Journal of Urban Mobility 7 (2025) 100106

Contents lists available at ScienceDirect

Journal of Urban Mobility

journal homepage: www.elsevier.com/locate/urbmob

Road Transport and Urban Mobility Greenhouse Gas Emissions Factor for Air Pollution Modeling in Burkina Faso

Issaka Abdou Razakou Kiribou [a,g,*], Tiga Neya [b,c], Bernard Nana [d], Kehinde Ogunjobi [b], Tizane Daho [a,d], Y. Woro Gounkaou [h], Faith Mawia Muema [e], Dejene W. Sintayehu [f]

[a] *Doctoral school of Informatics for Climate Change, University Joseph KI-ZERBO, 03 P.O.Box 7021 Ouagadougou 03, Burkina Faso*
[b] *West African Science Service Center on Climate Change and Adapted Land Use, WASCAL, Competence center, Boulevard Mouammar Kadafi, 06 P.O.Box 9507, Ouagadougou, Burkina Faso*
[c] *Ministry of the Environment and Ecological Transition, Directorate General for Climate Transparency, 01 P.O.Box 3926. Ouagadougou 01, Burkina Faso*
[d] *Laboratoire de Physique et de Chimie de l'Environnement / Université Joseph KI-ZERBO, Ecole Normale Superieure, Ouagadougou, 03 P.O.Box 7021 Ouagadougou 03, Burkina Faso*
[e] *Department of Civil, Construction and Environmental Engineering, Southeastern Kenya University, P.O. Box 170-90200, Kitui, Kenya*
[f] *The International Center for Tropical Agriculture, Addis Ababa P.O. Box 5689, Ethiopia*
[g] *Africa Centre of Excellence for climate Smart Agriculture and Biodiversity Conservation (ACE-Climate SABC) Haramaya University, Ethiopia, P.O.Box 138, Dire Dawa, Ethiopia*
[h] *Laboiratoire de Matériaux d'Hélio-Physique et de l'Environnement (La.M.H.E), Université Nazi Boni, 01 BP 1091 Bobo-Dioulasso, Burkina Faso*

ARTICLE INFO

Keywords:
Greenhouse gases
Urbanization
Vehicle carbon
Environmental impact of transport
Sustainable urban mobility
Burkina Faso

ABSTRACT

The road transportation sector is one of the largest contributors to fossil fuel consumption, while the energy sector being the greatest consumer overall. Urban growth increases transport and mobility demands to meet human needs. Few studies exist on greenhouse gas emission factors in developing countries. This study assessed and modeled greenhouse gas emissions factors with fossil fuel implications in road transport including urban mobility in Burkina Faso. The methodology entails the development of a bottom-up model to estimate fuel demand and emission factors under the IPCC 2006 guideline. It assesses greenhouse gases by establishing the specific emission factors using Ouagadougou City as a site of emission data processing. The analysis has included satellite NO_2 emission data. The city suffers from significant gas emissions and air pollutants resulting from the high vehicle fleet growth and fuel consumption. Indeed, the transport sector consumes 89 % of fossil fuels sold in Burkina Faso. There is an average carbon dioxide (CO2) emission factor of 3.7623 kg/l and 3.270 kg/l for diesel and gasoline vehicles, respectively. Thus, in 2019, gasoline and diesel accounted for 71 % and 21 % of total fuel consumption respectively, and produced a total amount of 1034 513.84 tons of CO2 (1034.5 GgCO2). In the business-as-usual condition, an average annual CO_2 production of 213.71 thousand tons is simulated from 2019 to 2040. A total emission of 4 486 559.34 tons (4486.64 GgCO2) by 2040 is expected with a share of 62 % for gasoline and 38 % for diesel. With an average emission of 1.89 mol/m2, the satellite tropospheric nitrogen dioxide concentration is mostly affecting the Central Business Division (CBD) of Ouagadougou City. It corresponds to 56 µg.m-3 which is beyond the WHO standard of annual average exposure. Thus, these findings alert the need for urgent environmental regulations and climate change mitigation actions for sustainable mobility.

