both private and public vehicles are 523.5 thousand Metric Tonnes with the contribution of 69.9% of emissions from private vehicles. These results show that in all three scenarios private vehicles contribute more in CO_2 emissions equivalent.

From these above results, fuel consumption and air pollution are positively correlated since for the three scenarios the fuel consumption is associated with corresponding CO_2 emissions equivalent hence reduced fuel consumption is accompanied by low CO_2 emissions equivalent.

4.4 Conclusion and recommendations

From the prediction we did using the three scenarios which are BAU, scenario 1 and scenario 2 we saw that in the three scenarios there is a significant contribution of private vehicles in CO_2 emission equivalent ,this is not different from the study (Transportation, U.S. Department of, 2010) stating that in U.S national averages demonstrate that public transportation produces significantly lower greenhouse gas emissions than private vehicles. The scenario 2 shows that by increasing public vehicles at 60% or more there is a lower CO_2 emission equivalent comparing to both BAU and scenario 1. To reach this decrease in greenhouse gas emissions for coming years, different policies encouraging passengers to use public transport would be introduced so that the number of private vehicles would be reduced which lead to the decrease in overall emissions.

The proposed recommendations are the followings:

i. The policy of using electric vehicles would help in reducing fuel consumption and greenhouse gas emissions from road transport.

ii. During peak hours, some road taxation could be applied according to road profile this would help in reducing jam and congestion.

iii. Restriction of roads for public transport only, this would reduce the congestion and increase time saving in waiting public vehicles.

iv. Introduction of more efficient vehicles in both public and private transport.

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6. Appendix

Table 7. Number of registered vehicles in Rwanda from 2011 to 2018

Category	2011	2012	2013	2014	2015	2016	2017	2018
Caterpillar	0	3	25	75	105	126	140	145
Bus	426	489	549	769	1059	1264	1465	1576
Trucks	3089	3378	3738	4070	4961	6049	6851	7694
Pick up	13213	14472	15163	15734	16402	17245	17940	18618
Special engine	537	638	733	832	1187	1726	2249	2856
Jeeps	13349	15828	17361	18583	20276	22292	24344	26715
Microbus	138	147	151	153	254	545	1032	1466
Minibus	5043	5528	5827	6058	6160	6283	6336	6411
Cars	19109	22699	24834	26850	30238	33080	35060	36951
Motors	49718	60980	67382	74774	85072	93866	101829	112404
Trailers	721	750	812	851	887	920	934	976
Semi-trailers	184	186	186	194	218	232	277	316
Tricycles	18	61	63	68	73	73	73	73
Unknown	0	0	0	1	1	2	3	3
Total	**105545**	**125159**	**136824**	**149012**	**166893**	**183703**	**198533**	**216204**

Table 8. Fuel consumption from Private vehicles

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel consumption (Million gallon(US))	100.0	10.7	13.0	15.8	19.3	23.5	28.5	34.7	42.2
Gasoline consumption (Million gallon(US))	100.0	7.6	10.9	15.7	22.5	32.3	46.4	66.6	95.7

Table 9. CO2 emission equivalent from private vehicles (thousand Metric Tonne)

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
Diesel CO2 emission equivalent	100.0	123.5	136.3	150.5	166.2	183.5	202.6	223.7	247.0
Gasoline CO2 emission equivalent	100.0	70.2	79.4	89.8	101.6	115.0	130.1	147.2	166.6

Table 10. Fuel consumption from public vehicles

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
diesel consumption (Million gallon(US))	100.0	12.4	14.0	15.9	18.0	20.3	23.0	26.0	29.4
gasoline consumption (Million gallon(US))	100.0	8.5	9.2	9.9	10.6	11.4	12.3	13.3	14.3

Table 11. CO2 emission equivalent from public vehicles

Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
DieselCO2 emission equivalent (thousand metric tonne)	100.0	92.1	101.7	112.3	124.0	136.9	151.1	166.8	184.2
Gasoline CO2 emission equivalent (thousand metric tonne)	100.0	51.7	55.7	60.0	64.6	69.6	75.0	80.8	87.0