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GREENHOUSE GAS EMISSION IN ROAD TRANSPORT AND URBAN MOBILITY IN OUAGADOUGOU: EVALUATION AND MODELLING OF ITS EFFECT ON AIR POLLUTION

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DEDICACE

We give thanks to God the Almighty. Glory to him, the lord of the universe for granting us the opportunity to produce this document.

I dedicate this work to:

My late mother BOUKARE ASSANA for her countless efforts in our education, the sense of righteousness and dedication that she never ceased to instill in us during her lifetime. May God welcome him to his heavenly paradise.

Gratitude

This document is the result of a long process which required the participation of several people to whom I would like to thank warmly.

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Abstract

The transport and urban mobility sector in Burkina Faso is one of the sectors that strongly contributes to greenhouse gases (GHG) emissions, as well as atmospheric pollutants. The aim of this study was to assess and model road transport and urban mobility contribution to greenhouse gas emissions and fossil fuel demand. Thus, the methodology of is consisted of the assessment of road transport legislation related to environment protection in Burkina Faso. The development of a bottom-up model to estimate the historical trends of vehicle fleet growth and energy demand using the Long-Range Energy Alternative Planning (LEAP) software. It assesses greenhouse gases by establishing the specific emission factors and takes the city of Ouagadougou as a case study which represents 48% of the urban population of the country and 83.67% of the vehicle fleet.

The results show a significant air pollutants and GHG emissions, which coupling with the high vehicle fleet growth resulting in fuel consumption of more than 89% of the fossil fuel sold in Burkina Faso. Gasoline occupies 10% and is 98% consumed by two-wheelers. Diesel occupies 90% and is 80% consumed by trailers and trucks. Thus a total of 0.47 GtCO2eq/year of Carbone dioxide (CO_2) is emitted, diesel vehicles contribute to 87.49% and gasoline vehicles for 12.51%. The most air pollutants are CO_2 (4734851.666 tons), NOx (60879.311 tons), CO (23076.198 tons) and some trace of NO_2, SO_2 etc. The CO_2 emission is led by tractor and truck vehicle, respectively 55.20% and 20.25%, flowed by Motorbike (8.48%), Vans (7.42%), Private vehicle (5.02%) and Bus (3.5%) for CO_2. The CO emission is dominated by the private cars, 73.84%, with gasoline and by truck vehicle with diesel 72.4%. The NOx is dominated by motorbike with gasoline fuel 77.76% and by truck with diesel 72.40%. The stratospheric ozone is mostly affected in the central area of the city.

Thus, this project showed the need of an incentives of environmental regulations and climate change mitigation for sustainable mobility. It may assist the policymakers in achieving lower emission in both, air pollutant and GHG emission in road transport.

Key words: Greenhouse gases, Road transport, Urban Mobility, Ouagadougou

Résumé

Le secteur des transports et de la mobilité urbaine au Burkina Faso est l'un des secteurs qui contribue fortement aux émissions de gaz à effet de serre (GES), ainsi qu'aux polluants atmosphériques. L'objectif de cette étude est d'évaluer et de modéliser la contribution du transport routier et de la mobilité urbaine aux émissions de gaz à effet de serre et à la demande de combustibles fossiles. Ainsi, la méthodologie a consisté en l'évaluation de la législation du transport routier liée à la protection de l'environnement au Burkina Faso. Le développement d'un modèle ascendant pour estimer les tendances historiques de la croissance du parc de véhicules et de la demande d'énergie à l'aide du logiciel de planification alternative énergétique à long terme (LEAP). Il évalue les gaz à effet de serre en établissant les facteurs d'émission spécifiques et prend comme cas d'étude la ville de Ouagadougou qui représente 48 % de la population urbaine du pays et 83,67 % du parc automobile.

Les résultats montrent des émissions de polluants atmosphériques et de GES importantes qui, couplées à la forte croissance du parc automobile, se traduisent par une consommation de carburant de plus de 89% des combustibles fossiles vendus au Burkina Faso. L'essence occupe 10% et est consommée à 98% par les deux-roues. Le diesel occupe 90% et est consommé à 80% par les remorques et les camions. Ainsi un total de 0,47 GtCO2eq/an de dioxyde de carbone (CO_2) est émis, les véhicules diesel contribuent à 87,49% et les véhicules à essence pour 12,51%. Les polluants atmosphériques les plus importants sont le CO_2 (4734851,666 tonnes), les NOx (60879, 311 tonnes), le CO (23 076 198 tonnes) et quelques traces de NO_2, SO_2 etc. L'émission de CO_2 est dominée par les tracteurs et les camions, respectivement 55,20 % et 20,25 %, suivit par les motos (8,48 %), les fourgonnettes (7,42 %), les véhicules particuliers (5,02 %) et Bus (3,5%). Les CO sont dominées par les véhicules particuliers à 73,84%, et par les poids lourds avec le diesel 72,4%. Les NOx sont dominées par les motos à essence 77,76% et les camions au diesel 72,40%. L'ozone stratosphérique est principalement affecté dans la zone centrale de la ville.

Cette étude montre la nécessité d'une incitation à la réglementation environnementale et stratégie d'atténuation au changement climatique pour une mobilité durable. Il peut aider les décideurs à réduire les émissions de polluants et de GES dans le transport routier.

Mots clés : Gaz à effet de serre, Transport routier, Mobilité urbaine, Ouagadougou

Acronym and abbreviation

DGMU	General Directorate of Urban Mobility
DIRMO	Road Infrastructure and Mobility Department
SDAU	Urban Planning Master Plan
MTMSUR	Ministry of Transport, Urban Mobility and Road Safety
DGNET	General Directorate of Standardization and Technical Studies
CTGO	Greater Ouagadougou Transport Council
SOTRACO	Ouagadougou Public Transport Company
LEAP	Long-Range Energy Alternative Planning
SONABHY	Burkinabe National Hydrocarbons Company
DGTTM	General Directorate of Land and Maritime Transportation
ONASER	National Office of Road Safety
GHG	Greenhouse Gas
UNFCCC	United Nations Framework Convention on Climate Change
IPCC	Intergovernmental Panel for Climate Change
UNEP	United Nations Environment Program
CCVA	Motor vehicle control center
SDAGO	Greater Ouagadougou Development Master Plan
ONTTB	Burkina National Land Transport Organization
OTRAF	Organization of Road Haulers in Faso
PNMU	National Urban Mobility Policy
MEEVCC	Ministry of the Environment, Green Economy and Climate Change
PNDES	National Economic and Social Development Plan
GWPs	Global Warming Potentials
IPPU	Industrial Processes and Product Use
AFOLU	Agriculture, Forestry and Other Land Use
WHO	World Health Organization
RGPH	General Population and Housing Census
CH_4	Methane
N_2O	Nitrous Oxide
CO_2	Carbone Dioxide
HFC	Hydrofluorocarbon
NMVOC	Non-Methane Volatile Organic Compounds
LPCE	Environmental Physics and Chemistry Laboratory
NCV	Net calorific values

Chapter 1: GENERAL INTRODUCTION

1.1 Introduction

Over a century, greenhouse gases such as of carbon (CO_2), methane (CH_4) etc. concentration increased exponentially in the atmosphere (Steinberger et al.). This phenomenon is to be put in relation with human activities. Human needs for energy has led man to burn large amounts of fossil fuel. The urban growth due to increase of population leads to the increase of important quantity of energy consumption such as fossil fuel, wood, charcoal etc. Indeed, global population living in urban areas reached 50% at the beginning of the 21st century and is expected to reach 60% by 2030 (Dubresson and Jaglin). The fastest rates of urbanization are found in the developing world (UNFPA, 2014). The transportation sector (cars, trucks, ships, trains, and planes etc.) is the greatest one active contributor to fossil fuel consumption in cities and generates the largest share of greenhouse gas emissions. Over 90 percent of the fuel used for transportation is petroleum based (United States Environmental Protection Agency, 2018) contributing significantly to environment pollution trough greenhouses emission. The interactions between urban areas and global environmental change can create a diversity of impacts that can be grouped in two broad categories: those originating in urban areas that have a negative effect on global environmental change, and global environmental changes that have negative effects on urban areas (Simon and Holloway). This perspective ignores the fact that many of the processes implicit in urbanization can actually have a positive overall effect on global environmental change, and fails to recognize that the spatially varied consequences of global environmental change are likely to affect different urban areas in a variety of different ways. Referring specifically to climate change, the Executive Director of the United Nations Centre for Human Settlements (Kirk, 1988) has stated that cities are responsible for 75 per cent of global energy consumption and 80 per cent of greenhouse gas emissions (Dodman and Uwi). Clinton Foundation estimates that cities contribute approximately 75 per cent of all heat-trapping greenhouse gas emissions to atmosphere, while cities comprises of only 2 per cent of land mass (Dodman and Uwi). Yet at the same time, detailed analyses of urban greenhouse gas emissions for individual cities suggest that – per capita – urban residents tend to generate a substantially smaller volume of greenhouse gas emissions than residents elsewhere in the same country. In 2004, transport accounted for 26% of world energy use and 95% of this was generated by fossil fuel burning internal combustion engines. It estimates that “Unless there is a major shift away from current patterns of energy use, projections foresee a continued growth in world transportation energy use of 2% per year, with energy use and carbon emissions about 80% above 2002 levels by 2030 (Josefina and Meza, 2018).

In developing countries, transportation energy use is rising faster, range from 3 to 5% per year) and is projected to grow from 31% in 2002 to 43% of world transport energy use by 2025 (Barker et al., 2007). Countries with high motorization have far higher per capita emissions than developing countries (Short et al., 2009). For instance, the average CO_2 per capita in London is 1.3 tons while in Delhi it is 0.4 tons (Hickman and Banister, 2009). Vehicles are the largest source of GHG emissions in most urban areas. Therefore, greenhouse gases emitted from urban transport sector are carbon dioxide (CO_2), the majority one, methane (CH_4), Nitrous dioxide (NO_2), and small of amount of hydrofluorocarbon (HFC) resulting from the use of mobile air conditioners and refrigerated transport. Anthropogenic volatile organic compounds (VOCs), carbon monoxide (CO), and nitrogen oxides (NOx), all of which are important precursor compounds to tropospheric ozone (O_3) and secondary organic aerosol formation, are predominantly emitted from vehicles in urban areas (Chavez-baeza and Sheinbaum-pardo). As part of a global effort to identify greenhouse gas emissions and to set targets for emissions reductions, the United Nations Framework Convention on Climate Change (UNFCCC) requires all member states to submit regularly their National Greenhouses Inventory Report. The Intergovernmental Panel on Climate Change (IPCC) provides a detailed methodological framework to accomplish this, which assesses all the greenhouse gases emitted from four main sectors: energy; industrial processes and product use; agriculture, forestry and other land use; and waste. This engagement shows the importance of greenhouse gas effect on global impact on climate.

Located in the heart of West Africa, Burkina Faso is a landlocked country where the sector of transports plays an important role in the economy. Its geographical position makes the country a compulsory area of transit to some Saharan countries (Niger and Mali) for their access to the sea. Ouagadougou city, a fast-developing city has more than 2,000 000 Motorbikes and 67.83% of registered vehicles in 2018 were private cars with approximately one private car per household (DGTTM, 2018). The population has grown by 3.7% per annum passing from 1.8 million in 2008 to 2.5 million in 2019. The only city in Burkina Faso that accounts for more than 45.6% of the urban population (RGPH, 2019). It has around 100,000 new inhabitants each year with an area radius equal to 12km and can reach 15km in 2025 (SDAGO, 2020). Thus, the urban sprawl leads to an increase in the distances between workplaces and the homes of city dwellers. This growth of population and space leads to the increases of motorized vehicles uses which has increased by 4.3% per annum. The average age of vehicles fleet is 17 years old (CCVA, 2019). The rate of mobility is about 2.3 (Ouagadougou Municipality, 2017), which is higher than the regional rate of 1.2 in 2017. Only 11% of the city population are using public transport. The bad conditions of vehicles, the massive use of two wheel vehicles result in the main source of fossil fuel consumption, can therefore contribute to the greenhouse gas emission leading to air pollution.

The methodology for inventory of greenhouse gases in Burkina Faso is based on survey data and secondary data used from the administration and institutions. It focuses on the strategies of mitigation and adaptation. It uses default emission factor to assess GHG emission. Therefore, the lack of specific emission factor, fuel consumption/demand and the fleet availability data cannot enable us to assess accurately the real specific contribution of transport and mobility on GHG emission. In addition, transport sector is a crucial component of modern life which characterize urbanization. So far, less study has been carried out for greenhouse gas emission in urban transport and mobility in Burkina's cities and to address air pollution.

This study intends to develop specific emission factor and reliable fleet availability data in order to provide more reliable historical trend of GHG emission in urban transport and its effect on air pollution.

It will help to develop sustainable transport principles in order to provide a fairness of mobility access across and within generations in Burkina Faso cities in this context of climate change.

1.1.2- study objectives

a-Main objective

This study seeks to assess and model greenhouse gas emission relating to urban road transportation and mobility sector and its effect on air pollution.

b- Specific Objectives

The specifics objectives of this thesis are to:

- assess road transport and mobility legislation related to environment protection in Ouagadougou;
- assess and model road transport and mobility fossil fuel consumption and demand in Ouagadougou;

- evaluate the urban road transport greenhouses gases emission and its effect on air pollution in Ouagadougou.

1.1.3- Research questions

- What are the types of greenhouse gases emitted from the transport sector in Ouagadougou's cities?
- what is the share or quantity of fuel consumed by transport and urban mobility in Ouagadougou?
- How does the greenhouses gases from road traffic and mobility contributes to air pollution in Ouagadougou's City?

1.1.4- Research hypothesis

- Road transport and urban and mobility legislation is taken enough account of the environmental protection in Burkina Faso (Ouagadougou);
- The transport sector in Burkina Faso emit all the different type of greenhouses gases recognize by IPCC.
- Urban road transport and mobility greenhouse gases emission is increasing and contributing to Air pollution on Ouagadougou city;

1.2. Dissertation outline

This master thesis has five chapters. Chapter 1 is focuses on the background of the study, problem statement and justification, research questions, objectives of the study and research hypothesis. Chapter 2 presents the literature review, it provides the definition of key concepts used in this study and summarize previous works related to each specifics objectives in the current study. Chapters 3 is focuses on the methodology which presents the study area, describes the method used per objectives of the study. Chapter 4, is most focuses on the main results and discussions of the study. Chapter 5, the last chapter focuses on the conclusion and recommendations of the study.

Chapter 2: LITERATURE REVIEW

Since Burkina Faso has ratified the United Nations Framework Convention on Climate Change (UNFCCC) in June 1992 (MEEVCC 2015) some studies has been done to estimate GHG emission including the regular report on inventories of anthropogenic emissions using the IPCC 2006 guideline. Nowadays, the country had two national communications on climate change 2001 and 2014 (Burkina Faso second NDC, 2014). So, these communications considered the main economics sectors including transport and energy sector for the whole country. This section consists to review an existing literature related to this research topic.

2.1- Concept note clarification

The conceptual framework allows understanding the subject. It leads to grasping the key elements of the study because concepts may vary depending on contexts or disciplines.

2.1.1. Greenhouse gas (GHG)

According to Intergovernmental Panel on Climate Change (IPCC, 2006), GHG are the gases that absorbs and emits radiant energy within the thermal infrared range, causing the global warming or atmosphere temperature rising. The primary greenhouse gases in Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3). Without greenhouse gases, the average temperature of Earth's surface would be about −18 °C (0 °F), rather than the present average of 15 °C (59 °F)

2.1.2. Emission factor and activity data

An **activity data** is a quantitative measure of activity that results in a GHG emission or removal (examples: the amount of energy, fuels or electricity consumed, material produced, service provided or area of land affected). **Emission factor** is the coefficients which quantify the emissions or removals per unit activity (IPCC, 2006). Therefore, the basic equation to estimate greenhouse gases emissions = Activity Data ● Emission Factor.

For example, in the transport sector fuel consumption would constitute activity data, and mass of carbon dioxide emitted per unit of fuel consumed would be an emission factor.

2.1.3. Energy intensity

Energy intensity is a measure that is often used to assess the energy efficiency of a particular economy. The numerical value is traditionally calculated by taking the ratio of energy use (or energy supply) to gross domestic product (GDP), indicating how well the economy converts energy into monetary output (Anon, 2008). In this case, energy intensity is calculated by passenger and freight, and determine the average. Therefore, the average energy intensity of passenger and freight transport is determined by the fleet composition (number and type of vehicle), the vehicle utilization (occupancy rates and load factors) and driving characteristics (speeds, distances).

2.1.4. Urban

In its primary acceptation, urban is opposite of rural, the former apply to a city which has a minimum proportion of non-agricultural assets, between 25 and 50% of urban assets, and the second in the village, the countryside where agriculture, breeding are the main activities. This is a fundamental criterion of differentiation between these two environments, the rural way of life being different from the way of urban life, even if the increasingly pronounced interpenetration of the two environments tends to remove those limits. Then, Urban definition differs from one country to another: 200 inhabitants in Iceland and Norway, 2,000 inhabitants for the urban municipalities of France, 20,000 inhabitants in Belgium (UN, 2000). According to United Nation (2014), a city is an urban unit of a “human settlement” that is extensive and heavily populated (20,000 inhabitants) in which most human activities are concentrated: habitat, commerce, industry, education, politics, culture, transports, services.

In Burkina Faso, a city is an administrative entity, the head office or the capital of an administrative unit (*Province*) and must have at least 10,000 inhabitants. Even if it absorbed old villages (OUATTARA Ardjouma). In decentralization politics, the cities are organized in urban and rural municipalities: to be consider us urban municipality, the city must have at least one permanent agglomeration of twenty-five thousand inhabitants and whose economic activities make it possible to generate own annual budgetary resources of at least 25,000,000 territorial FCFA (INSD, 2004).

2.1.5. Transport and Mobility

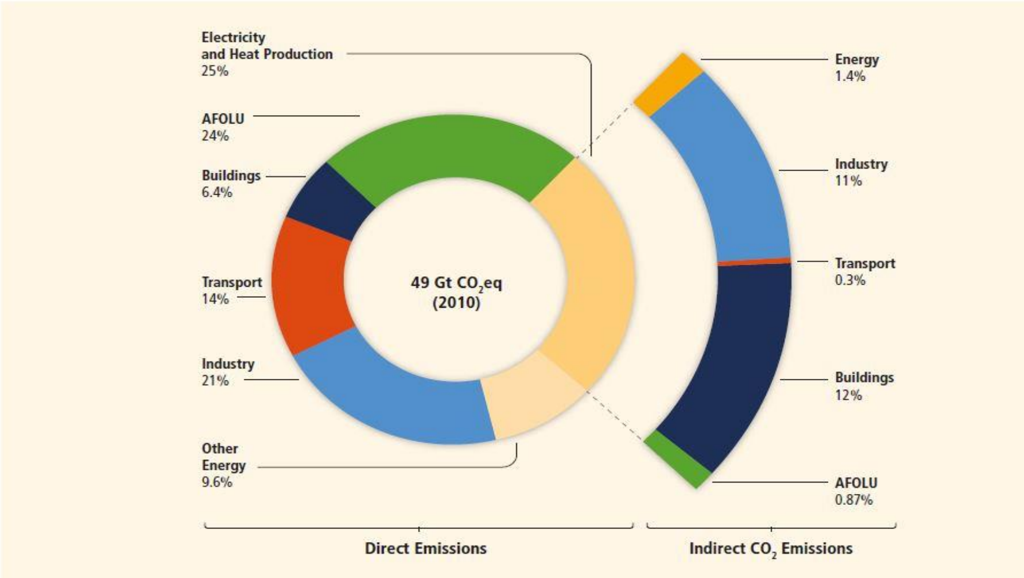
Transport is an expression for the satisfaction of mobility needs with different means of transportation—for everyday travel, people walk, cycle, drive or take public transport. There are two main groups such as people with a distinct preference for using private vehicles, and people who prefer so-called “ecomobility”—the combination of public transport with walking and cycling (Maurer et al.).

According to Cambridge Dictionary, 2019, Mobility is the fact that it is easy to move or transport something from one place to another, or to use it for a different purpose. Thus in transport field, Mobility is the way of people to accede or reaching a destination, e.g. a shop, the doctor, the workplace, a school, the pharmacy, a friend etc. Its therefore involved traffic e.g. vehicles/instruments, cars on a road, fuel consumed, road space, traffic lights, trains, noise, concrete etc. therefore, mobility has an origin and destination with an incitement.

2.2. Review of existing literature

2.2.1- Sources of greenhouses gases emission

Fossil fuels are the main source of energy and it still supply 84 percent of world energy. Transportation is extremely energy intensive sector with over 98 percent depending on petroleum products (Forbes, 2020). This energy source has been known not to be environmentally friendly because, their combustion releases a lot of greenhouse gas into the atmosphere that contribute to the enhancement climate change. Global warming, the phenomenon of increasing average air temperatures near the surface of Earth over the past one to two centuries derives from the enhancement of greenhouse gas in the atmosphere (Stocker and al., 2001). It occurs when carbon dioxide (CO_2) and other air pollutants and greenhouse gases in the atmosphere absorb sunlight and solar radiation that have bounced off the earth's surface (IPCC, 2007). All these emissions are linked to human activities, which evolve the fossil fuel consumption. Emissions of the GHGs covered by the Kyoto Protocol increased by about 70% (from 28.7 to. 49.0 $GtCO_2$-eq) from 1970–2004, with carbon dioxide (CO_2) being the largest source, having grown by about 80%. The largest growth in CO_2 emissions has come from power generation and road transport. The transport sector is one of the sector contributing most of the GHG emission because of the use of fossil fuel after energy (Figure 1).