Synopsis: Minimal research exists on gas emission factors in Africa, this study reports GHG emission factors of road traffic with the implication of fuel consumption.

1. Introduction

Over a century, greenhouse gases such as carbon (CO_2), methane (CH_4), concentration has increased exponentially in the atmosphere (Dubresson & Jaglin, 2010; Steinberger et al., 2009), which is inherent to human activities. The human need for energy has led man to burn

---

* Corresponding author.
E-mail addresses: krazakou200248@gmail.com, kiribou.i@edu.wascal.org (I.A.R. Kiribou).

https://doi.org/10.1016/j.urbmob.2025.100106
Received 8 January 2024; Received in revised form 19 January 2025; Accepted 21 January 2025

substantial amounts of fossil fuel, and the population increase, correlate with high consumption of fossil fuel, wood, and charcoal, particularly in urban areas. The global population living in urban areas reached 50 % at the beginning of the 21st century and is expected to reach 60 % by 2030 (UNPA, 2014), with developing countries having the highest rates of urbanization (Freire et al., 2014). This has contributed to increase urban transportation and mobility demands. The transportation sector is the greatest active contributor to fossil fuel consumption in cities and generates the largest share of greenhouse gas emissions (Sims R. et al., 2014). Over 90 % of the fuel used for transportation is petroleum-based (Wang & Zhang, 2012) contributing significantly to environmental pollution through greenhouse gas emissions. The Executive Director of the United Nations Centre for Human Settlements (Kirk, 1988) states that cities are responsible for 75 % of global energy consumption and 80 % of greenhouse gas emissions (Dodman, 2009). In 2004, the transport sector accounted for 26 % of world energy use, of which 95 % of the energy was obtained from burning fossil fuel in internal combustion engines (U.S. Energy Information Administration | International Energy Outlook 2016, 2016). Unless there is a major shift from current patterns of energy use, projections foresee continued annual growth of 2 % in world transportation energy use, with carbon emissions expected to increase by 80 % by 2030 (Dodman, 2009).

In developing countries, transportation energy demand is increasing rapidly at a range of 3 to 5 % per year and, estimated to grow from 31 % in 2002 to 43 % of world transport energy use by 2025 (Barker et al., 2007). Since road transportation is one of the contributors in energy consumption, vehicles are the largest emitters of GHGs in most road transport (Albuquerque et al., 2020). The main greenhouse gases emitted are carbon dioxide (CO_2), methane (CH_4), Nitrous dioxide (NO_2), and a small amount of hydrofluorocarbon (HFC) released from the use of mobile air conditioners and refrigerated transport (Chavez-Baeza & Sheinbaum-Pardo, 2014). Anthropogenic volatile organic compounds (VOCs), carbon monoxide (CO), and nitrogen oxides (NOx), important elements gases to tropospheric ozone (O3) and secondary organic aerosol formation, are principally emitted from vehicles in urban areas (Chavez-Baeza & Sheinbaum-Pardo, 2014). As part of a global determination to identify greenhouse gas emissions and set targets for emissions decrease, the UNFCCC requires all member states to regularly submit their National Greenhouses inventory report and IPCC provides a detailed methodological framework to achieve it. An emission factor (EF) which is a coefficient that quantify the gases emission per unit activity is necessary to perform GHG assessment in the sector like road transportation (Giuliano et al., 2015). This.is important for environmental regulation in road transportation sector where the emissions tend to increase due to structural changes related to gross domestic product (GDP) per capita increase as countries became richer. Thus, the development path of infrastructure and settlements taken by developing countries and economies in transition will have a significant impact on the future share of transport related emissions of GHG (Sims R. et al., 2014). This situation demonstrate a significant environmental effects of road transportation in cities where the movement of people, goods are fundamental component of modern society (Rodrigue, 2024)