Source: IPCC, 2014

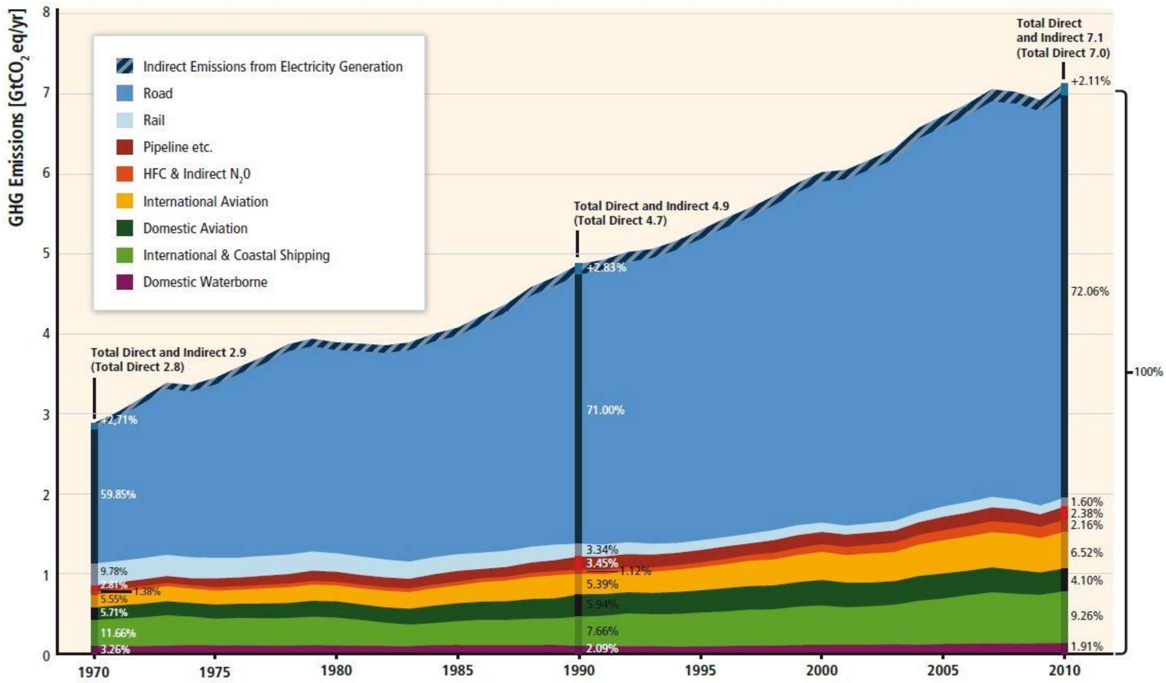
Figure 1: Global CO_2 emission per economic sectorial activity

The transport sector produced 7.0 GtCO2eq of direct GHG emissions (including non-CO2 gases) in 2010 and hence was responsible for approximately 23 % of total energy-related CO2 emissions 6.7 GtCO2 worldwide (Josefina and Meza, 2014).

The other gases such as Methane (CH_4) emissions rises by about 40% from 1970, with an 85% increase from the combustion and use of fossil fuels. Agriculture, however, is the largest source of CH_4 emissions. Nitrous oxide (N_2O) emissions grew by about 50%, due mainly to increased use of fertilizer and the growth of agriculture. Industrial emission of N_2O fell during this period (Barker et al.). So, to tackle this situation which causes global warming, the United Nations Framework Convention on Climate Change (UNFCCC) formed in 1992 by 196 parties, sets the ultimate objective to "stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system (The Paris agreement, 2015). To achieve this objective, all countries members should make a significant commitment to address greenhouse gas emission by determine the contribution of each economics sector. In Burkina Faso Transport sector is cited among the key emitted sector and, road transport occupies more than 60% of the emissions of the entire transport sector.

2.2.2- Urbanization and greenhouses emission in transport sector

The share of transport emissions tended to increase due to structural changes as gross domestic product (GDP) per capita increased, example, countries became richer. The development path of infrastructure and settlements taken by developing countries and economies in transition (EITs) will have a significant impact on the future share of transport related emissions and, consequently, total GHG emissions. This situation demonstrate that transport sector is the biggest consumer of fossil fuel and contribution much to global warming (Christopher K and al, 2010) . Movement of people, goods are fundamental component of modern society. It increases and shift towards motorized transport modes. It has been show that urbanization has an effective impact on transport and road energy use. Urban society brings several negative impact to both individual and society namely traffic congestion, accidents, noise, energy consumption, greenhouse gases emission and air pollution (Steinberger et al.). Therefore, population and economic growth have been suggested as the key drivers of transport demand. The larger the population of the city growth, the greater its transport and mobility demand will be (Rodrigue et al.). Consequently, mobility and transport demand increase fossil fuel consumption and road mode transport is the highest consumer of fossil fuel energy. It contributes to 71% of CO_2 eq emission in this sector (Figure 2).



Source: IPCC, 2014

Figure 2: Direct GHG emissions of the transport sector by transport mode rose 250 % from 2.8 Gt CO2eq worldwide in 1970 to 7.0 Gt CO2eq in *2010.*

2.3- Greenhouse gases quantification and measurement guidance

In order to allow each nation to assess national greenhouse gases emission, the Intergovernmental Panel on Climate Change provide a guideline for greenhouses gases inventory development (IPCC, "2006 IPCC Guidelines for National Greenhouse Inventories – A Primer, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Miwa K., Srivastava N. and Tanabe K."). This 2006 Guidelines represent a significant step forward in producing reliable, accurate, consistent and comparable inventories of emissions and removals of greenhouse gases. It updates earlier guidance, combine good practice guidance and new scientific and technical information on emissions and removals of greenhouse gases. It therefore provides methodologies for making estimates of national anthropogenic emissions and removals of greenhouse gases. These methodologies can be used to assist parties to UNFCCC in fulfilling their commitments to develop inventories of anthropogenic emissions and removals of greenhouse gases not controlled by the Montreal Protocol. The gases that contribute to climate change have been identified in IPCC assessment reports of 2006, while previous IPCC guidance of 1995 focused on the gases with Global Warming Potentials (GWPs) identified in the second assessment report (IPCC-SAR), the 2006 Guidelines cover a longer list of greenhouse gases with GWP values identified in the third assessment report (IPCC, "2006

IPCC Guidelines for National Greenhouse Inventories – A Primer, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Miwa K., Srivastava N. and Tanabe K.") or potential replacements for them (Table 1).

Table 1 : Greenhouse gases covered in the 2006 Guidelines

Name	Symbol(s)	In IPCC 1996 Guidelines	GWP available in TAR
Carbon Dioxide	CO_2	Yes	Yes
Methane	CH_4	Yes	Yes
Nitrous Oxide	N_2O	Yes	Yes
Hydrofluorocarbons	HFCs (e.g., HFC-23 (CHF_3), HFC-134a (CH_2FCF_3), HFC-152a (CH_3CHF_2))	Yes	Yes
Perfluorocarbons	PFCs (CF_4, C_2F_6, C_3F_8, C_4F_{10}, c-C_4F_8, C_5F_{12}, C_6F_{14})	Yes	Yes
Sulphur Hexafluoride	SF_6	Yes	Yes
Nitrogen Trifluoride	NF_3		Yes
Trifluoromethyl Sulphur Pentafluoride	SF_5CF_3		Yes
Halogenated Ethers	e.g., $C_4F_9OC_2H_5$, $CHF_2OCF_2OC_2F_4OCHF_2$, $CHF_2OCF_2OCHF_2$		Yes
Other halocarbons	e.g., CF_3I, CH_2Br_2, $CHCl_3$, CH_3Cl, CH_2Cl_2		Yes
	$C_3F_7C(O)C_2F_5$, C_7F_{16}, C_4F_6, C_5F_8, c-C_4F_8O		

Source:(IPCC, "2006 IPCC Guidelines for National Greenhouse Inventories – A Primer, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Miwa K., Srivastava N. and Tanabe K.")

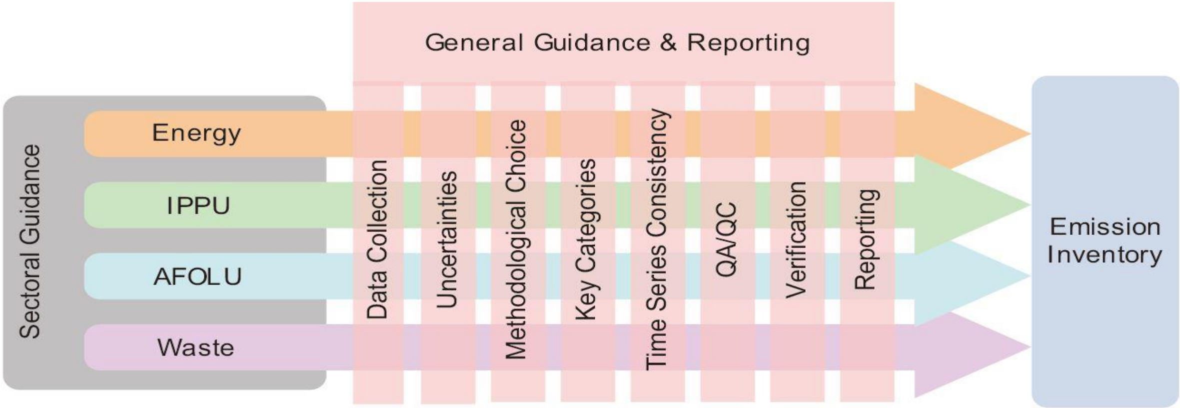
The GHG inventory depends on some principles such as geographic area, time (year and time series), sectors and categories (IPCC, "2006 IPCC Guidelines for National Greenhouse Inventories – A Primer, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Miwa K., Srivastava N. and Tanabe K."). At geographic level, inventories include in general greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction. There are some special issues such as missions from fuel use on ships or aircraft engaged in international transport should not be included in the national inventory. Also, CO_2 emissions from road vehicles should be attributed to the country where the fuel was sold. The same principle can be applied to other gases depending on the data used. For time, the inventories contain estimates for the calendar year during which the emissions to (or removals from) the atmosphere occur. Where suitable data to follow this principle are missing, emissions/removals may be estimated using data from other years applying appropriate methods such as averaging, interpolation and extrapolation. A sequence of annual greenhouse gas inventory estimates (e.g., each year from 1990 to 2000) is called a time series. Because of the importance of tracking emissions trends over time, countries should ensure that a time series of estimates is as consistent as possible. The Greenhouse gas emission and removal estimates are divided into main sectors, which are groupings of related processes, sources and sinks: Energy, Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Use (AFOLU) and Waste. Each sector comprises of individual categories (e.g., transport) and sub-categories (e.g., cars). Countries construct a national total inventory from the sub-category level because accurate estimates can only be made at this level and because this detail makes inventories more useful to policymakers. A national total greenhouses gases emission is calculated by summing up emissions and removals for each gas. There are two exceptions. Firstly, CO_2 emissions from the use of biomass for fuels are not included in the national totals but are estimated and reported separately. Any net emissions should be covered in the AFOLU sector. Secondly, where CO_2 emissions are captured from industrial processes or large combustion sources, emissions should be allocated to the sector generating the CO_2 unless it can be shown that the CO_2 is stored in properly monitored geological storage sites (IPCC 2006, Vol.2 Ch.5).

- **Inventory Process and Management**

As with the 1996 Guidelines and the two volumes of the IPCC Good Practice Guidance the most common simple methodological approach is to combine information on the extent to which a human activity takes place (**called activity data**) with coefficients which quantify the emissions or removals per unit activity called emission factors. The basic equation apply for greenhouses gases assessment is: **Emissions = Activity Data ● Emission Factor.** For example, in the transport sector **fuel consumption** would constitute **activity data**, and **mass of carbon dioxide emitted per unit of fuel consumed** would be an **emission factor**. The basic equation can in some circumstances be modified to include other estimation parameters than emission factors. Where time lags are involved, due for example to the time it takes for material to decompose in a landfill or leakage of refrigerants from cooling devices, other methods are provided, for example first order decay methods. The 2006 Guidelines also allow for more complex modelling approaches.

- **Inventory quality**

The inventory quality ensures the respect of all step from data collection to reporting depending on the sector (Figure 3).



Source:(IPCC 2006)

Figure 3: Relationship between general and sectoral guidance

Experience has demonstrated that using a good practice approach is a pragmatic means of building inventories that are consistent, comparable, complete, accurate and transparent – and developing them in a manner that improves inventory quality over time. Indicators of inventory quality are: Transparency with clear documentation, completeness, consistency, comparability and accuracy.

2.4- Greenhouse inventory in transport sector: IPCC Good Practice Guidance and Uncertainty Management

Energy sector has been split into Non-metallic Minerals, Transport Equipment, Machinery, Mining and Quarrying, Wood and Wood Products, Construction, Textile and Leather, Other (Ole Kenneth 2013). Therefore, in transport sector, Carbon dioxide (CO_2) emissions from combustion using fossil fuel result from the release of the carbon in fuel during combustion. CO_2 emissions depend on the carbon content of the fuel and vehicle maintenance. During the combustion process, most carbon is emitted as CO_2 immediately (Trofimenko et al.). However, some carbon is released as carbon monoxide (CO), methane (CH4) or non-methane volatile organic compounds (NMVOCs), all of which oxidize to in the atmosphere within a period of a few days to about 12 years. The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories account for all the released carbon as CO_2 emissions. The other carbon containing gases are also estimated and reported separately. The reasons for this intentional double counting are explained in the Overview of the IPCC Guidelines. Unoxidized carbon, in the form of particulate matter, soot or ash, is excluded from greenhouse gas emissions totals. There are three methods provided in the IPCC Guidelines for for greenhouses gases inventories: two Tier 1 approaches which is the Reference Approach and the Sectoral Approach using default emission factor over time period, the Tier 2/Tier 3 approach which is a detailed technology-based method, also called bottom-up approach.

- **Tier 1 Reference Approach and Tier 1 Sectoral Approach**

This method estimates CO_2 emissions from fuel combustion in several steps: Estimation of fossil fuel flow into the country (apparent consumption); Conversion to carbon units; Subtraction of the amount of carbon contained in long-lived materials manufactured from fuel carbon; Multiplication by an oxidation factor to discount the small amount of carbon that is not oxidized; Conversion to CO_2 and summation across all fuels.

For the tier 1 sectoral approach, the total CO_2 is summed across all fuels (excluding biomass) and all sectors that using energy.

- **Tiers 2 and 3, the Detailed Technology-Based Approach**

The total CO_2 is summed across all fuels and sectors, plus combustion technologies (e.g. stationary and mobile sources). Both approaches provide more disaggregated emission estimates, but also require more data.

The Reference Approach provides only aggregate estimates of emissions by fuel type distinguishing between primary and secondary fuels, whereas the Sectoral Approach allocates these emissions by source category. The aggregate nature of the Reference Approach estimates means that stationary combustion emissions cannot be distinguished from mobile combustion emissions. Likewise, the Sectoral Approach is not always able to differentiate between different emission source categories within an economic activity (e.g. between use of gas or oil for heating or for off-road and other mobile machinery in the construction industry).

- **The choice of method**

The method choice is country-specific and is determined by the level of detail of the activity data available as illustrated in the chart flow (Figure 4), decision Tree for selecting the Method for Estimation of CO2 Emissions from stationary or mobile combustion. The '**bottom-up' approach** is generally the most accurate for those countries whose energy consumption data are reasonably complete. Consequently, inventory agencies should make every effort to use this method if data are available.

- **The choice of emission factor**

The choice of CO_2 emission factors (EF) for fossil fuel combustion depends on the availability of existing data within the country because the calorific values vary more widely between and within fuel types, as they are dependent upon the composition of chemical bonds in the fuel (IPCC, “2_Energy.Pdf”). Net calorific values (NCVs) measure the quantity of heat liberated by the complete combustion of a unit volume or mass of a fuel. Default data in the IPCC Guidelines are based on NCVs. For traded fuels in common circulation, it is good practice to obtain the carbon content of the fuel and net calorific values from fuel suppliers, and use local values wherever possible. If these data are not available, default values can be used. (Figure 5, in Annex)

So far, the literature review shows that, less studies have been carried out for greenhouse gas emission in urban transport and mobility in Burkina’s cities and to address air pollution. Those exiting addressed air pollution with an in situ measurement. But many studies have been done in others countries and it show to huge dependence of transport sector to fossil fuel ant it real contribution to greenhouse gases.

Chapter 3: STUDY AREA, MATERIAL AND METHOD

This section of our research consist to show the methodology that have used to perform the topic. The methodology is based on mathematical equation using the LEAP software model. The study area has been choosing according to its urban characteristics, the demography and its vehicle's fleet. It can also be explaining by the accessibility of the data.

3.1. Study area

Our research field concern the whole Burkina Faso in order to take into account all the motorized vehicles (include the two wheels), and consider the whole cars fleet of the country. But Ouagadougou city, which is the bigest one of the country is the focuesed area of the study.

3.1.1- Urban population in Burkina Faso

Burkina Faso is a landlocked country in West Africa, located between 9°20' and 15°05' of North latitude, 5°20' of West latitude and 2°03'in East longitude. The land area is 274 000 square km (Km2). Its population has been estimated to 20 487 979 inhabitants with an average density of 74.77 inhabitants per km², according to the General Population Census in 2019 (RGPH, 2019). The rate of the population growth is estimated to 2.93% per year.

The urban population includes all people residing in urban municipalities. Note that the Burkinabé urban universe has a set of 49 urban communes made up of 45 administrative centers of province to which are added Niangoloko, Bittou, Garango, Pouytenga, localities, administrative centers of departments considered as municipalities urban under the general code of local authorities. In 2019, the urban population is estimated by 5 398 305 inhabitants, or 26.3% of the country's whole popualtion. With 45 cities, the country has 49 cities in all. The various population censuses carried out in Burkina show a rapid increase in the urban population and has steadily increased over the years. It went from 22.7% in 2006 to 26.3% in 2019 (INSD, 2019). The city of Ouagadougou, with approximately 2,500,000 inhabitants, is by far the most populated city of Burkina Faso. Ouagadougou and Bobo-Dioulasso are the country's largest urban centers which represent 62.2% of the country's urban population respectively 45,5% for Ouagadougou and 16,7% for Bobo-Dioulasso (INSD, 2019). The smallest city is Gayeri at the Eastern part of the country with less 1% of the urban population (0,7%). Moreover, between the 1960 survey and the census at the end of 2019, the total population of Burkina Faso was multiplied by 4,2 and the urban population by 27. But 3 out of 5 city dwellers in Burkina Faso, live in Ouagadougou or Bobo-Dioulasso. Lead by Ouagadougou, it indicates that the growth of the urban population will continue. These two cities (Ouagadougou, Bobo-Dioulasso), represent the main urban centers of the country (Figure 4), the spatial representation of the urban population in Burkina Faso.

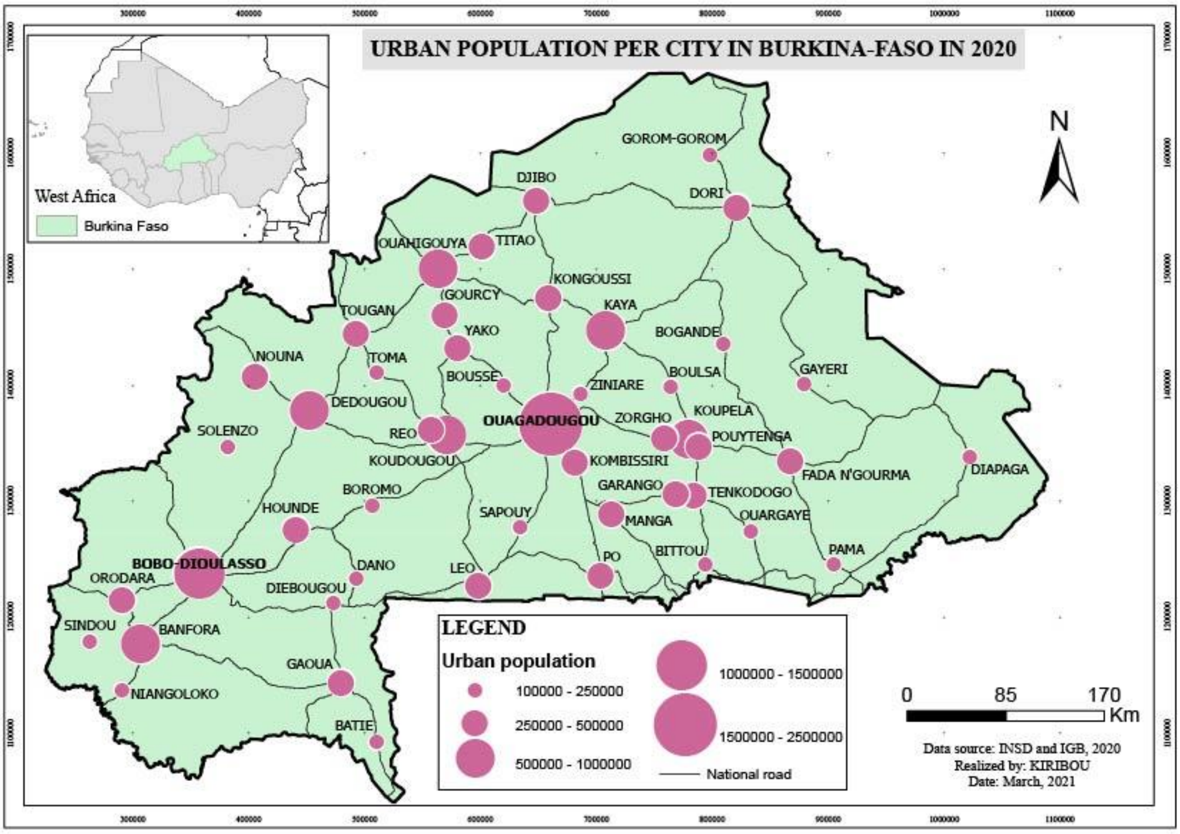


Figure 4: Spatial distribution of urban population in Burkina Faso

Futhermore, in Burkina Faso, the socio-economy is dominated by agricultural and the tertiary sector. Mining sector represents 71% of export earnings in 2020. But the urban population lives exclusively on thertiary sector activities such as industry, trnasport, hand craft etc.

3.1.2- Presentation of Ouagadougou

Out of all the urban population in Burkina Faso, Ouagadougou is located in the heart of the country. Its strategic position makes it an important pole of economic growth and a center of political decisions for the country. Its population accounts for 45.5%. In 1999, it has been created greater Ouagadougou. It was established as a project by "Decree 99-270 / PRES / PM / MITH / MATS / MEE / MEF of July 28, 1999 and defined Grand Ouagadougou as" the geographical area included within the administrative limits of the province of Kadiogo and the department of Loumbila (province of Oubritenga) ". Greater Ouaga can therefore be considered today as the territory covering the urban commune of Ouagadougou, the rural communicipalities of the province of Kadiogo (Central region) such as Koubri, Komsilga, Komki Ipala, Saaba, Pabré and Tanghin Dassouri and the rural communities of Loumbila in the province of Oubritenga (Central Plateau region). This territory which covers approximately 3,304 km² and straddles two (2) regions ”1. Greater Ouaga has two components: i) an urban component represented mainly by the urban commune of Ouagadougou and ii) a rural component represented by the seven (07) rural areas. It located between 12°19'60" Northern latitude and 1°30'0" Western Longitude (figure 5).

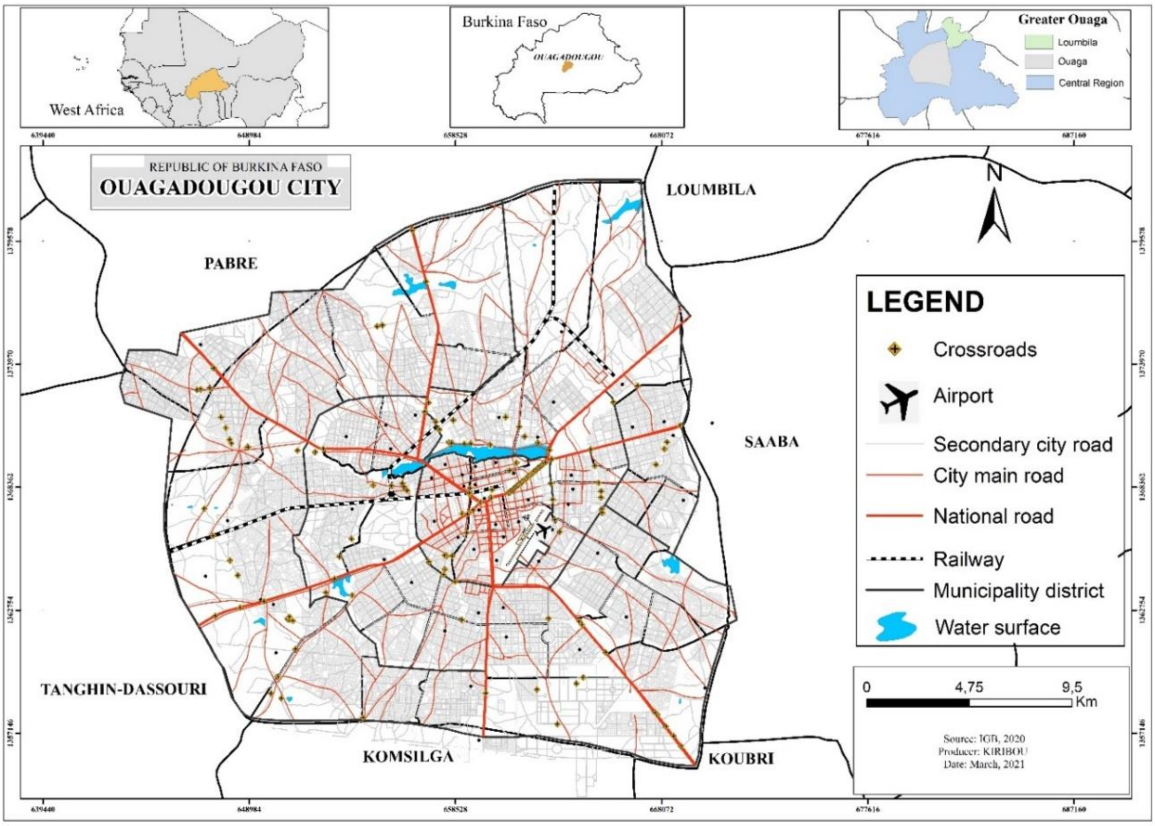


Figure 5: Ouagadougou city and its outskirts

This rapid demographic growth and the demands of the urban environment have led to an increase in mobility needs.

3.1.3- Ouagadougou's demographic growth

The population of Ouagadougou city, like that of the capitals of the developing countries, is growing at a very rapid rate of 7.6% per annum (Guengant). With this high density of human settlement, its population could reach 6 million inhabitants by 2030. This population growth rate is supported by a high birth rate and above all by an intense rural exodus. Thus, from 1960 to 2019, Ouagadougou city’s population grew from 59126 to 2453 496 inhabitants. It has multiplied by 42 in almost 6 decades (59 years). Ouagadougou's urban sprawl also reflects its demographic growth. From 1985 to 2019, the surface area of Ouagadougou increased from 80 km² with a radius of 5 km to 500 km² with a radius of 15 km (figure 6).

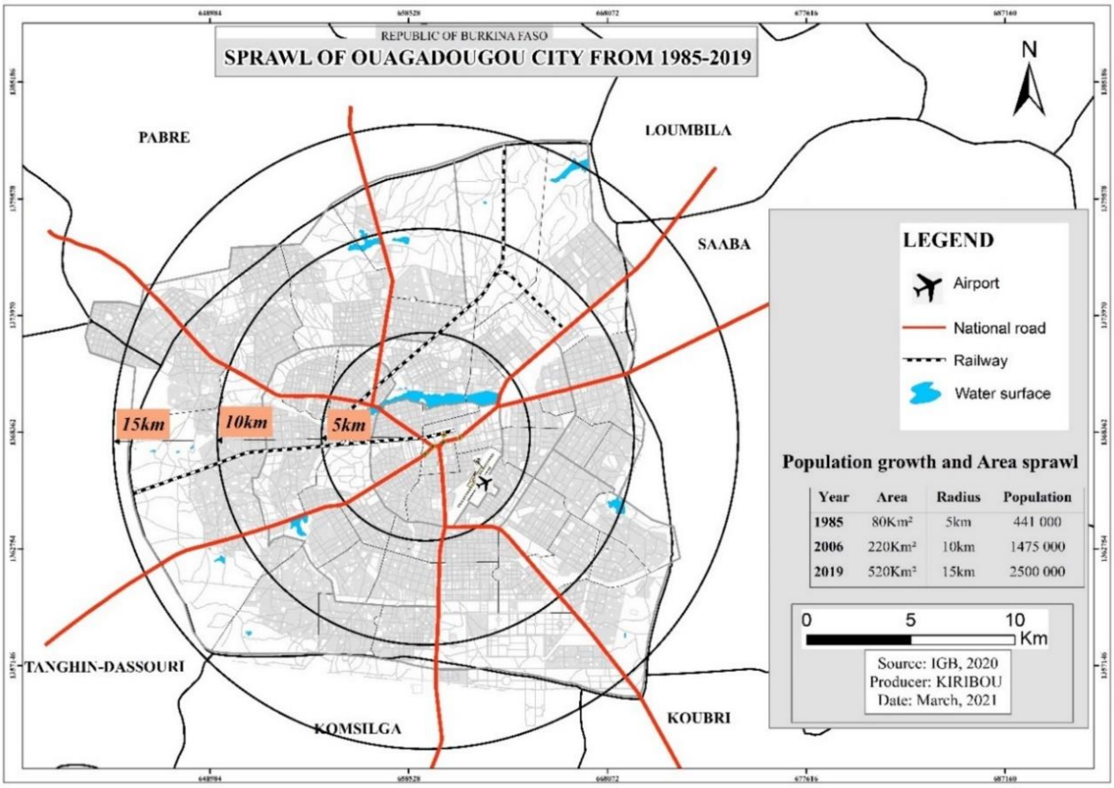


Figure 6: Population growth of Ouagadougou and the spread of its agglomeration

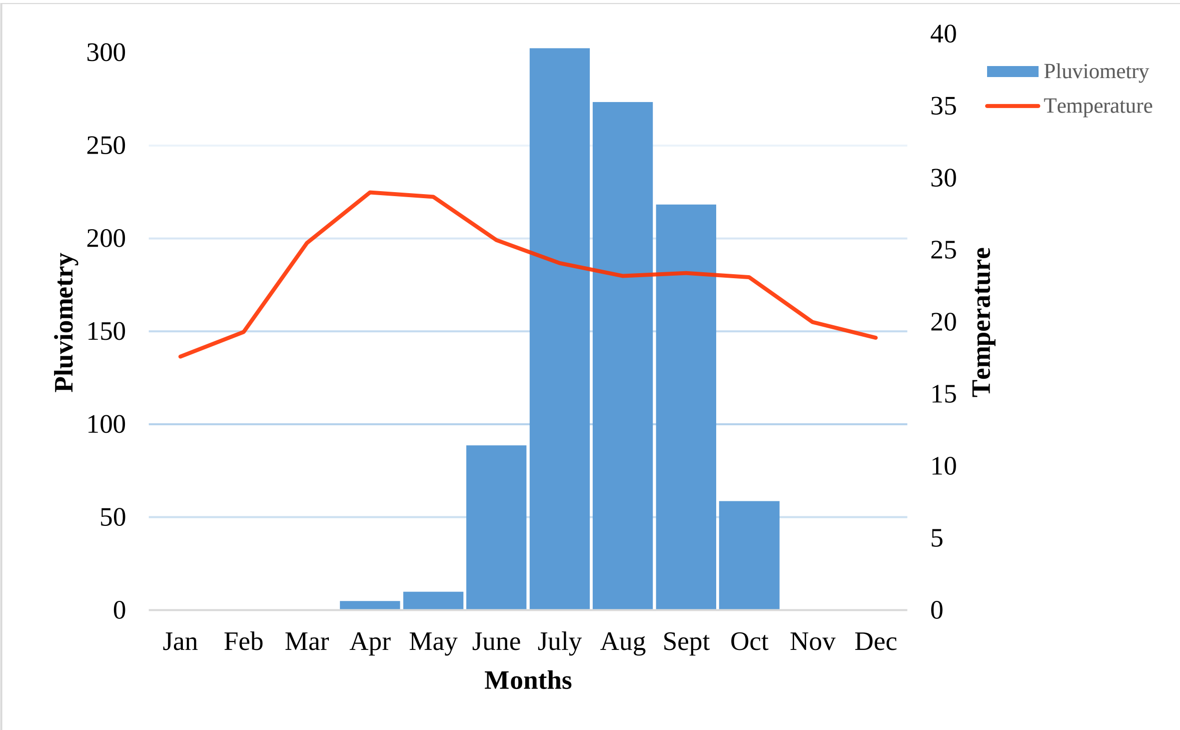
In this growth dynamics, it will cover an area of approximately of 700 km² by 2025 (SDAGO, 2020). It spatial organization shown tree (3) main areas:

- a sparse periphery made up mainly of non-residential areas;
- a city centers whose commercial and administrative functions as well as the polarization are reduced to make way for a less dense residential landscape beyond the circular boulevard.
- an hyper center characterized by high density and a high level of infrastructure bringing together administrative services, the most frequented commercial facilities such as stations, hotels, central markets publics offices etc.

3.1.3- Climatic characteristics

Due to its geographical position, Burkina Faso is highly exposed to difficult condition of climate and often to extreme weather. It includes three major climatic zones namely the Sudanese zone, the Sudano-Saharan zone, and the Saharan zone. These last decades, it suffers from inclement weather and the impacts of climate change. These climates hazards are floods, droughts, strong winds and a high variability in the duration of dry and rainy seasons. All these impacts make it difficult to manage the sectors of production that depend on natural resources, such as agriculture, fisheries and forest resources. They also compounded the difficulty in security planning food, epidemics and the management of water resources, and in particular the operations of hydroelectric dam (National Adaptation and Action Plan, 2007). Yet the life of populations in Burkina, is strongly dependent on the natural environment.

Located between the Sudano-Saharan zone and the Sudanese zone, Ouagadougou city faces the challenges of climate change every year. It already had a bad flood in September 2009 with a high rainfall. Seriously surprised by its intensity and duration with almost 300mm of water in 10 hours of time, the torrential rain is an exceptional event in the land of Ouagadougou. Much of habitats combined, public infrastructure, bridges, schools, administrative buildings, social and economic institutions of all kinds are washed away. This situation made everyone aware about climate change such as decision-makers, citizens, climate change sceptic and alike that the hazards of this phenomenon spare no one. Therefore, according to the climatic condition, the climate of Ouagadougou is characterized by an alternation of longer dry seasons and a short rainy season (Figure 7).



Source: ANAM, 2019

Figure 7: Ombrothermal diagram of Ouagadougou in 2020

3.1.4- Transport and mobility

A landlocked country, the transport sector plays a very decisive role in the economic development of Burkina Faso. The sector has a very important link in the economic and social production of Burkina Faso which, in addition to being a landlocked country, also serves as a transit country for other landlocked countries such as Niger and Mali. The system is largely dominated by land transport, which is mainly based on road. In term of transport infrastructure, there are 622 km of railroad track (517km in operation), 23 airports served by directs flights from Burkina Faso, the classified road network in 2018 was 15,304 km, of which 3,650 km were asphalted, or 24% of the network. It is made up of 6,728 km of national roads, 3,550 km of regional roads and 5,026 km of departmental roads (Annuaire Statistique, Transport; 2018). The transport activity is highly ruled by road sub-sector with 84,3% Burkinabe freight in 2018, and the road imports represent 85.3% and exports for 73.4% (MTMUSR, 2018). The road transport in Burkina Faso consumed 93% of the volume of hydrocarbons. Diesel is the best-selling hydrocarbon with 598.8 thousand toe. The hydrocarbons consumption is increasing every year (20% between 2016 and 2017). In 2018 the transport sector contributed 114.73 billion Fcfa to the formation of national wealth (MTMUSR, 2019).

3.2- Method

3.2.1- Legislation related to environmental protection

For this purpose, international commitments on environmental protection and climate change ratified couple with National policy on environment protection, climate change and sustainable development related to transport sector and National urban mobility strategy implemented by the Ministry in charge of Transport were recorded and analysis. To highlight those policies or legislation impact on greenhouses reduction and environmental protection and air pollution, historical growth of the motorized vehicle fleet in Burkina Faso from 2004 to 2019 with a scenario of fleet evolution from 2020 to 2040 was also analysis.

3.2.2. Greenhouses gases estimation

3.2.2.1 Sampling /sample estimation

Sampling is an important tool considered viable and indispensable for the execution of scientific research procedures, since they provide scientific evidence about the universe as a whole and can be used in all types of project, becoming tools of great interest (Mahaluça et al., 2019). The ever increasing demand for research has created a need for an efficient method of determining the sample size needed to be representative of a given population. In the article “Small Sample

Techniques," Morgan and Krejcie has published a formula for determining sample size (Krejcie and Morgan).

For this study purpose Ouagadougou city Cars and Motorbike fleet from the General Directorate of Land and Maritime Transportation (DGTTM) of 2019 were used and the Equation below has been used to determine the sample of vehicles population to be measured.

$$\boldsymbol{S} = \frac{\boldsymbol{X}\ \mathbf{2}\boldsymbol{NP}\ (\mathbf{1}-\boldsymbol{P})}{\boldsymbol{d}\mathbf{2}(\boldsymbol{N}-\mathbf{1}) + \boldsymbol{X}\ \mathbf{2}\boldsymbol{P}(\mathbf{1}-\boldsymbol{P})} \qquad \textbf{(Equation 1)}$$

S = required sample size.

X2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (3.841).

N = the population size.

P = the population proportion (assumed to be .50 since this would provide the maximum sample size).

d = the degree of accuracy expressed as a proportion (.05).

Sample size was determined by using this formula of Morgan (Asil and Azarshahr). According to Morgan principles, for a mother population greater than or equal to 1,000,000, the sample considered remains constant and equal to 384 split by vehicle type and fuel type (Table 2)

Table 2: Vehicles samples per type and per fuel type in 2019 in central region

Type	**Population**	**Sample**	**Share**	P/Gasoline	P/Diesel	**S/Gasoline**	**S/Diesel**
Private Cars	147158	47	12%	113312	33847	36	11
Vans	54374	17	4%	3806	50568	1	16
Trucks	26803	8	2%	0	26803	0	8
Bus (Public)	16636	5	1%	665	15971	0	5
Tractors/Trailor	64 190	20	5%	0	64 190	0	20
Others Vehicles	665	0	0%	172,9	492,1	0	0
Motorbikes	921 400	287	75%	921400	0	287	0
Total	**1 231 226**	**384**	**100%**	**1039356**	**191870**	**324**	**60**

Source: Calculation, 2021

This fact is illustrated in the graph in appendix 2. Thus, taking into account the fleet of vehicles and by applying the principle of Krejcie and Morgan, a sample of 384 vehicles were considered as representative of the vehicle fleet in the city of Ouagadougou. This sample was distributed according to the categories of vehicles according to a statistical sampling method known as stratified sampling. This method makes it possible to faithfully attribute the proportions of the different categories of vehicles of the national fleet to the sample considered in this study and vice versa. It defines as one in which every unit in the population has a chance ($0 < x < 1$) of being selected in the sample which can be accurately determined.

3.2.2.2- Emission factor estimation per vehicle type

To estimate emission factor per vehicle type Six types of vehicles were considered in the measurement, others vehicles types which are special vehicles have taken into account in private cars, because of their characteristics. It did not affect the sample of vehicles types that have been measured. The gas measurements were taken at idle with the device named **Testo 350-XL** gas analyzer (image in Annex). Since gas emissions are a function of vehicle load and other factors, a number of calculation operations were performed in order to obtain the actual gas amounts. Thus in order to be able to correct this lack, the data obtained in ppm measurement units are first normalized with respect to the excess air during the measurement, then multiplied by the density of the type of gas measured in mg/m^3. The smoke power of the fuel type in m^3 of gas per Kg of fuel is used to calculate the amount of gas in grams per amount of fuel consumed in kg. These operations were applied to all the gases measured in order to complete the measurement. All this process allows to calculate the emission factor. The emission factor which is a mass of carbon dioxide emitted per unit of fuel consumed is calculated with fuel type density in kg. For, that the measurement of engine exhaust emissions was made based on the Senegalese standard NS 05-060 in the absence of a national standard on emission control procedures. The benches for the control procedures of the euro standards are not available at the national level in Burkina Faso. The tests were carried out at idle speed in accordance with the Senegalese standard. It flows the process below:

When the vehicle arrives for the CCVA check, the various steps are carried out in order to measure the exhaust gases:

- ❖ The recording of vehicle data, i.e. type, brand, estimated consumption, year, average distance traveled, etc.
- ❖ While checking and checking the electrical elements (headlights, flashing lights) measured the composition of the engine exhaust gases at idle.
- ❖ The emissions data are measured in real time with a time step of one (01) second over a period of two minutes corresponding to the average time during which the emission values are stable. Several series of measurements are carried out (on average between three (03) and five (5) emissions measurements).

To simplify emission factor estimation, it is assumed that fuel efficiency is constant, regardless of vehicle age. Emission factors for GHG emissions is therefore determined using those data of local pollutants from Physics Laboratory of Joseph KI-ZERBO University. From 2004 forward, emission factors for lightweight vehicles based on the CCVA standard was considered (*according to the distance and age*). Emission factors for all type of vehicle were integrated. The means of emission factor recorded during of measurement at CCVA was computed to attribute emission per type of vehicle. Then, to obtain the reel amount of gases measured, the operation consisted in multiplying by the fossil fuel density which are for example, 850 kg/m3 for diesel, and 750 kg/m3 for gasoline.

Also daily satellite gridded data on atmospheric pollution such as stratospheric ozone is recorded with location were the level of transport density is high were considered to highlight the atmospheric pollution on the map.

3.2.3- Fossil fuel demand and consumption by transport and urban mobility

3.2.3.1- Factors of fossil fuel consumption in transport sector.

The energy consumption is depending on some factors such as annual average travel distance, fuel efficiency or economy, average number of occupancy or loads factors, etc.