Burkina Faso is a landlocked country where the road transportation sector plays a significant role in the economy including urban development characterized by an exponential cities growth passing from 15.4 % in 1996 to 31.4 % in 2019 (INSD, 2022; UN-HABITAT, 2019). In this context of economic and urban dynamics, the country submitted its second national communication in 2015 to UNFCC using default emission factors. It is therefore important to assess and determine the specific EF for the country to reflect the reality in GHG assessment. The specific EF is highly recommended by UNFCC for better implementation of the national Measurement Reporting and Verification (MRV) tool to gather accurate information from country's NDC report (Singh et al., 2016; UNFCC, 2014). This is really critical for the developing world particularly in transportation sector since the fuel does not have a standard quality for all countries (Fu et al., 2022). The specific EF per country, is fundamental to measure and identify specific GHG emissions sources for an activity related to energy consumption and enables companies to quantify their environmental impact particularly in transportation sector (DCycle, 2024). The cost-effectiveness of the EF in GGH assessment makes it appropriate for road transport and urban mobility studies which needs details and larger scale estimations to guide decision making in targets emissions reduction, and transport infrastructure planning. This help making urbanization process environmentally friendly with sustainable urban mobility. Thus, this study has developed emission factors and reliable fleet availability data to provide a more reliable historical trend of GHG emission in road transport and its contribution to air pollution. It assessed and model GHG emissions relating to the road transportation sector and urban mobility in Burkina Faso using the IPCC 2006 guideline (Jim Penman et al., 2006). It has also assessed urban NO_2 of the capital city, from satellite because of its harmful impact on human health, since the country urban growth is led by Ouagadougou which represents 46.4 % of the urban population (UN-HABITAT, 2019). From 2010 to 2015 it was estimated that 1.85 million (95 % uncertainty interval [UI] 0.93–2.80 million) new pediatric asthma cases were attributable to NO_2 globally in 2019, two-thirds of which occurred in urban areas, particularly in developing world (Anenberg et al., 2022). Furthermore, NO_2 emission causes naturally impaired visibility and contributes to acid rain. All this together consists of guiding policymakers to make cities livable, and climate-resilient that balance development with environment health and quality of life in Burkina Faso.

2. Literature review

Economy development is greatly dependent on transportation sector, which support the global modernization in freight movement, and urban mobility (Cascetta & Henke, 2023; Ma et al., 2020). This sector highly contributes to the societal and economic inclusiveness in any geographic area in the world. However, the high dependency of on fossil fuels (e.g. gasoline, diesel) underscore the transport sector environmental degradation through emissions (Proost & Van Dender, 2012a). In the context of climate change mitigation arrangements, sustainable transport development is a critical component for the achievement of Paris agreement actions plan (International Transport Forum, 2018; IPCC, 2023a).

It has established in 2019 IPCC report, that transport sector contributes 23 % to the global energy related CO_2 emission, 8.7 GtCO2-eq emitted (IPCC, 2023b, 2023a). and most of countries specifically, developing countries still using the tier 1 of IPCC 2006 guideline which using defaults emissions factors leading to use gap on the accuracy given that the fuel in the developing countries don't have the same standard meaning the same emission factor. Therefore, climate mitigation target actions from transportation sector, will require substantial transformative change with leaving no one behind for inclusive sustainable development achievement by using the specifics emissions factors. For that purpose, UNFCCC recommended countries to move from IPCC tier 1 method which using default emission to IPCC Tier 3 method that promote specific emission factor on GHG measurement (UNFCC, 2014). Unfortunately, some countries such Burkina Faso don't have that standard explaining therefore, the need of this study. The low-carbon emissions target, to reduce greenhouse gases (GHG) emissions towards achieving the Paris agreement goal of 1.5 °C in transport sector is a critical action for parties (Arioli et al., 2020).Thus, a regular GHG emissions assessment from transport energy related consumption by all countries should be a critical indicator in sustainable transport system development, particularly in urban area. This should be made with a specific emission factor (EF).