3.2.3.1.1- Annual average travel distance

The average annual distance has been calculated considering the vehicle type. The average distance has been determined by collecting information's from the vehicle dashboard when the measurement was taken place. The total travel distance has been collected from its entry into circulation in Burkina Faso. Before being put into circulation in Burkina Faso, an import vehicle would have already traveled an average distance of 90,000 km for private Cars, 100,000 km for Trucks, 80,000 km for road Tractors/Trailers and 50,000 km for Vans. But some vehicles of the same category entered Burkina Faso without having traveled any distance. These are new vehicles put into service for the first time. Thus, the vehicle's distance in Burkina Faso is calculated by subtracting its import distance from the total vehicle distance travelled. This process consists of minimizing errors or an exaggeration of the distance. For the other categories of motorized vehicle such us Bus, Motorbike and others, have been considered as newly put into circulation in Burkina Faso accordingly to the information's obtained during the investigation.

3.2.3.1.2- Fuel efficiency or economy

The fuel efficiency/economy which is the average fuel consumption of a vehicle per year in km/liter has been calculated. The fuel efficiency or the fuel economy data information has been recorded from the compliance documents and from all the sample size of the vehicle that have been measured during the survey. The average fuel economy is therefore calculated from these data and therefore compute to all these types of motorized vehicles.

Average number of occupancy or loads factors is the capacity of the vehicles charge when running. The load factor is the ratio of the average load to total vehicle freight capacity (vans, lorries, train wagons, ships), expressed in terms of vehicle kilometers. Empty running is excluded from the calculation. Empty running is calculated as the percentage of total vehicle-kilometers which are run empty (Mendagri, 2008). The load or the charges of the vehicle is the main parameter into their categorization such as passenger's road vehicles, freight road vehicles etc. The load factor in this study has been calculated from the survey data on the vehicles charges and some information gotten from CCVA. It just concerns road passenger's vehicles: private Cars, Bus, Motorbikes.

3.2.3.2- Fossil Fuel demand and consumption estimation

To estimate field demand, fossil fuel consumption model was used based on the Long-Range Energy Alternatives Planning (LEAP) software. This is a modeling software program that enables the assessment of energy consumption from all economy sector. It was developed by the Stockholm Energy Institute's Long-range Energy Alternatives Planning with additional support from the United Nations Environment Program (UNEP), and is a joint UNEP/SEI activity. LEAP is an accounting framework, within which the user can create models of demand and supply. The LEAP model requires data for at least the base year (start year) and any of the future years. Then, using the function such as interpolation or extrapolation or the growth rate method, the future energy demand can be calculated. The equation below describes the energy demand.

$$\mathbf{E}_t = \sum_{jit} \boldsymbol{V}ijt * \boldsymbol{d}ijt * \boldsymbol{fe}ijt \qquad \text{(Equation } \mathbf{2}\text{)}$$

where:

E (J) is the energy demand for urban transport, **t** is the calendar year; **i** is the vehicle type, **j** is the fuel type,

Vijt is the vehicle population of the fuel type **j** for vehicle type **i** in the year **t**;

dijt **(km)** is the fleet average annual vehicle distance travelled of fuel type **j** for vehicle type **i** in the year **t**; and

feijt (J/km) is the fleet average on-road fuel economy of fuel type **j** for vehicle type **i** in the year **t**.

3.2.3.3- Greenhouse assessment

For greenhouses gases assessment LEAP model was used because it is a modeling software program that enables the assessment greenhouses gases from fuel consumption per type of gases.

a- Carbon dioxide (CO_2) emission

For the carbon dioxide assessment purpose the equation 3 of LEAP was used

$\mathbf{CO_{2\,t}} = \sum_{jit} \mathbf{V}ijt * \mathbf{d}ijt * \mathbf{fe}ijt * \mathbf{EF}jt$ (Equation **3**)

where: $\mathbf{CO_{2t}}$ is the **CO2** emissions in year **t**, **EF**jt is the emission factor (g/Km) of fuel type **j** in year **t**

dijt **(km)** is the fleet average annual vehicle distance travelled with fuel type **j** for vehicle type **i** in the year **t**;

feijt (g/km) is the fleet average on-road of fuel type **j** for vehicle type **i** in the year **t**.

b- Methane or N2O emission

For methane and N_2O emission assessment the equation 4 from LEAP model was used

$\mathbf{G}_{ty}=\sum_{jit} \mathbf{V}ijt * \mathbf{d}ijt * \mathbf{F}jiyt + \sum_{jit} \mathbf{C}$ (Equation **4**)

where: $\mathbf{G}_{ty}$ is the emission of GHG gas **y** in year **t**, where **y** could be $\mathbf{N_2O}$ or CH_4;

$\mathbf{F}_{jiyt}$ is the emission factor of gas **y** (g/km) of fuel **j** for vehicle type **i** in year **t** and

C is the emissions during the warm-up phase (cold start) (kg).

c- Amount of greenhouse gases emission

To estimate the amount of overall greenhouses emitted the emission from each different type of gases were summed. But, before summed its each type of gases was converted to CO_2 equivalent using their Global Worming Potential (GWP) Equation 5. GWP used were 1;

$\mathbf{E_G} = \boldsymbol{CO_{2t} + G_{ry} * N_2O}$ **GWP/Ch4 GWP** (Equation **5**)

3.2.3.4- Greenhouses gases effect on air pollution

To estimate the criteria Air pollution, the Equation 6 was used.

$\mathbf{V}pv_{ijt} = \sum_{t=0} \mathbf{V}\,pvijt * (1 + \mathbf{S}ij) - \mathbf{OUT}ijTt$ (Equation **6**)

where: **0** is the base year (in this case 2019), **S**ij is the historical annual rate of new vehicles putting in circulation by type **i**, and **OUT**ijTt is the disposal rate that represents the number of type **i** vehicles of year model **T** that are no longer circulating in year **t**. In the case of public transportation, **V**ijt is calculated based on the historical growth of the fleet.

In order to measure the gases emitted by transport sector effect on air pollution, a specific location have been identified such as city-center car parks with their geographic coordinates.

3.4- **Material (**Data and tools)

Statistics data of vehicle age, Average distance, average fuel consumption by category of vehicle, population of controlled by CCVA was used in the model, atmospheric satellite data. Also, the rate of Mobility in the city of Ouagadougou was considered. The following software and material have been used.

Free software and python programming language were used for GIS and statistical data analysis.

LEAP software was used to analyze the data integrated into the model, C++ programming for coding and data analysis, Python for statistical data analysis, Google Earth Engine for atmospheric data extraction.

Geographic Positioning System (GPS), Testo 350-XL exhaust gas analyzer were used to collect data or measure greenhouse gas emission and pollutants from the sample of the Cars, Motorbikes, etc. A Smart phone survey with whit kobo tool kit or ODK were used for survey.

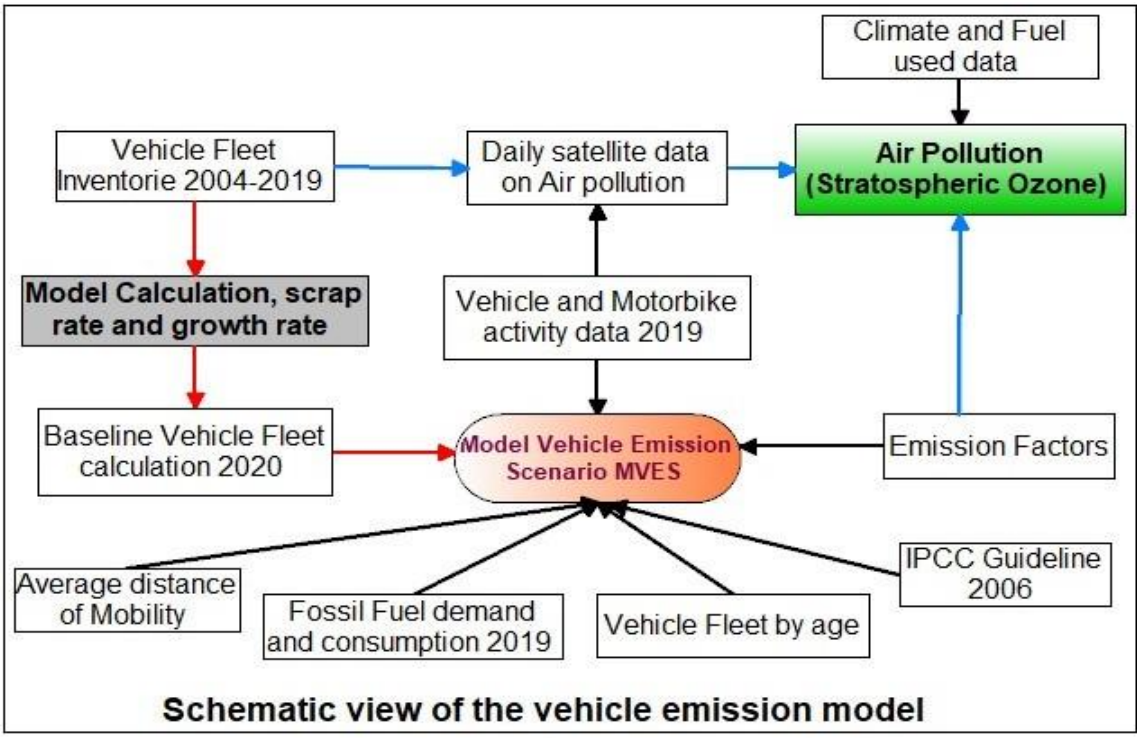


Figure 8: Schematic view of the greenhouse gas development model

The mythology of this research is a bottom up design model which consist to assess, model and evaluate fossil fuel demand and consumption, greenhouse gases emission and its effects on air pollution in the city of Ouagadougou. It uses the LEAP modeling software and bases on the vehicle’s sample for the gases measurement.

Chapter 4: RESULTS AND DISCUSSIONS

4.1- Transport and environmental legislation and protection in Burkina Faso

4.1.1- Burkina Faso's international commitments on environmental protection and climate change

The organization of the United Nations Conference on the Environment and development (UNCED) in Rio de Janeiro in 1992 was the starting point for awareness of the central and holistic nature of the environmental dimension in the development process. This new vision led Burkina Faso to ratify the various conventions resulting from Rio and to engage in a process of developing action plans for the implementation of each of these conventions in response to their requirements. It started participant to the international conference on climate change such as the 1st Conference of the Parties to the Climate Convention (COP 1) of 1995 in Berlin. Through other numerous conferences such as that of Kyoto in 1997, United nation conference on climate change in 2006, Cancun conference in 2010, the Paris agreement in 2015, to name just only these, Burkina Faso has shown a real volunteer to protect environment and combat climate change. The main objective of all these internationals conventions is the environment protection and reduce greenhouse gases emission and mitigate the global warming. It therefore tackles indirectly transport sector which uses mainly fossil fuel as energy.

For the climate change adaptation, Burkina ratified the UNFCCC in 1993 and KYOTO protocol in 2005. Among of national policy and strategies for climate change, some document has been produced such as:

- The National Strategy for implementing the Climate Change Convention adopted in 2001.
- The National Action Program for Adaptation to Climate Change (NAPA) in 2007.
- The development of a framework NAMA (2008).
- The National Adaptation Plan (NAP, 2014).

All these actions and policies target the greenhouse gases emission reduction. The main economics sector selected are agricultural, Energy, Forestry etc. the transport sector is not especially targeted, despite being the second largest source of greenhouse gas emissions in Burkina Faso according to the National Determine Contribution Report in 2015.
The transport sector has emitted 782 to 2,439 GHG (GgCO2 eq.) from 2007 to 2015 (Burkina Faso, NDC, 2015). It can reach 6,925 GgCO2 eq by 2030.

4.1.2.- National policy on environment protection, climate change and sustainable development related to transport sector.

Developed and adopted on 2nd April 2013 the environmental law and legislation establishes the fundamental rules that governs the environment in Burkina Faso. The article 1 of this law, the environment has been defined as the set of natural or artificial physical, chemical and biological elements and economic, social, political and cultural factors that have an effect on the process of sustaining life, the transformation and development of the environment, resources or not and human activities. This law aims to protect living beings against harmful or inconvenient attacks and risks which hamper or endanger their existence due to the degradation of their environment and to improve their living conditions. It promotes the principle of sustainable development which consists of allowing the present generations to meet their needs without compromising the ability of future generations to provide for theirs.

The application of these law and legislation is the responsibility of the Ministry of Environment Green Economy and Climate Change. Therefore, this current environment code or legislation sets at the paragraph 3, as part of the fight against air, water and soil pollution. The actions are at:

- Point 66, the government is taking the necessary measures to limit or reduce pollution that affects the quality of the living (environment) and biodiversity;
- Point 68, the import of any good likely to generate pollution is subject to standards in force.
- Point 69, public authorities are taking the appropriate measures to develop public transport in order to reduce atmospheric pollution.

Many efforts have been done to reinforce environment protection and fight against climate change. The Ministry of Environment, Green Economy and Climate Change with its directions such as National Council for Sustainable Development, General Directorate for Environment Preservation, National Office of Environmental Assessment ensure the promotion of sustainable development through the execution and respect of this environmental code.

For the moment, despite the old age of the vehicle fleet and the predominance of individual transport in urban areas in Burkina Faso, there are no ratified decrees or laws limiting the age of vehicles on importation. There are no laws setting the standards for greenhouse gas emissions in transport and urban mobility. It seems like anything is not yet done targeting transport sector to respect and protect environment in Burkina Faso. Therefore, what are the strategies of ministry of transport to take environment and climate challenges in their actions.

4.1.3- National urban mobility strategy by the Ministry in charge of Transport

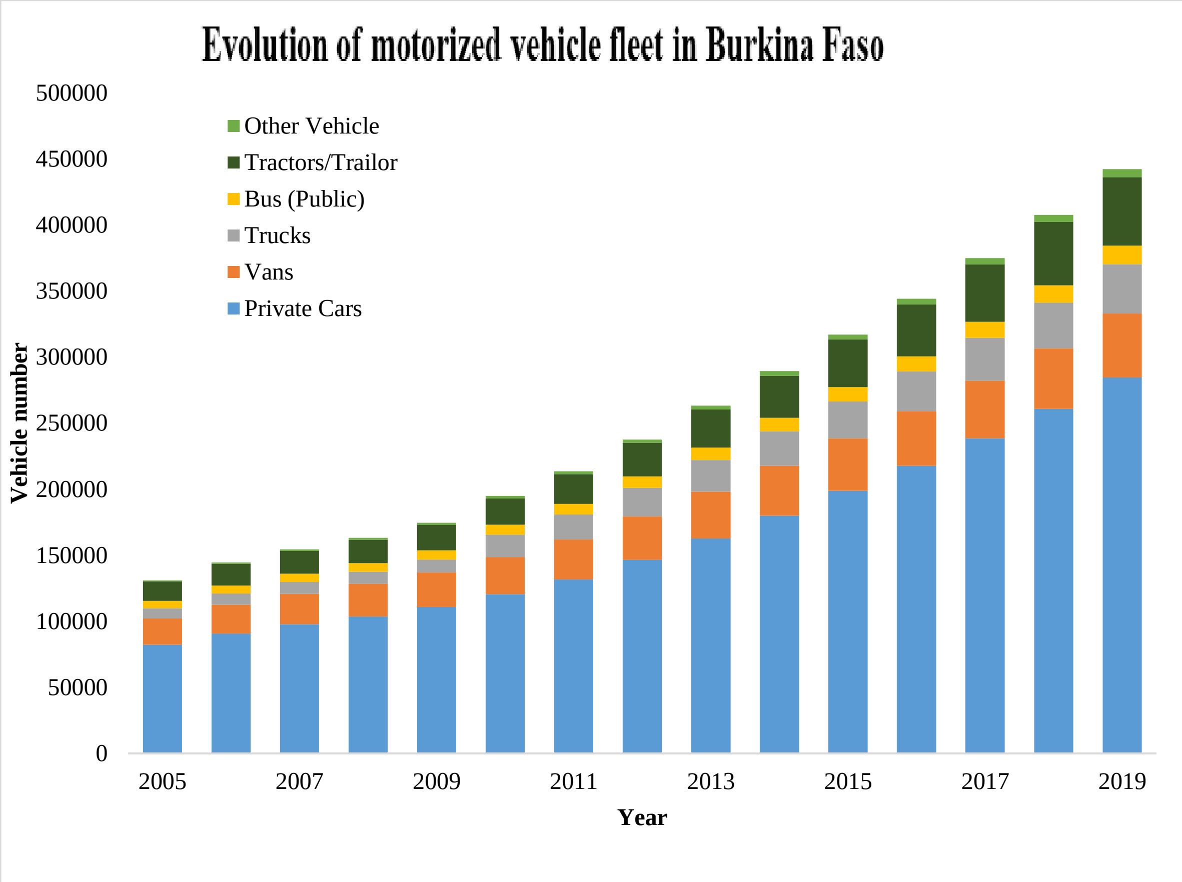
The national urban mobility policy 2030 (PNMU 2030) mainly consists of guaranteeing the greatest number of people good accessibility to jobs (including markets) and to public services (health, education, etc.). It should serve as a basis for the development of efficient urban transport systems, which make it possible to travel at an acceptable cost for households while establishing a sustainable financing model for the State. It aims to reduce the weight of the transport sector in imports and maintain a large number of jobs while integrating them into the formal economy. It seeks to limit the impacts on health and the environment and contribute to the reduction of deaths linked to daily mobility. PNMU 2030 fits into the general framework of the current National Economic and Social Development Plan (PNDES 2016 - 2020) which aims to "transform the structure of the national economy of Burkina Faso" while maintaining "strong and inclusive growth to the means of sustainable consumption and production patterns”. It aims to improve the efficiency of governance in the transport sector, to bring out efficient industries and services, to boost economic growth by improving the conditions of mobility and to fight against poverty by improving the accessibility of households. This National Urban Mobility Policy 2030 aims to strengthen the role of the country's cities as a driving force for economic growth. The PNMU 2030 objectives also respond in an operational manner to the recent international commitments of the State for sustainable development, starting with the 2030 agenda which sets the 17 sustainable development goals (SDGs) and the Paris agreement on the Climate for which Burkina Faso has committed, through the Nationally Determined Contribution (INDC), to reduce its greenhouse gas emissions by at least 6.6% by 2030, but potentially by 11.6% according to a scenario conditional on international support. Despite all these initiatives, how is the state of transport and urban mobility in Burkina Faso?

4.1.4- State of transport and mobility in Burkina Faso

The transport and mobility statement is based on the historical growth of the vehicle fleet from the year 2004 to 2019. It consists of analyzing the fleet evolution, categorizing the fleet per vehicle type and show the trend before demonstrating the growth scenario in the coming year.

4.1.4.1- Historical growth of the motorized vehicle fleet in Burkina Faso

In Burkina Faso the vehicle fleet is categorized in six (6) types of vehicles. The vehicle fleet has therefore experienced strong growth since 2005 (Figure 9).

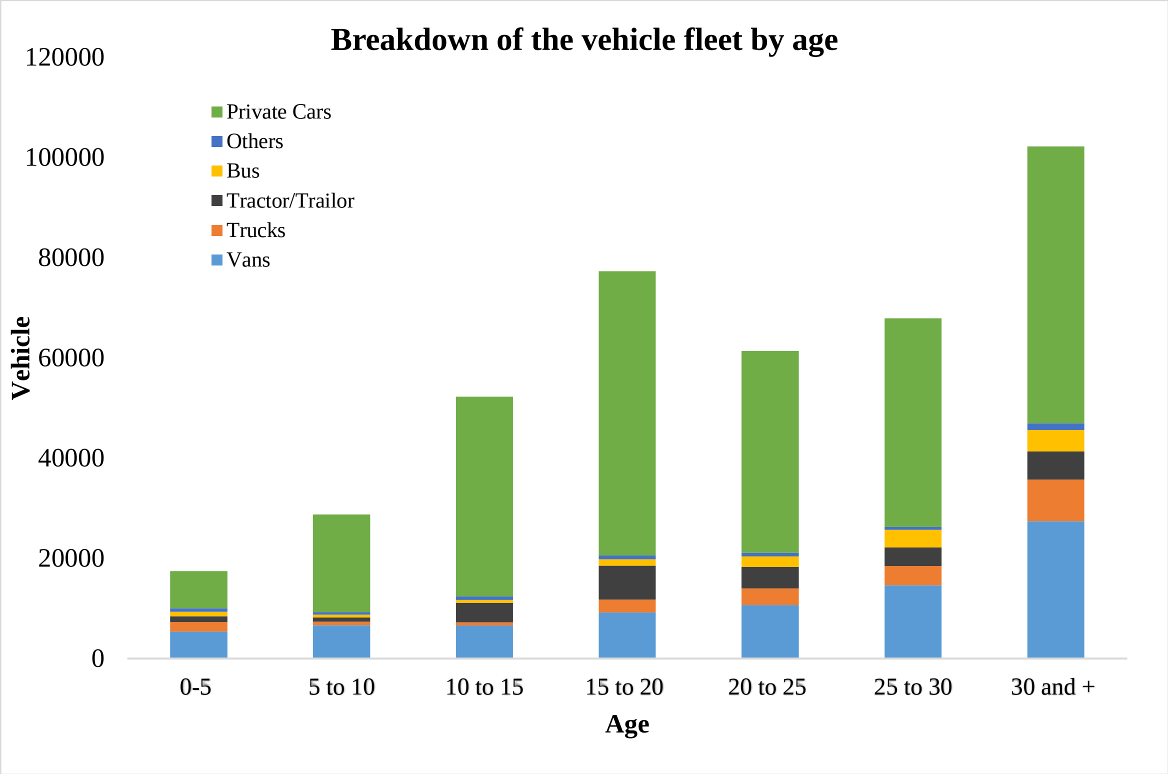


Source: DGTTM, DGESS transport, 2019

Figure 9: Categorized of vehicles fleet

From 2005 to 2019, there is around 3852540 of the vehicle fleet in Burkina Faso. It has therefore increased 256836 vehicles per year, an increase of 7.14% per year. In a decade, the vehicle fleet has increased by 209%. Public transport which especially are bus, taxis is less developed compared to individual or private transport. In 2019, there was 62.8% of private cars and 03.6% of public cars, the number of private vehicles is 17 times greater than that of public vehicles. The private cars are grown by 12% annually, while the public cars increased by 0.2% per year. Seven (7) out of 10 persons use private cars and 1 out 10 persons use public cars. Therefore, only 3% of Ouagadougou citizens run their daily activities with the bus or public transport. The other type of vehicles such as trailors/tractors, vans, trucks etc. are mainly use for goods transportation within the city or between cities.

The vehicle's fleet in Burkina Faso is very old. 19% of the vehicles are between 15 and 20 years and 25% are above 30 years. 43% of the fleet is under 20 years and 57% are above 25 years. The private cars are more among of the cars fleet. 73% of the private cars are under 20 years. The average age of the vehicle fleet in Burkina Faso is 17 years old in 2018 (Figure 10).

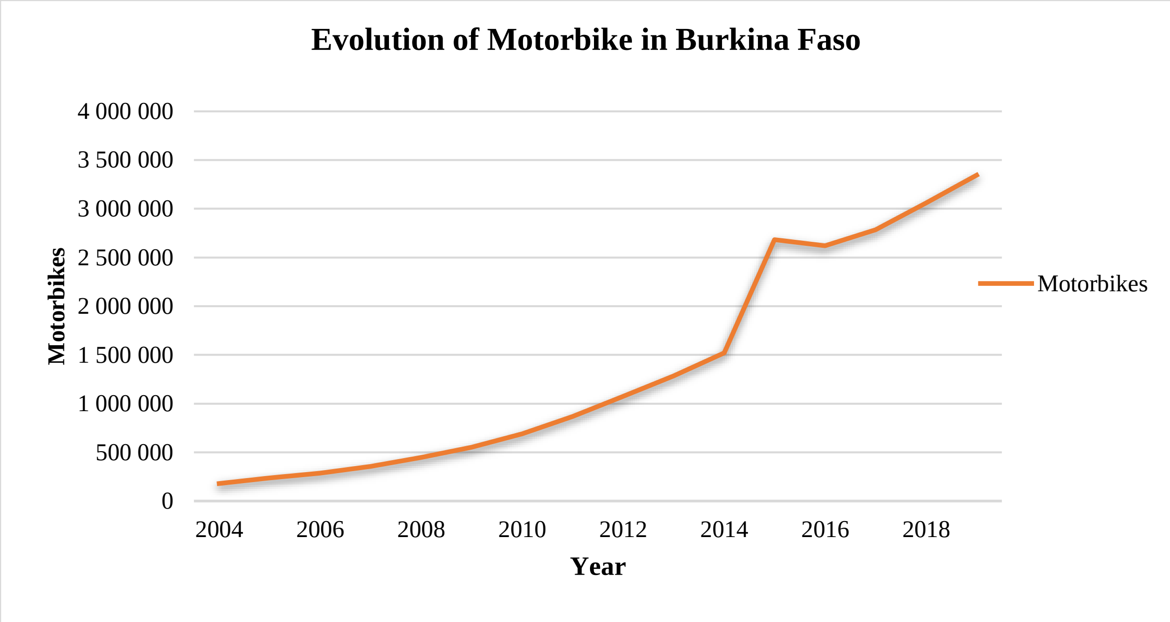


Source: DGESS Transport

Figure 10: Distribution of vehicle fleet by age

4.1.4.2- Evolution of two wheelers or motorbike

Burkina Faso is a major consumer of two-wheeled vehicles. The motorcycle travel is the most recurrent mode of mobility among of city dwellers. In 2018, around 2,329,400 two-wheelers were subject to registration. There is undoubtedly a predominance of two motorized wheels. Their number has been multiplied by 5, from 2008 to 2018, increasing from 447,426 units to 2,329,400 units. It corresponds to an average annual growth rate of + 20%, while that of the automobile is of the order of + 10% over the same period. Thus, the motorbike fleet has grown exponentially since 2004 (Figure 11).



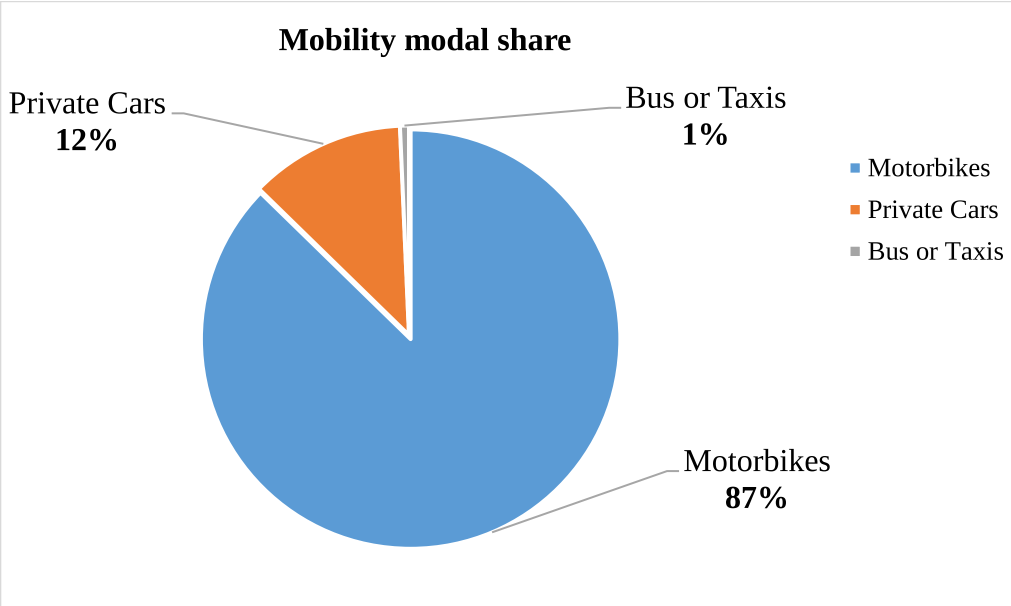
Source: DGTTM, 2019

Figure 11: Motorbike evolution in Burkina Faso

The city of Ouagadougou has the highest concentration with more than half of motorbikes (56.89%). Record shows that, out of 100 vehicles circulating in downtown of Ouagadougou, 75 are two-wheelers (Ouagadougou traffic plan development report., 2020).

4.1.4.3- Urban mobility

Human displacement is the act of going from one place (origin) to another place (destination) in order to carry out an activity (motive). All these daily trips structure mobility and depend on many factors, the complexity of which reflects the organization and functioning of the life of the inhabitants of urban cities. The tree main area of its spatial organization lead to the high urban mobility of city dwellers. Ouagadougou records approximately 1,000,000 people moving in and out of the city center daily. All these movements are for the essential basics services concentrated in the downtown (Schools, administrations, markets, universities etc.) In Ouagadougou, travel practices can be analyzed according to origin-destinations, times, reasons and modes of travel. But the development of the hyper center of Ouagadougou was quickly constrained by artificial obstacles such as the Ouagadougou international airport, dams', military camps etc. These screens surround the hyper center and only allow access by radials on the east and south-west flanks and two crossings on the north dams. This situation hinders mobility, given the nature of the centripetal and centrifugal flows of the circulations. Therefore, the distribution of the use of the different modes by the populations for their movements characterize this mobility. The motorized two-wheeler is the most used mode with nearly 7 people out of 10. Private cars follow with almost 2 in 10 people. Almost 62% of trips were to the four former first district, which corresponds to the heart of the Ouagadougou city. Taxis and buses ranked last with less than 1 person out of 10. The two-wheelers are mostly used (75%) in Burkina Faso (Figure 12).



Source: Survey, 2021

Figure 12: Share of modal in mobility

The craze for owning a private car among city dwellers does not really change the gap with motorized two-wheelers. In this regard, the evolution of the fleet of vehicles and two-wheelers subject to registration says long. It is important to notice that the registration figures have followed the same trend in the demographic, economic in Burkina Faso since 2008.

4.1.4.4- The vehicles fleet growth scenario from 2020 to 2040 per fossil fuel used.

It is important to evaluate how Base on their annual growth rate; the number of vehicles could increase considerably in the coming years. The average growth rate of the vehicle fleet is 9.94% including the motorbikes. So, truck and others vehicle (special vehicle) respectively 12.9% and 15.4% have an above average growth rate of the fleet, but their number is lower than other categories of vehicles. The tractors and motorbikes have the medium growth rate respectively 9.4% and 9.10% and vans and bus have the lowest growth rate. Furthermore, there is two types of vehicles according to the fuel used in the road transport: diesel vehicle and gasoline vehicle. The scenario is based on the fossil fuel type used and 2020 as a base year and 2040 the end year. Therefore, we have gasoline vehicle fleet and diesel vehicle fleet.

Gasoline vehicle have increase up to almost 11.6 million from 2020 to 2040, either an increase of 550 thousand per year. It mainly always dominated by motorbikes (Figure 13).

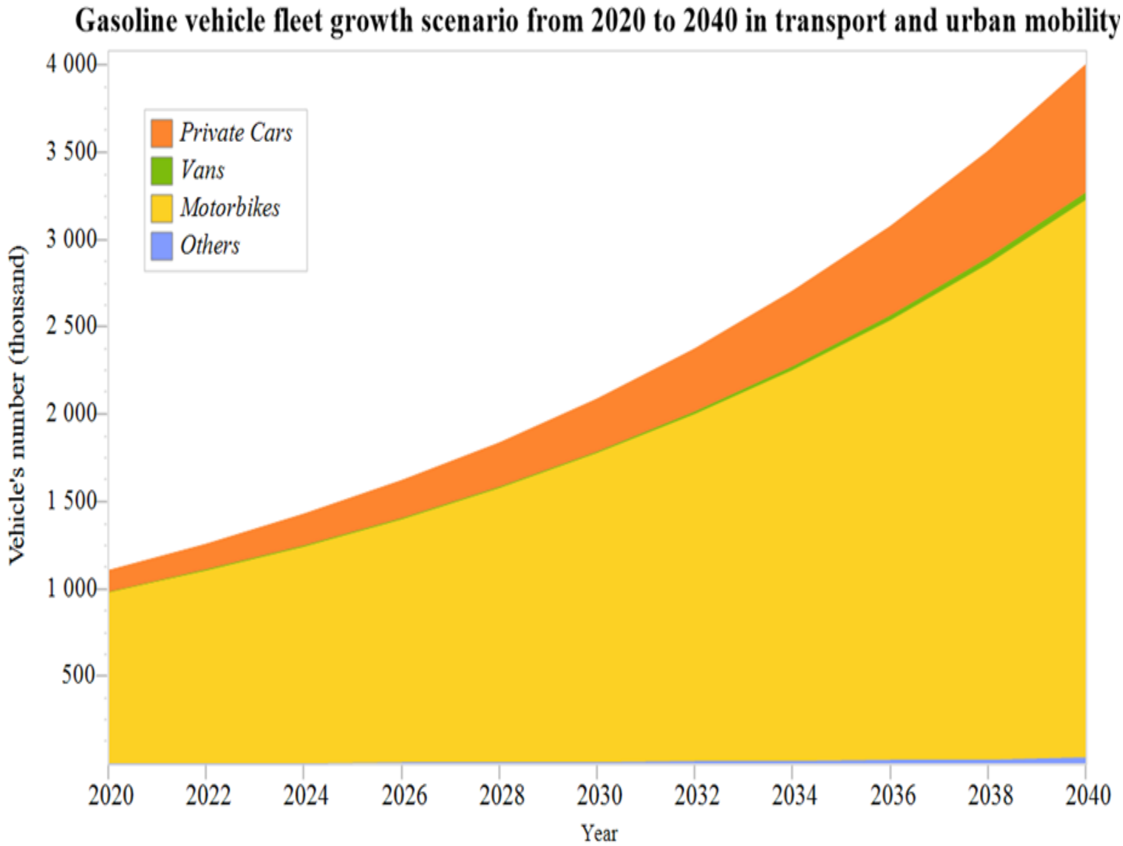


Figure 13: Gasoline vehicle fleet growth scenario

The motorbikes are more than 83%, almost 21% of gasoline private cars vehicles fleet that will be running in the city. It shows that the motorbike fleet is digressing by 1% per year and Private cars growing by 4% each five years.

Diesel vehicles are mainly dominated by Tractors, Vans, and Private Cars respectively by 33.45%, 26.36%, 17,6%. Then, by 2040, the fleet will increase up to 16.68% either, 1,25 million of vehicles, an increase of 62.645 thousand vehicles per year. In detail, the fleet will be dominated in number by truck, tractor/trailer. The private cars and bus number will slightly regress respectively by from 17% to 7% for private cars and 8% to 3% for bus (Figure 14).

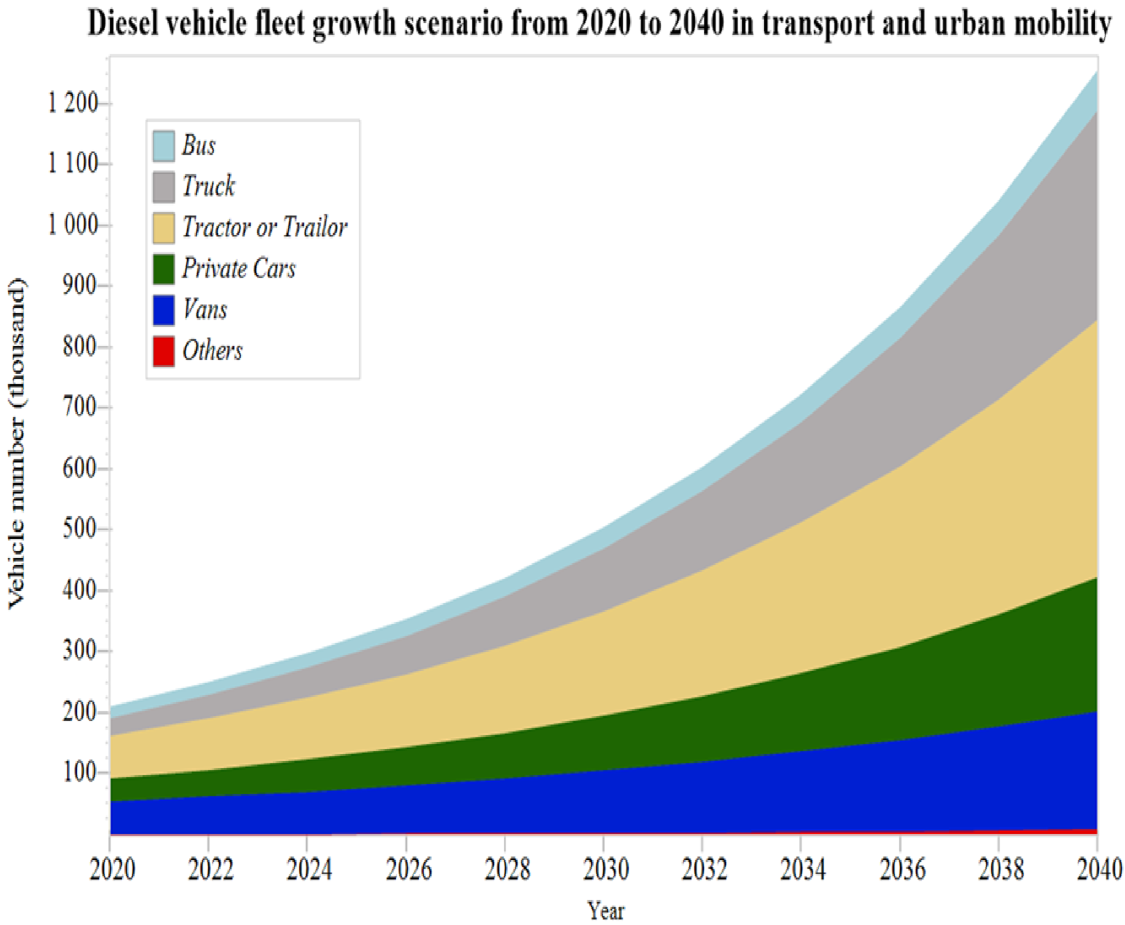


Figure 14: Diesel vehicle fleet growth scenario

Despite the wide international environmental convention ratified and the national existing legislation on environment protection, the road transport sector in Burkina Faso is not enough take in account. Private vehicle and motorbike number still growing exponentially with very old of vehicle fleet, 17-year-old of average age in 2019. The fleet will double or multiply by two by 2040 and will still dominated by motorbikes, private cars etc. Therefore, without any politic of retrieving old vehicles from the circulation and strengthening environmental protection in transport and mobility, environment and human health will be affected.

4.2- Fossil fuel consumption and demand by road transport and mobility in 2019.

The fuel consumption has the key factors that takes into account for road transport. These factors determine the quantity of fuel consumption, the fuel demand and the greenhouse gases emissions.

4.2.1- Factors of fossil fuel consumption in transport sector.

The main factors that characterize fuel consumption are: annual average travel distance, average number of occupancy or loads factors of the vehicle, fuel efficiency or economy, vehicles population, etc. those factors have been determined considering the vehicle population (Table 3).

Table 2: Parameters of the fossil fuel consumption estimation

Vehicle Type	Average annual Distance of Vehicle	Average Fuel efficiency (Km/liter)	Load factor
Private Cars			
Gasoline	3387.67	11.38	2,5 Passengers
Diesel	4219.9	10.25	2,5 Passengers
Vans			
Gasoline	12392.08	12.5	12 Tones
Diesel	16563.15	9.7	12 Tones
Trucks			
Diesel	58014.58	6.29	15 Tones
Bus (Public)			
Diesel	13599.68	5.22	40 Passengers
Tractors/Trailer			
Diesel	50605.06	4.8	25 Tones
Others Vehicles			
Gasoline	3087.67	11.38	2,5 Passengers
Diesel	50014.58	7.2	2,5Passengers
Motorbikes			
Gasoline	3223.25	37.87	1,5 Passengers

Source: Survey, 2021

The results on fuel economy showed that, with 1 liter of gasoline, a private car and other vehicle can travel around 11.3 km, vans can travel 12.5 km and motorbike can reach 37.87 km. Moreover, with 1 liter of diesel, private car can travel 10.25 km, vans can reach 9.7 km, truck is 6.29 km, Bus can travel 5.22 km, tractor/trailer is 4.8 km and other vehicles, 7.2 km. Therefore, gasoline vehicles gain more distance and fuel consumption than diesel vehicles. It can be explained by the load factor and technical characteristics.

The load factor analysis shown that there is no difference within vehicle type and fuel used.

4.2.2- Fossil fuel consumption by the transport sector in 2019.

The most consumed fossil fuel in road transport in Burkina Faso is essentially made up of diesel and gasoline. These fossil fuel consumptions in Burkina Faso have increased from 441,3 million liters in 2010 to 1286.2 million liters in 2019 for the whole economy sectors. In one decade, the country has consumed a total of 844.9 million liters with 42% for gasoline and 58% for diesel. Thus, in 2019, transport and urban mobility sector has consumed a hug amount of 1153.24 million of liters, either a ratio of 89.66% of the whole general consumption in the country. The share consumption per fuel type and vehicles category show a disparity. Diesel is the most fossil fuel consumed with 90% (Figure 15).

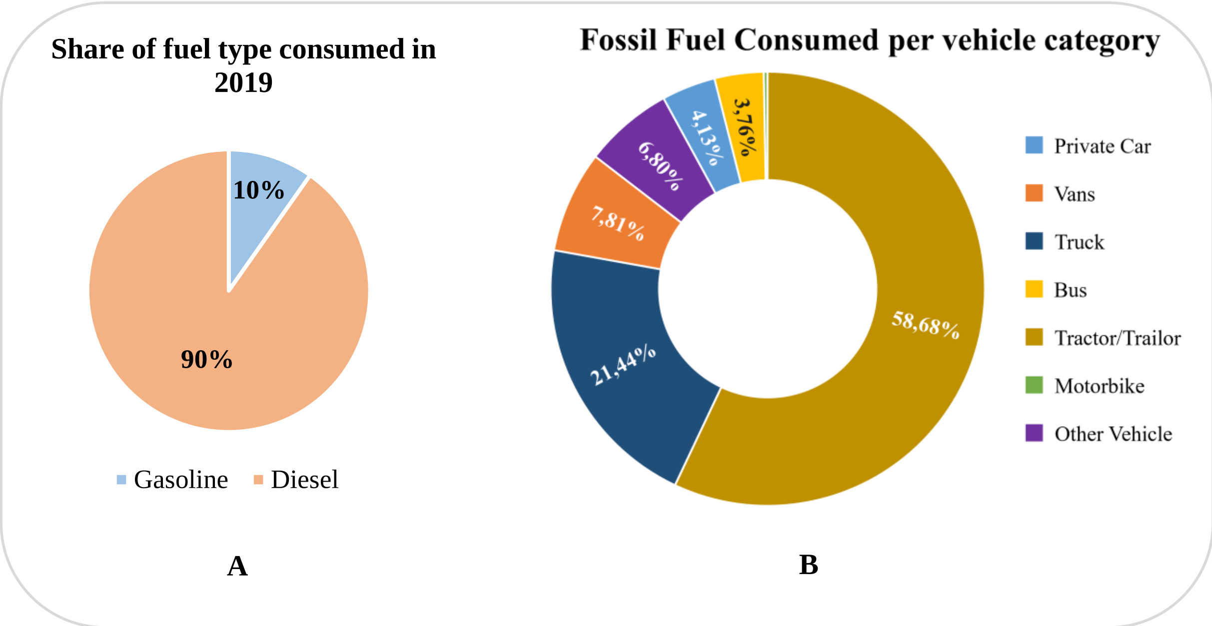


Figure 15: Share of fuel type consumed by transport and urban mobility in 2019: **A**) fuel type, and **B**) per vehicle category

The fossil fuel consumption by vehicle category also shown some disparity. Since the consumption is depending on the distance travelled, but not on the number of the fleet, all vehicle type does not have the same consumption. Then, the number of vehicle is not mean a hug consumption of fossil fuel. If the distance traveled by the vehicle is much, the fuel consumption will be consequently the same depending on the fuel efficiency. For example, motorbikes are representing 75% of the vehicle fleet, but consume less than 1% and bus which represents 1% of the vehicle fleet, consume 3,76%. Moreover, truck represents 2% and consume 21.44%, tractor/trailer represents 5% of the fleet and consume 58.68%, more than the half. Thus, some type of vehicles such as private Cars, Motorbikes, Bus etc. are more used in urban area than others type. They destined to people mobility in the cities and between cities, while the others vehicles types are mainly for freight transport. That therefore explain this hug different in the fuel consumption.

4.2.3- Fossil fuel demand scenario by transport and urban mobility from 2020 to 2040

The diesel fuel demand scenario from 2020 to 2040 has shown a very huge quantity of fossil fuel that will be consumed in the coming years. The fuel demand is high among of diesel vehicles fleet. The share consumption by 2040 in total diesel fuel is 36.20% for Truck and 56.75% for tractor/trailer, either an increase for truck vehicle by 14.76% and the slight regress in need of fuel for tractor or trailer by 2% in 2040. This different can be explain by increase of the distance travel. Truck are much travelling than the tractor vehicle. Bus and vans are consuming lest, either a respectively share need of 2.49% and 4.96% (Figure 16).

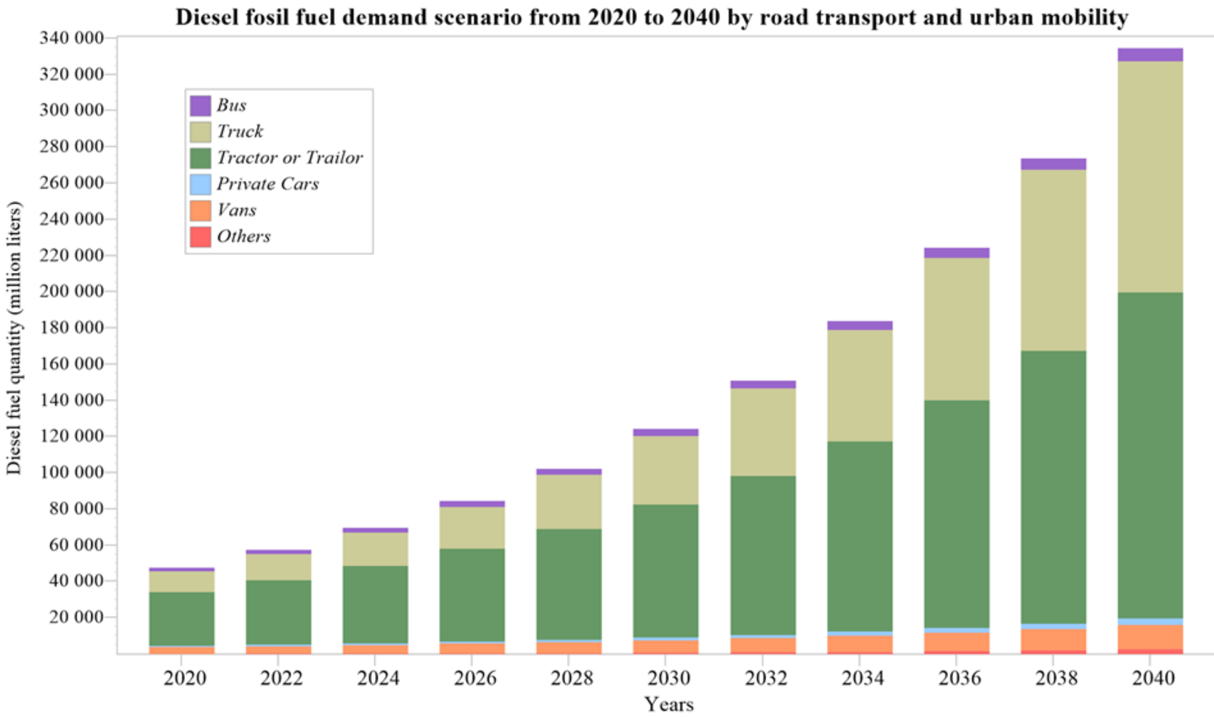


Figure 16: Diesel demand scenario from 2020 to 2040 by road transport and urban mobility

There is an average need of diesel fuel of 225324.25 million liters each 2 years per vehicle type either an average need of 37554.04 million per vehicle type during the scenario period.

By 2040, gasoline fuel of 25002.3 million liters will be consumed. More than 98% of consumption is by motorbike, others vehicle will be consumed less than 2% (Figure 17).

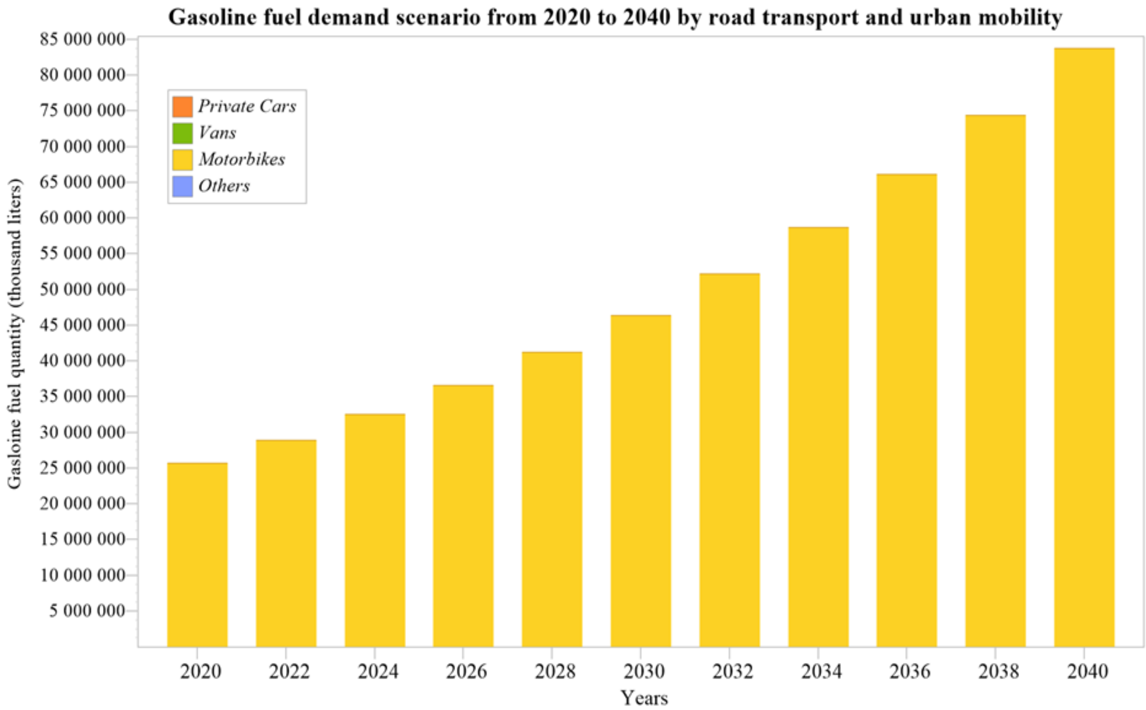


Figure 17: Diesel demand scenario from 2020 to 2040 by road transport and urban mobility

An amount of 809917.1 million fossil fuel will be consumed in 20140 either a need of 40495.855 million liters per year. The share need by the fuel type is 96.91% for diesel, and round 3% for gasoline vehicles. Therefore, there will be an increase of 6.91% since 2019 for diesel and a regress of 7% for gasoline vehicle. This difference does not mean a decrease in the number of gasoline vehicles, but the increase of the average annual distance travel by diesel vehicle which are particularly for the road freight transport in the cities and within the cities. This hug consumption of fossil fuel is the main source of greenhouse gases emissions.

4.3- Greenhouse gas emission from road transport and urban mobility in 2019.

Among of greenhouse gases such as CO_2, N_2O and CH_4, two of them have been gotten from the measurement. These greenhouse gases were CO_2 and N_2O. The N_2O was only a traces and during the measurements, the cells responsible for its collection are damaged. So we only considered CO2 which is the main greenhouse gases from transport.

4.3.1- Gases emission factors in transport and urban mobility per type of vehicle.

The emission factor is a mass of carbon dioxide emitted per unit of fuel consumed with fuel type density in kg. Therefore, the factors of the vehicles emission are the fuel used, the quantity of the fuel that is used during a period of time. The results revealed that the private vehicle and vans using gasoline have higher emission factor of CO_2 and CO compared to those using the diesel within the same type of vehicle, while, NOx emission factor is higher for private vehicle and truck using diesel (0.02165 and 0.05492) compared to the same vehicle type using Gasoline with 0.00094 and 0.0083 respectively (Table 4).

Table 4: Emission factor per type of gases and per fuel and vehicle type

Vehicles type	**EF CO_2 (kg/liter)**	**EF CO(kg/liter)**	**EF NOx (kg/liter)**	**Fuel density(kg/liter)**
Bus	3.25	0.012	0.029	0.85
Trucks	3.3	0.021	0.05	0.85
Vans	3.27	0.029	0.002	0.85
Tractor/Truck	3.23	0.024	0.022	0.85
Private Vehicle	3.23	0.024	0.022	0.85
Average	**3.256**	**0.0245**	**0.025**	**0.85**
Motorbike	3.8441	0.00245	0.0028	0.75
Vans	3.8172	0.08249	0.0111	0.75
Private Vehicle	3.8135	0.0421	0.0009	0.75
Average	**3.825**	**0.042**	**0.0049**	**0.75**

Source: field Survey, Measurement, 2021

4.3.1.1- Diesel and gasoline vehicle gases emission

The emission of vehicle is the product of each type of the fossil fuel consumed in kg or tons and demand of the vehicles and their emission factors. The amount of total gases emitted different elements to determine the emission factor are the annual average vehicle distance travelled, the type of fossil fuel used, the vehicle average fleet and the fossil density to obtain the reel of gases emitted as an atmospheric pollutant. These gases are: CO_2, CO, NOx. Therefore, the reel amount of gases measured was consisted to multiplied by each fossil fuel density (850 kg/m3 for diesel, and 750 kg/m3 for gasoline). The results revealed three mean gases such as CO_2, CO, NO_x. Compared to the expected gases from literature such as methane and N_2O among of greenhouse gases. Just two of them have been gotten from the measurement. These greenhouse gases were CO_2 and N_2O. The N_2O was only a traces and during the measurements, the cells responsible for its collection are damaged.

Then in 2019, a total amount of 5,026,506.977 tons of gases have been emitted of both (air pollutant and greenhouse gases). CO_2 (4734851.666 tons) is most emitted. As a pollutant, it is flowed by NOx (60879.311 tons). The CO (23076.198 tons) pollutant is less emitted. All this emission has been measured without include a load factor. It has been done at idle load. Thus, 4734851.666 tons of CO_2 by the vehicle fleet in Burkina Faso have been emitted. It dominated by the tractor/trailer vehicle and truck vehicle respectively with 55.20% and 20.25% of CO_2

emitted flowed by motorbikes (8.48%), vans (7.42%), private vehicles (5.02%), buses (3.5%), (Figure 18).

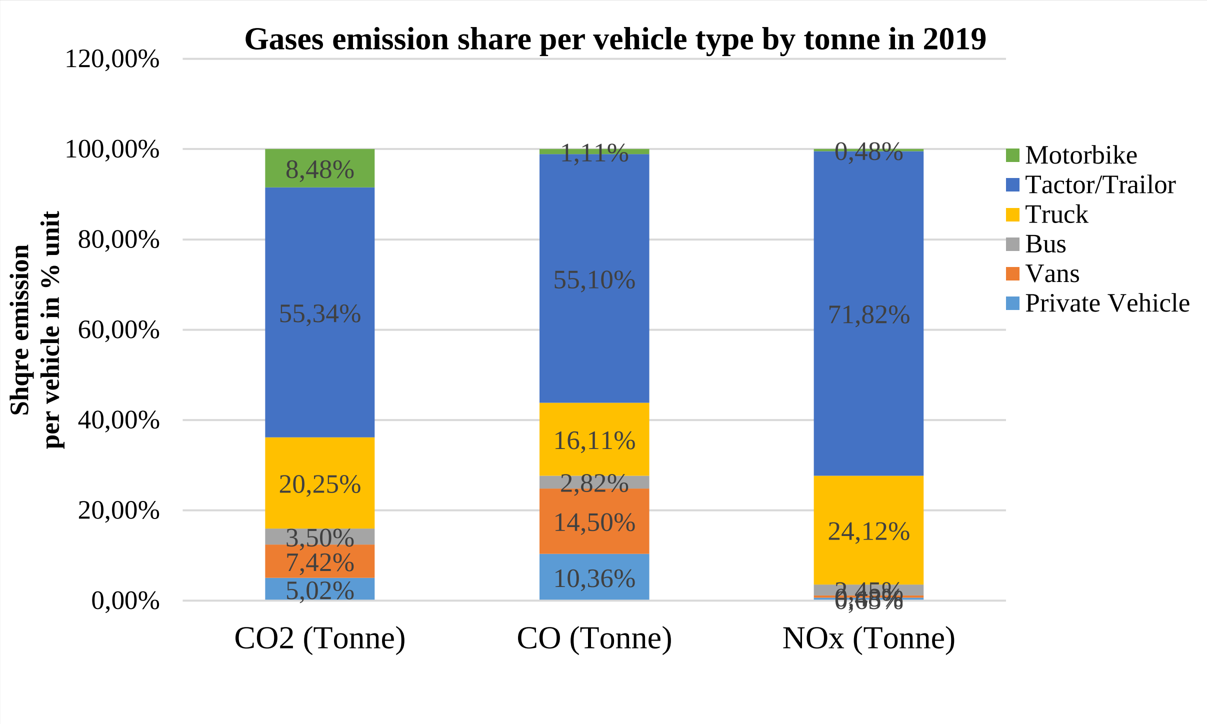


Figure 18: Gases emitted share per vehicle type in tons in 2019

The gases emission by fossil fuel type is much dominated by diesel fuel. 89.9% of CO_2 is emitted by diesel fuel vehicle gases, only 10% are emitted by gasoline fuel (Figure 19).

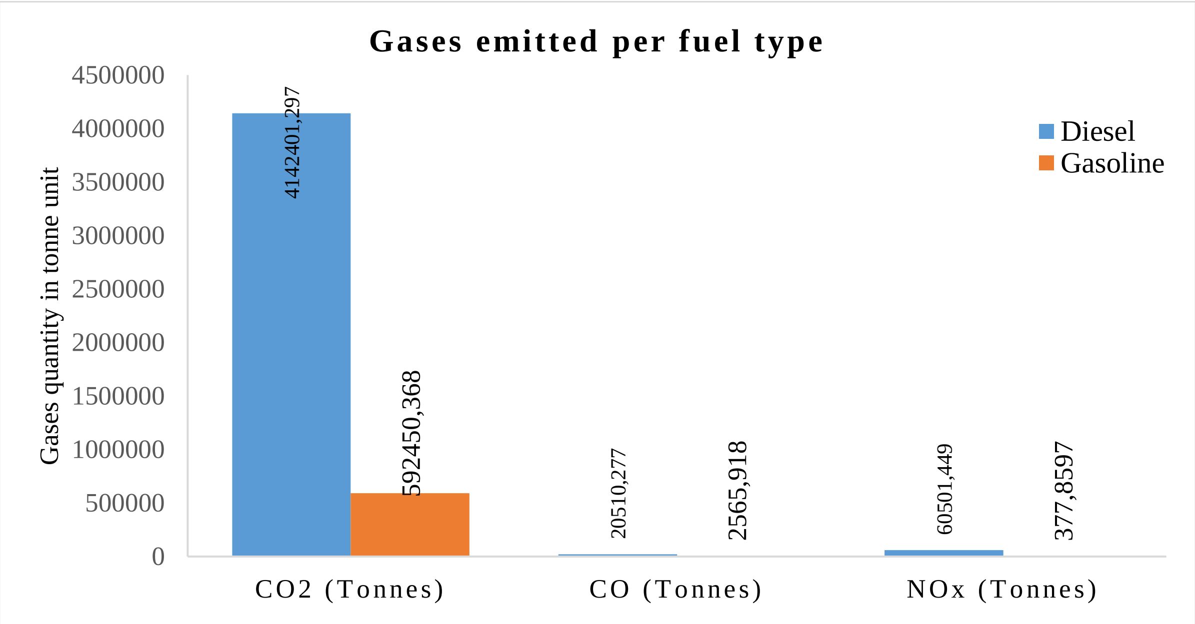


Figure 19: Gases emitted per fuel type

4.3.1.2- Vehicle greenhouse gases emission per fuel and vehicle type

The results that only CO_2 can be considered as the main greenhouse gases from transport. The amount obtained in tons, have been calculated with it global warming potential (GWP). Therefore, there is a total of 473485166.5 tons or **0,47 GtCO_2eq** of CO_2 emitted in 2019 with 87.49% for diesel vehicle and 12.51% for gasoline vehicle (Figure 20).

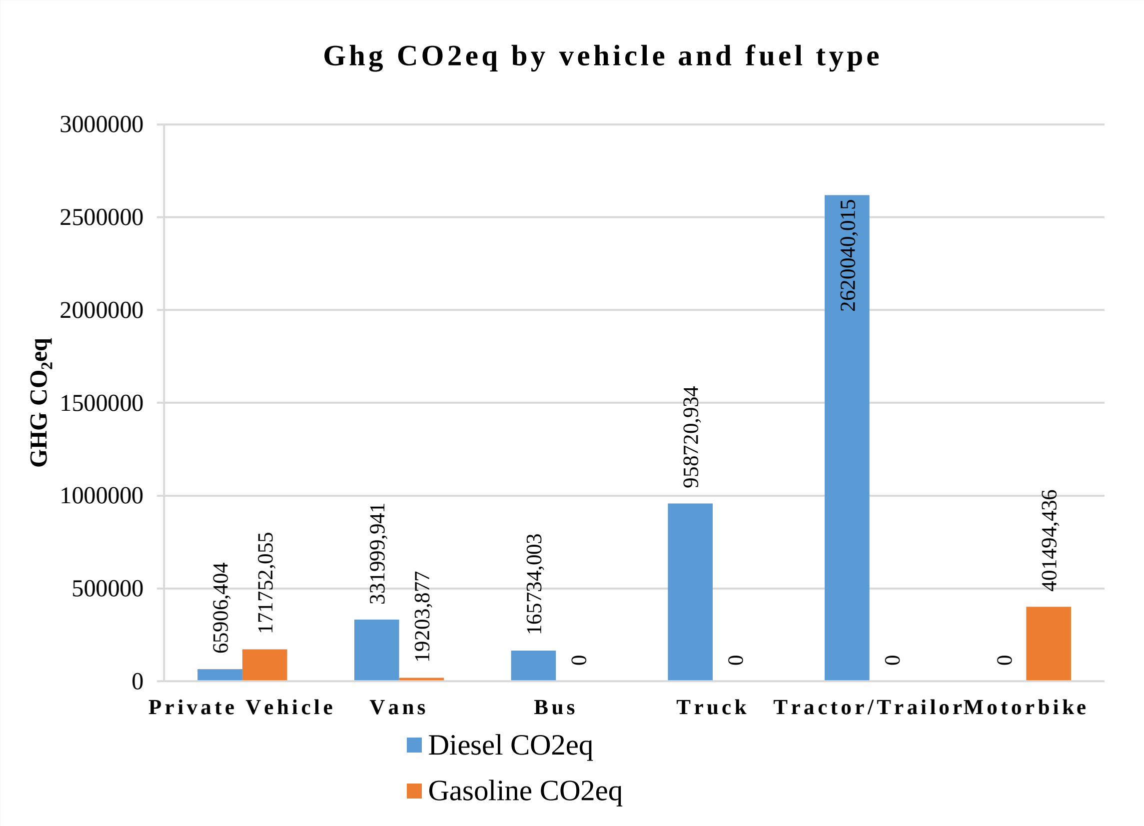


Figure 20: Ghg CO_2 by fossil consumed and vehicle type in 2019

The difference in the gases emission can be explained by the distance travelled and engine combustion system. The diesel vehicle such as trucks/trailer, vans are for freight transport, then traveled long distances compared to other vehicles.

4.3.1.3- Vehicle greenhouse gases CO_2eq emission scenario from 2020 to 2040

The short and long term scenario analysis of CO_2eq emission show the growth of the amount of the quantity that will be emitted in the coming years. In 2040, the total amount of CO_2eq emission under the current policy will be more than 24,000,000 tons, either an increase of 1.2 million CO_2eq that will be emitted each year. This growth in the amount of CO_2eq emit, still dominated by gasoline vehicle, either more than 97%. Among of vehicle category, according to the distance travel and the masse of fossil fuel uses, the CO2eq still dominated by tractors/trailer vehicles (53%), tractors vehicle (37%), vans vehicle etc. (Figure 21)

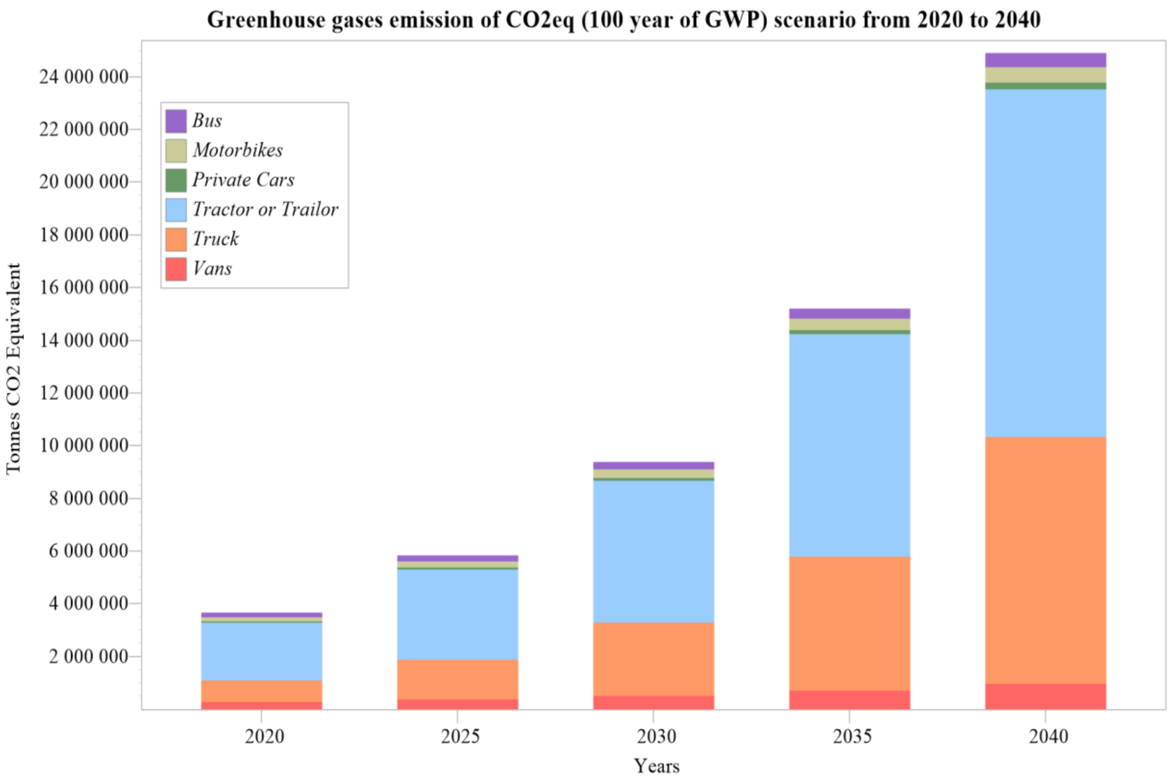


Figure 21: GHG in CO_2eq emission scenario 2020 to 2040

All these vehicles that will be emitting much are those using diesel and travelling much within the cities in the country. The gasoline vehicle emission still dominated by motorbikes which are not travelling much (long distance), but by their increasing in number from 2020 to 2040.

4.3.2- Gases emission effect on atmosphere

4.3.2.1- Pollutants emission per gases effect on air pollution

The result showed 23076.198 tons of NOx and 60879.311 tons of CO released in the atmosphere and leading to air pollution as fine particulate matter. It is formed through the incomplete combustion of fossil fuels. These emissions are depending on the fuel combustion. CO emissions is dominated by gasoline vehicles are justified by incomplete combustion due to a lack of oxygen of the fuel. In fact, during the intake phase of the cycle, if the air-gasoline mixture is not sufficiently rich in oxygen, combustion causes the emission of a large quantity of, moreover emissions by evaporation have an influence on VOC emissions. Note that the age of the vehicle is a very important factor and that vehicle maintenance also plays a big role in this CO emission.

NOx emissions dominated by diesel vehicles are explained by the fact that the engines of diesel vehicles have to withstand high temperatures and pressures to ignite the air-diesel mixture.

Thus, under high pressure and high temperature, NO is created by reaction between nitrogen (N) and oxygen (O), then in the presence of oxygen, the NO thus obtained is transformed into NO2. In addition, the load of diesel trucks and congested traffic in Ouagadougou are also the source of significant emissions of pollutants such as NOx at peak hours.

Furthermore, CO emission with gasoline vehicle is dominated by the private Cars, 73.84%, and by Truck vehicle with diesel 72.4%. The NO_x emission dominated by motorbike with gasoline fuel 77.76% and by truck with diesel 72.40% (Figure 22)

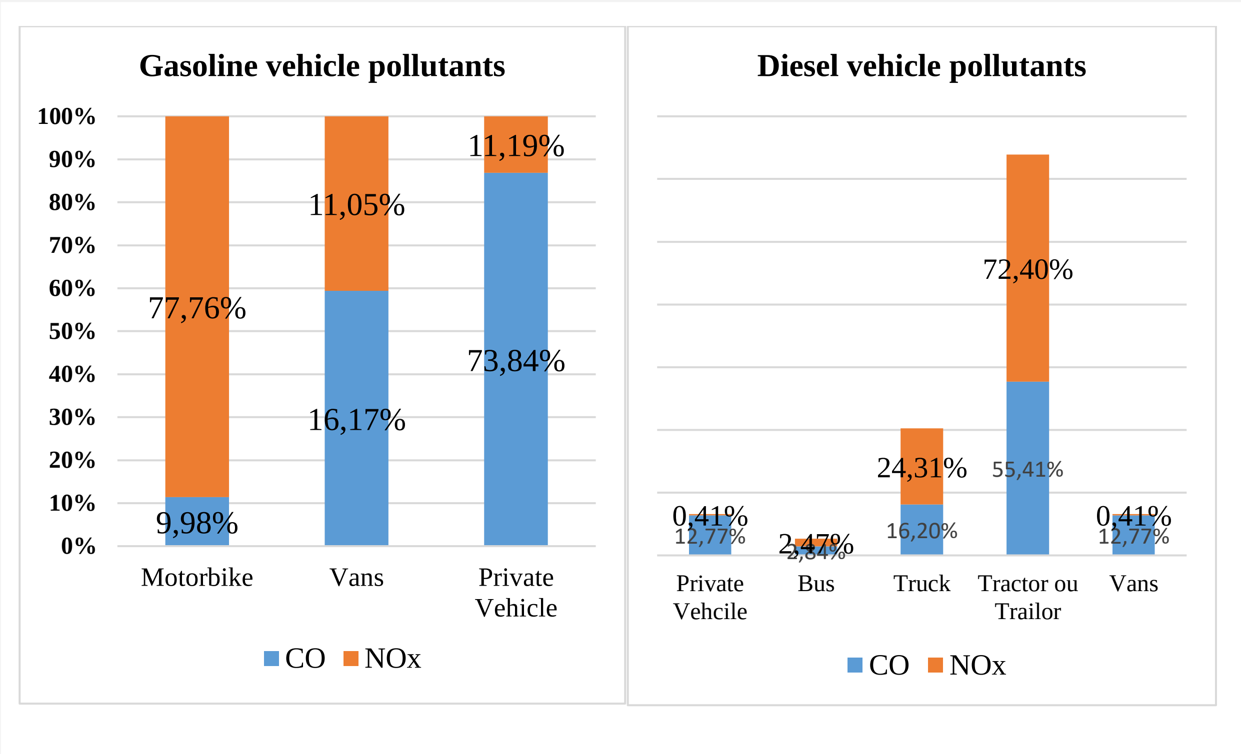


Figure 22: Pollution by fuel combustion (gasoline/diesel)

4.3.2.2- Tropospheric ozone (O_3) layer pollution

The troposphere, near ground-level, ozone molecules are both air pollutants, threatening the health of living things, and greenhouse gases, trapping heat and contributing to climate change. It constitutes 10% of total ozone in the atmosphere and located between the ground surface and about 10 to 16 km. Its presence contributes to air pollution and climate change. Unlike most other air pollutants, ozone is not directly emitted into the air. Tropospheric ozone is formed by the interaction of sunlight, particularly ultraviolet light, with hydrocarbons and nitrogen oxides, which are emitted by automobile tailpipes and smokestacks. This ozone is a powerful oxidant and in high concentrations, it has harmful effects on health, in particular by irritating the respiratory tract, and on ecosystems by reducing the growth and yield of crops. That is why it has been qualified as of "bad" ozone in opposition of the stratospheric ozone, which is the good one and playing an important role - absorbing ultraviolet radiation from the Sun and shielding earth from dangerous rays.

Thus, to measure this pollution in the Ouagadougou city, we gather the ozone daily data from satellite sentinel 5P atmospheric data with an identified location coordinate with GPS. The data recorded per day in mole/square meter(m^2), have been extracted on Google Earth engine over the Ouagadougou city. The monthly average pollution has calculated. The results showed the variation over a time. The period January to April have a low emission and high emission from May to December (Figure 23).

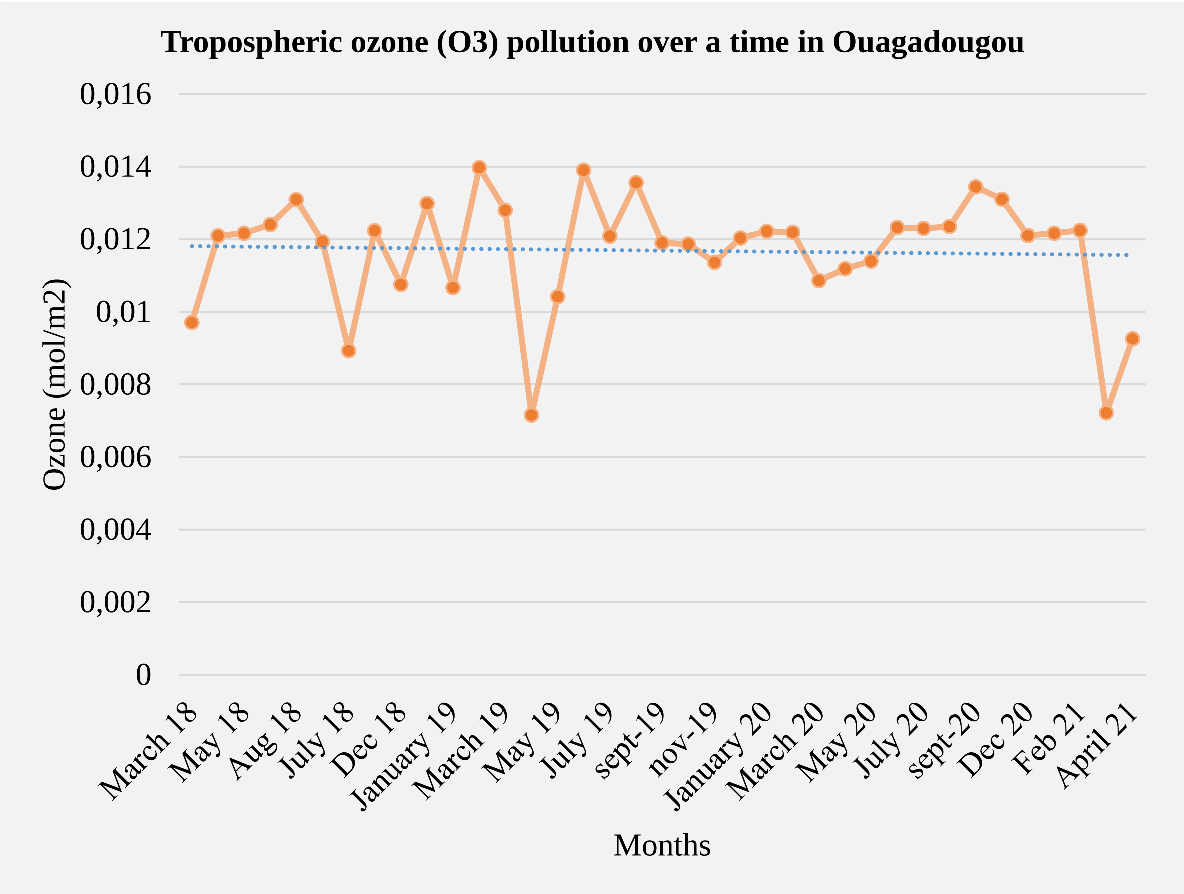


Figure 23: Tropospheric ozone (O_3) pollution over a time in Ouagadougou

The variation of the emission is therefore seasonal. It can be explained by the characteristics of each season or the level of human activities. The high ozone levels therefore occur during warm summer months. Since its needs Sun to fuel chemical reaction, after exhaust fumes from morning rush hour, the pollutants have had time to react in sunlight. Then this period is the perfect environment for the production of ozone pollution. The ground level of earth surface is clear, no dust and Sunlight can reach directly the ground level of the Earth. The low emission is corresponding to the period of harmattan where the ground layer of the atmosphere is loaded with dust. This situation can reduce the speed of solar radiation, particularly, the ultraviolet radiation energy chemical reactions with human activities.

The geographical location of the tropospheric ozone pollution shows the spatial distribution of the O_3 pollution in the central part of the city. The highest concentration is around the Airport location, the various activity area (ZACA), central market. The value is above of the national standard of exposure or exhibition (150-200 µg/m^3)[1]. (Figure 24).

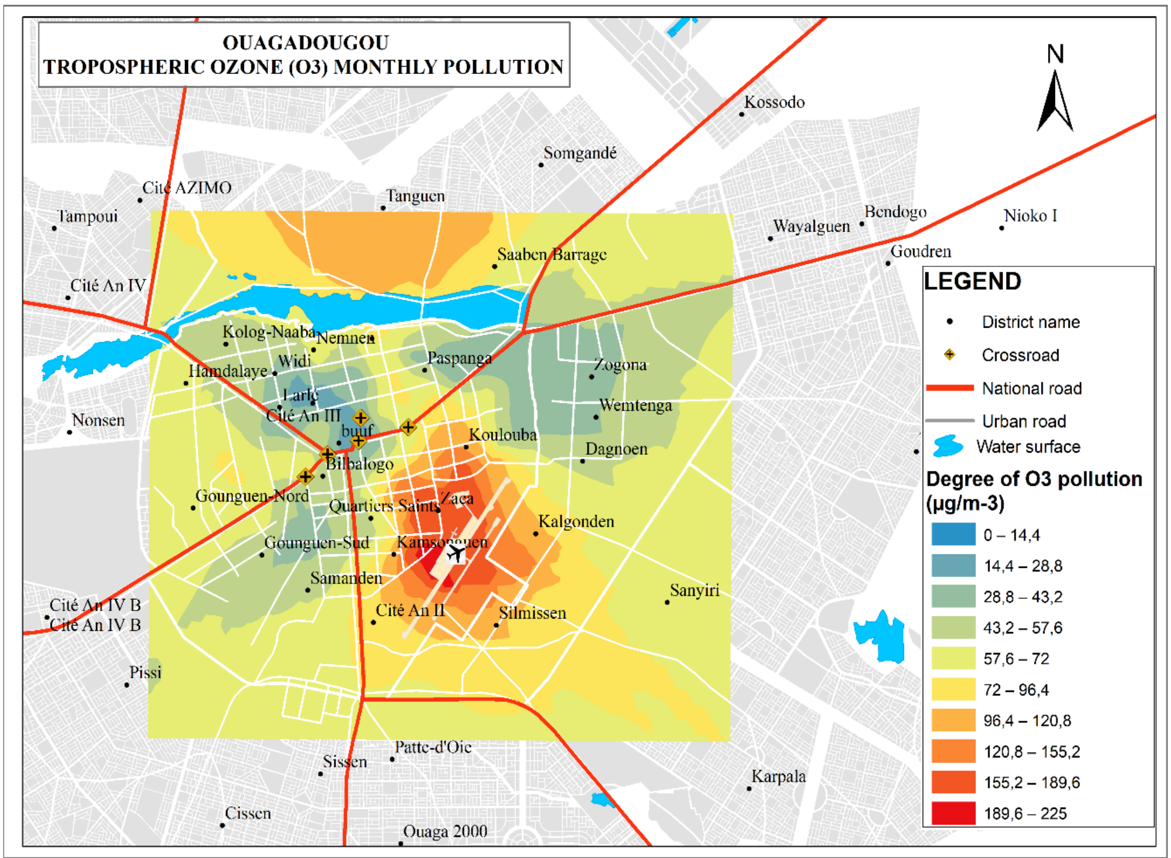


Figure 24: Tropospheric ozone (O_3) monthly pollution in the central city of Ouagadougou

The value of the other area has been gotten by interpolation using kriging method. It is an inverse distance weighted and directly based on the surrounding measured values or on specified mathematical formulas that determine the smoothness of the resulting surface. 114 geographical position (places) where the density of mobility is dense have been collected and the ozone data have been collected based on those locations.

[1] The national standard of O_3 exhibition is set for 1h. It means one cannot be exposed at the value 150-200µg.m^{-3}

4.4- Discussion

Energy consumption analysis in road traffic and urban mobility is a research that requires a lot of data and the hug challenge is the establishment of emission factor. This study demonstrates that the fossil fuel consumption by road traffic is about 89% with 10% of gasoline and 90% for diesel. This high demand of energy by transport sector has been demonstrated by many studies that used the Long-Range Alternative Energy Planning computer software to analyze the contribution of transport on fossil fuel consumption. In 2008, a research that carry out on a sustainable passenger road transport scenario to reduce fuel consumption, air pollutants and GHG (greenhouse gas) emissions in the Mexico City Metropolitan Area (Chavez-baeza and Sheinbaum-pardo, 2014) with LEAP demonstrated the high dependence of transport sector on fuel consumption and demand. It therefore shows that the road traffic is the hug consumer of fossil fuel such as diesel, gasoline, LPG in the Mexico metropolitan city. Thus fossil consumption depends on the vehicle's fleet, the growth of population, the vehicle fleet growth rate and the country urban transport politics and policy. A research in Oman city shows that the vehicle fleet growth rate is higher than the human population growth with an approximately one (1) private car per household (Amoatey and Sulaiman). This situation increases fossil fuel demand and consumption. In Ouagadougou there is 2 over 5 persons have a private motorbike and 1 private car per household. That is therefore demonstrating the huge consumption of fossil fuel and consequently contribute much to the atmospheric pollution and greenhouse gases.

Most gases that were measured in several studies that have been carried in Ouagadougou were CO, NOx, N2O, CO2, SO2 etc. In this research, the same gases have been measured except N2O and SO2. Among the gases measured most of them are atmospheric air pollutant highlighting the contribution of road transport and urban mobility on air pollution in Ouagadougou. Most of studies that was done previously are very much focused on air pollution. Air pollutant emissions inventory from road traffic in Ouagadougou (Somda, 2018) study showed that urban transport contributes significantly to air pollution through the road transport sector. Its study shows that this urban center emits a considerable rate of pollutant of 34,679.40; 2556.99; 7854.23; 42.76; 98.77; 307.64; 467.09 and 7172.76 tons of pollutants respectively for CO, $COVNM$, NOx, $N2O$, $NH3$, $PM2.5$, $PM10\ et\ SO2$. Moreover, the similar research done in Ouagadougou by 2011 on air pollutant modeling (Nana al.; 2011) confirm this hug contribution of urban road transport to air pollutant in Ouagadougou. Al this studies target the impact of atmospheric pollution on human health. Their methodology is based on localized measurements with identified sites where the flow of road traffic is considered important. They did not include greenhouse gases calculation in their research. The study on sustainable passenger road transport in Mexico, demonstrates the contribution of transport of Mexico City to atmospheric air pollution and climate change. It also developed some scenarios of gases mitigation and reduction with LEAP. Thus in our study, we used LEAP for just analyzing fossil fuel demand and consumption by road transport and urban mobility in Burkina Faso without any alternative scenario of its reduction. This research just shows the trend in order understand the situation. Some countries have a standard or policies on gases emission in road transport and urban mobility. The absence of any standard and policy make the analyses difficult because of the absence of reference base.

In addition to aforementioned factors, urbanization and its related features such as urban form and urban density have been increasingly acknowledged as import factors in explaining travel demand and transport energy use in recent year (Rodrigue and al., 2006). The rapid urbanization entails a huge demand of motorized vehicles and increases moto vehicles fleet. It rises the final energy consumption for transport reached 28 % of total end-use energy in 2010 (IEA, 2012b), of which around 40% was used in urban transport (IEA, 2013). For example, in Algeria with an ever-increasing fleet of motor vehicles in the cities, most of which are practically old ones. The assessment of the quantity of CO2 pollutant known as the most significant greenhouse gas emission from traffic in Algeria states the increases of the demand in fuel consumption with the rapid urbanization, which undeniably intensifies polluting emissions (Leila and Noureddine 2014). It shows that as the situation goes, it has become the utmost urgency to wonder about a possible support that may be given to this sector in order to evaluate how air quality is managed in a durable way with the high emission of greenhouse gas. Therefore, estimating the pollutants quantities released in the air is an important stage in the evaluation of air quality. The approach used is mainly based on a number of assumptions, which allows us to find the amount of 192 g/km/day CO2 released into the urban atmosphere of the city of Batna (Leila and Noureddine 2014). In Oman city about 76% of registered vehicles as of 2014 were private cars with approximately one private car per household. It shows that the growth of automobile is faster than the growth of human population. From 2000-2009, Oman city population has increased by 2% per annum while automobile usage in the country has increased by 4.3%. Due to very limited public transportation system, traffic congestion and emission from vehicles are high during working days since majority of individuals uses private vehicles as only means of transport (Amoatey and Sulaiman, 2017). The leadership of Sultanate of Oman has pledged to cut down greenhouse (GHG) emissions by 2% as a commitment to United Nation Framework

Convention on Climate Change (UNFCCC). It exactly characteristics of Ouagadougou city. The rapid growth of vehicle fleet and the spread of urban area are the most key of urban transport and mobility rise and fuel consumption and demand.

Atmospheric CO2 concentrations have increased by almost 100 ppm since their pre-industrial level, reaching 379 ppm in 2005, with mean annual growth rates in the 2000-2005 period higher than in the 1990s. The total CO2-equivalent (CO2-eq) concentration of all long-lived GHGs is now about 455 ppm CO2-eq (Rogner et al. 2007). Incorporating the cooling effect of aerosols, other air pollutants and gases released from land-use change into the equivalent concentration, leads to an effective 311-435 ppm CO2-eq concentration (Barker et al. 2007). With CO2 emissions and air pollutants, unsustainable transportation has economic, social and other environmental impacts. For example, traffic congestion has economic, social and health impacts in urban areas (Chavez-baeza and Sheinbaum-pardo 2014). Studies in major cities in west Africa show that most of them face the problem of pollution. This pollution will increase in the coming years due to the rapid growth of urban population. The atmospheric pollution studied in major cities particular, in the city of Ouagadougou shown that air pollution is mainly due to motorized two wheels that are 70% of the fleet. The air quality measurement campaign in the city of Ouagadougou has permitted to know the levels of concentration of major air pollutants (Nana 2011). The issue of this campaign shows that the concentrations of N2O remain below the limit set by the WHO standard in the entire city except downtown where values often exceed the standard. The average concentrations of SO2 are low in general throughout the city. However, the concentrations of BTEX and PM10 is a major concern in the city because, the limits of the WHO standard are exceeded. The second part was devoted to modeling. An emission model was used to simulate aerosol emissions in West Africa desert with Ouagadougou as a case study (Nana 2011). The research focus on Air pollution measurement and modelling by using a chemistry transport model Polair 3D in Ouagadougou city, but not taken specifically transport sector and its greenhouse gases emission. Our study did not do a measurement campaign with a site of measurement. It used the satellite data with in site or specific location to evaluate ozone pollution and get the same result. Otherwise, most measurement was direct using the gases analyzer, which allowed to determine the amount emission.

To develop a sustainable road transport some strategies of lower GHG emission are the best way. Some big city develops a project to reduce GHG emission in both criteria air pollutants.

It is the case in Mexico where sustainable passenger road transport scenarios have implemented to assist the Mexico City to achieve air pollutant emission such as (CO, NOx, NMVOC (non-methane volatile organic compounds), and PM10) and GHG (greenhouse gas) (CH4, N2O and CO2), while promoting better mobility and quality of life (Chavez-baeza and Sheinbaum-pardo, 2014). They developed a bottom-up model to estimate the historical trends of energy demand, criteria air pollutants and GHG emissions caused by passenger vehicles circulating in the Mexico City Metropolitan Area (MCMA) in order to construct a baseline scenario and two mitigation scenarios that project their impact to 2028. Mitigation scenario “off” considers increasing fuel efficiencies and introducing new technologies for vehicle emission controls. Mitigation scenario “BRT” considers a modal shift from private car trips to a Bus Rapid Transport system. The results show significant reductions in air pollutants and GHG emissions if the will be a good politics of environmental regulations. The case of Ouagadougou also shown the needed of an incentives environmental regulation to enable a smart city development or promote sustainable urban transport and mobility

Chapter 5: Conclusion and perspectives

5.1- Conclusion

This research work has highlighted, the inventory of vehicles and motorcycles of Burkina Faso in the city of Ouagadougou for the year 2019. It allowed to collect and calculate the pollutants emissions relating to the vehicle fleet. Given the immensity of the motorized vehicle fleet, in particular dominated by two-wheelers (75%) and due to its ever-growing population and even the average growth of the vehicle fleet (9,94%/year), the city of Ouagadougou contributes significantly to air pollution and greenhouse gases emission from the road transport sector. It was therefore important to know what was this contribution of road transport to GHG emission in Burkina Faso.

Therefore, results showed that for the moment, despite the average old age of the vehicle fleet (17 years old), and the predominance of individual transport in urban areas in Burkina Faso (80%), there are no decrees or laws limiting the age of vehicles on importation. There are no laws setting the standards for greenhouse gas emissions in transport and urban mobility. Then the road transport and urban mobility legislation has not taken enough account the environmental protection in Burkina Faso. Our first hypothesis is therefore invalidated.

It has been also showed that with the rapid growth of the vehicle fleet, the transport sector is the main consumer of the fossil fuel imported and sold in Burkina Faso. It is account for 89% for the whole consumption with 90% for diesel and 10% for gasoline. The motorbikes are the main consumer of gasoline (98%), trucks and trailers are most consumer of diesel, 82,12% for both. The scenario of the fossil fuel demand coupling to the vehicle fleet growth show that the consumption will double each five years. But the consumption is still dominated by motorbike, truck and trailers. Road transport and urban mobility sector is therefore, the main consumer of fossil fuel in Burkina Faso. Then our second hypothesis is therefore confirmed.

There are three types of gases that has been measured: CO_2 (4734851,666 tons) is most emitted, it is flowed by NO_x (60879,311 tons) and The CO (23076,198 tons) pollutant is less emitted. In 2019, with a total of 4734851,666 tons of CO_2 by the vehicle fleet, tractor or trailer and truck vehicle respectively have emitted 55.20% and 20.25% of CO_2, followed by motorbike (8.48%), vans (7.42%), private vehicles (5.02%) and buses (3.5%). There is a total of 0.47 $GtCO_2eq$ of CO_2 emitted in 2019 with 87.49% for diesel and 12.51% for gasoline. Then, our third hypothesis which stated that the transport sector and urban mobility is contributing to GHG emission in Burkina Faso is also confirmed.

In the light of all these results, a regular study on GHG emission in transport sector would update an activity data and the emission factor. It will therefore necessary to carry out the cost projection study to mitigate transport sector in this context of climate change. This will help decision makers to develop a sustainable transport by satisfying people's need while taken care of environment and climate.

5.2- Recommendations

'Sustainable transport', arising from the concept of sustainable development. It aims to provide accessibility for all to transport in order to help meet the basic daily mobility needs consistent with human and ecosystem health. It also aims to constrain GHG emissions by, for example, decoupling mobility from oil dependence use. Avoided journeys and modal shifts due to behavioral change, uptake of improved vehicle and engine performance technologies, low-carbon fuels can help to mitigate climate change by transport sector. Also, the investments in related infrastructure, and changes in the built environment, together offer high mitigation potential. Therefore, to achieve this goal while satisfying people's need, the transport sector in Burkina Faso have to:

- Develop extant laws and regulations to limit the age of vehicles for importation destined for Burkina Faso, new vehicles have a more improved combustion system;
- Promote a modal shift of transport and mobility through the development of public transport, which could reduce the number of two-wheelers in favor of buses in the cities and in between;
- Deepen a research fuel efficient or economy in order to help people import less fuel consumer vehicle;
- Renew the car park or fleet by scrapping old vehicles through a policy of subsidizing public transport and facilitating the purchase of new vehicles for citizens;
- Promote carpooling in inter-urban transport, it could help to reduce fuel consumption;
- Set up an emission standard or threshold and prohibit access to vehicles outside this standard in certain places of residence with a high density of human population such as the central town;
- Promote a research on cost project management on climate adaptation and mitigation by road transport;
- Promote soft modes of transport such as pedestrians, bicycles, etc.
- Circumscribe a buffer zone in the city center and prohibit the circulation of certain vehicles (old or very polluting vehicles)

- The urban plan leads to long traffic, then improve the development of outskirts municipality with basic social services.
- Develop an approach concealing accidents and air pollution by reduction traffic lights.

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https://www.africancentreforcities.net/greenhouse-gas-emissions-global-cities/

Google Earth Engine data extraction code link:

https://code.earthengine.google.com/2cfdd4cffd7d693ae0001a3eabc86c4e

APPENDIX

Table 2: Morgan and Krejcie sample table calculation

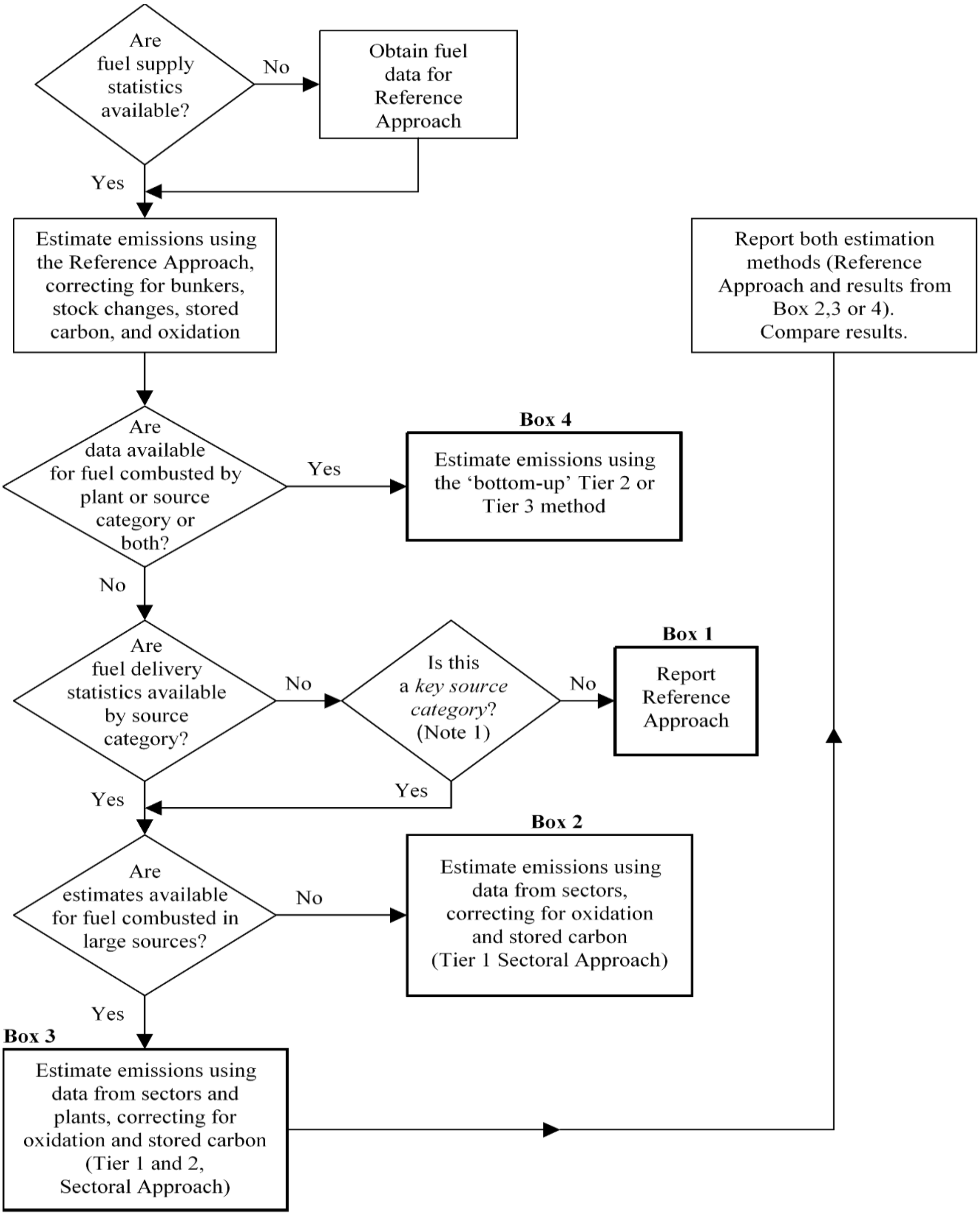
N	S	N	S	N	S
10	10	220	140	1200	291
15	14	230	144	1300	297
20	19	240	148	1400	302
25	24	250	152	1500	306
30	28	260	155	1600	310
35	32	270	159	1700	313
40	36	280	162	1800	317
45	40	290	165	1900	320
50	44	300	169	2000	322
55	48	320	175	2200	327
60	52	340	181	2400	331
65	56	360	186	2600	335
70	59	380	191	2800	338
75	63	400	196	3000	341
80	66	420	201	3500	346
85	70	440	205	4000	351
90	73	460	210	4500	354
95	76	480	214	5000	357
100	80	500	217	6000	361
110	86	550	226	7000	364
120	92	600	234	8000	367
130	97	650	242	9000	368
140	103	700	248	10000	370
150	108	750	254	15000	375
160	113	800	260	20000	377
170	118	850	265	30000	379
180	123	900	269	40000	380
190	127	950	274	50000	381
200	132	1000	278	75000	382
210	136	1100	285	1000000	384

Note.—*N* is population size. *S* is sample size.

Source: Krejcie & Morgan, 1970

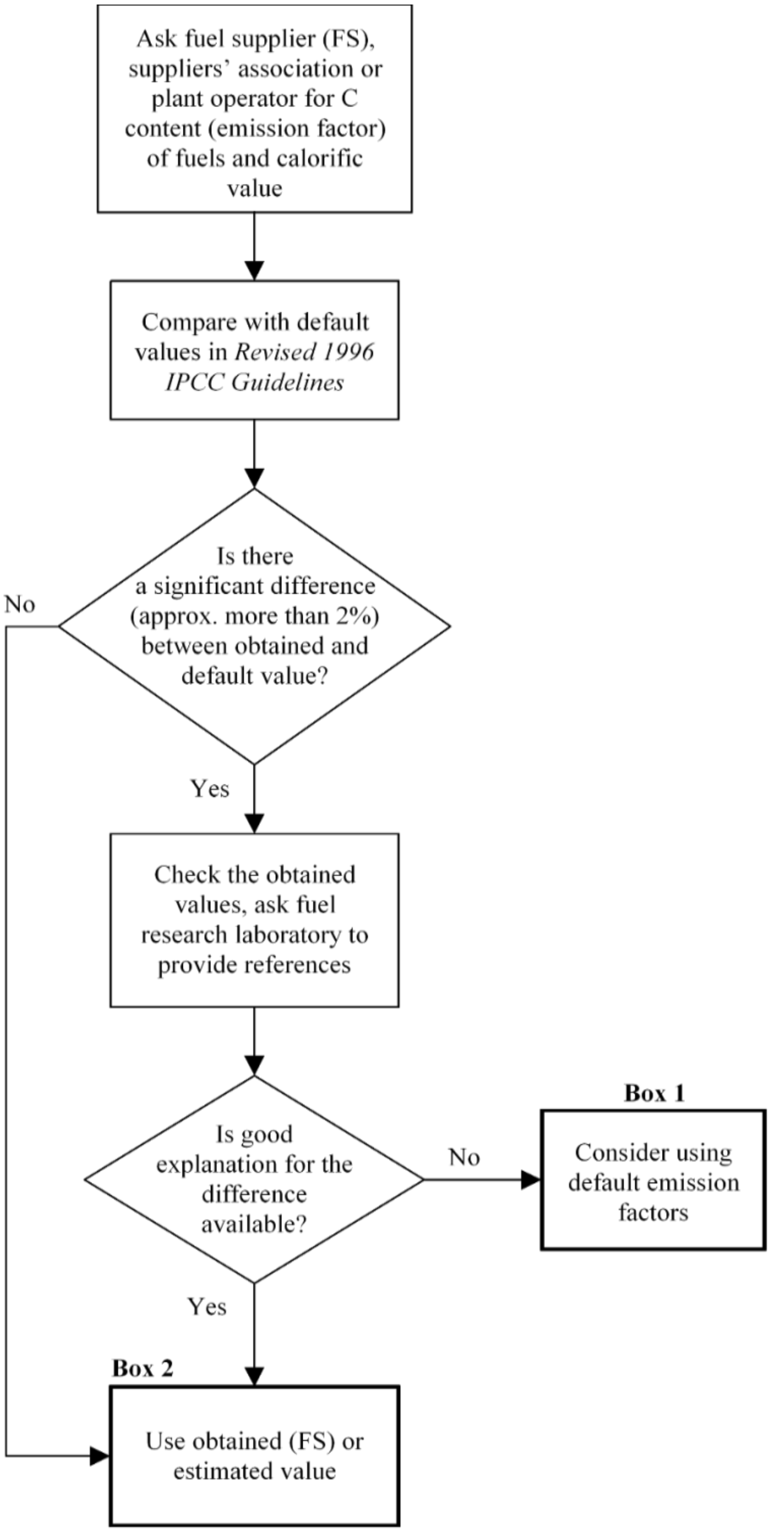
Testo 350-X

Figure 25: Decision for selecting the method for estimation of CO_2 emission in transport sector



Source: IPCC, 2006

Figure 26: Decision Tree for selecting calorific values and Carbon Emission Factors



Source: IPCC, 2006

Table 3: Share gases emitted per vehicle in 2019

Vehicle type	Fossil fuel	CO_2 (Tons)	CO (Tons)	NOx (Tons)
	Diesel	65906,404	496,298	354,926
Private Vehicle	Gasoline	171752,055	1894,739	42,2767
	Total	**237658,459**	**2391,038**	**397,202**
	Diesel	331999,941	2930,717	248,882
Vans	Gasoline	19203,877	414,995	41,756
	Total	**351203,818**	**3345,712**	**290,638**
Bus	Diesel	165734,003	651,656	1490,958
Truck	Diesel	958720,934	3716,908	14681,496
Tractor/Trailor	Diesel	2620040,015	12714,698	43725,187
Motorbike	Gasoline	401494,436	256,184	293,827
Total		**4734851,666**	**23076,198**	**60879,311**

Table 2: Synthesis of data

Type	Format	Scale/Resolution	Source	Importance
Historical data of Cars and Motorbike fleet	Excel/Csv	National, from 2004 to 2018	DGTTM, SOTRACO, CTGO	Integrate into fossil fuel consumption analysis and demand.
laws, articles, legislation documents	Word, Pdf	National	Ministry of environment	Analyze the urban transportation and their legislation related to environment protection in Burkina Faso
Statistics data of average distance of the Cars fleet	Csv	Ouagadougou	Survey	To determine the fossil fuel consumption and Gases emission.
Statistical data of Fossil fuel consumption	Csv	National, from 2009 to 2018	DGTTM	Identify and assess the type of GHG emitted according to the fossil fuel used
Geospatial data	Shape file	National, Ouagadougou	IGB, BNDT	Study area presentation, analyze of spatial dynamics, road network etc.
Climate data	Excel	Ouagadougou, from 1990 to 2020	ANAM	Analyze the impact of GHG on local climate trend
GHG emission factor and activity		Ouagadougou	LPCE Laboratory, IPCC	Calculate the total GHG emitted in transport sector by year.
Population statistics	Excel	National	INSD	Determine the evolution of urban population and mobility demand.
Air pollution data	Csv, Tiff	Ouagadougou	IPCC, Sentinel Satellite-5, Survey	Air pollution model calculation

Table 4: Emission factors calculation

Vehicle Type	Registred Vehicle	Average annual Distance/Vehicle	Fuel efficiency (Km/liter)	Fuel intensity (Liter/Vehicle)	Fuel consummed (liter)	Fuel density in kg/l	Mases of fuel consumed (kg)	EF CO2 (kg/l)	EF CO(kg/l)	EF Nox (kg/l)
Private Cars										
Gasoline	113312	3387,67	11,38	297,6862917	33731429,09	**0,75**	44975238,79	3,81351	0,04207	0,00094
Diesel	33847	4219,9	10,25	411,697561	13934727,35	**0,85**	16393796,88	3,22827	0,02431	0,02165
Vans					0					
Gasoline	3806	12392,08	12,5	991,3664	3773140,518	**0,75**	5030854,025	3,81722	0,08249	0,0083
Diesel	50568	16563,15	9,7	1707,541237	86346945,28	**0,85**	101584641,5	3,26821	0,02885	0,00245
Trucks										
Diesel	26803	58014,58	6,29	9223,303657	247212207,9	**0,85**	290837891,7	3,29641	0,01278	0,05048
Bus (Public)					0					
Diesel	16636	13599,68	5,22	2605,302682	43341815,42	**0,85**	50990371,08	3,2503	0,01278	0,02924
Tractors/Trailor					0					
Diesel	64190	50605,06	4,8	10542,72083	676737250,3	**0,85**	796161470,9	3,29084	0,01597	0,05492
Others Vehicles					0					
Gasoline	172,9	3087,67	11,38	271,3242531	46911,96336	**0,75**	62549,28448	3,81351	0,04207	0,00094
Diesel	492,1	50014,58	7,2	6946,469444	3418357,614	**0,85**	4021597,192	3,22827	0,02431	0,02165
Motorbikes					0					
Gasoline	921400	3223,25	37,87	85,11354634	78423621,6	**0,75**	104564828,8	3,83967	0,00245	0,00281

Source: Survey and measurement, 2021

Table 5 : Burkina Faso ambient air quality standards

Polluants	Limit value (in μg.m^{-3})	Duration of exposure
CO	30 mg.m^{-3}	1 heure
SO_2	200 `a 300	1 heure
NO_2	100 `a 170	1 heure
Particules	200 `a 300	24 heures
Plomb	2	1 an
Ozone	150 `a 200	1 heure

Source*: Ministry of Health, in Nana, 2011*