With the UNFCC recommendation for GHG emission inventory by country, much efforts are made by many countries to develop a specific EF with academic and public institutions, and researchers. Thus, the United States Environmental agency has established an EF, in transport sector with a regular update on CO_2, CH_4, and N_2O, in fossil fuels vehicles in USA (U.S. EPA, 2021). In Europe the Smart Freight Centre based in Netherland provides an extensive list of GHG emission factors associated with different fossil fuels used in the road transport, which assists companies to effectively implement GHG inventory in freight sector (Smart Freight Centre, 2021). Furthermore, to implement indirect top-down GHG estimation in road transport, Mukherjee et *al.*, investigated in the use of deep learning approach to estimate emissions with satellite imagery in the United States, which can be considered as a scalable near real time GHG estimation (Mukherjee et al., 2021). Transport carbon estimation from road network with open data approach including origin-destination flows were possible with the use of machine learning, which therefore proves the effectiveness of carbon emissions inventory for sustainable mobility management (Zeng et al., 2024). Furthermore, to promote profitable, sustainable and competitive business in India, the country has established a specific road transport EF prevalent to each energy related vehicle type in 2015 (Indian GHG Program, 2015). These innovative researches contribute advancing GHG emissions investigation in road transport. However, as fossil fuel used in transport sector depends on many factors including, fuel quality, engines combustion, continuous efforts are requiring in further investigation for effective policy implementation (Ghorbani et al., 2024). Efforts should be made with developing countries, particularly in Africa were many countries still using default EF related to their GHG inventory for the NDC report to UNFCC. Although IPCC provides Guidance methods for estimating GHG emissions, countries are encouraged to adopt the "bottom-up" approach with specific EF, particularly in transport sector with local data. This is preferred over IPCC defaults, because fossil fuel composition and calorific values depends on many factors (Arioli et al., 2020; Eggleston et al., 2006; IPCC, 2023b; Masui et al., 2021).

3. Method

3.1. Study area

This study was carried out in Ouagadougou city in Burkina Faso, a landlocked country located in the heart of West Africa between 9°20′ and 15°05′ North latitude and 5°20′ West and 2°03′in East longitude (Fig. 1). It covers an area of 274 000 km^2 with an estimated population of 20 487 979 people and an annual growth rate about 2.93 % (INSD, 2019). It has 45 cities according to the national urban definition (INSD, 2022) and ranked 119 positions out of the 196 countries).

The capital city Ouagadougou is the leading rapidly grown city which accounted for 45.5 % of the national urban population and 40 % of the vehicle fleet in 2019 (INSD, 2019). The urban sprawl leads to an annual increase in the use of motorized vehicles of 4.3 % dominated by two wheelers (Bamas, 2003). Only 11 % of the city population uses public transport. In this city, road transport is the main mode of transportation accounting for 84,3 % of freight in 2018 (MTUMSR, 2019). The national road network is made up of 6728 km (about 4180.59 mi). In 2018, about 93 % of the volume of hydrocarbons was imported by road transport in this country (MTUMSR, 2019).

3.2. Sampling

In this study, Ouagadougou city Cars and the Motorbike fleet of 2019 have been used. A sample of 1,231,226 vehicles, which represents 40 % of the national vehicle population (3 068 308) was used. The data are from the general directorate of Land and Maritime Transport (MTUMSR, 2019). It is a cumulative data from 2005 to 2019. The sample size was determined using the Morgan formula for its simplicity (Abdul et al., 2021; Uakarn et al., 2021) and, the vehicle fleet are categorized per fuel type.

$$S = \frac{X\ 2NP\ (1-P)}{d2(N-1) + X\ 2P(1-P)} \tag{1}$$

S, the sample size; **X2,** the table value of chi-square for 1° of freedom at the desired confidence level (3.841); **N,** the population size. **P,** the population proportion (assumed to be 0.50 since this would provide the maximum sample size); **d** = the degree of accuracy expressed as a proportion (0.05). For a population greater than or equal to 1000,000, the sample considered remains constant and equal to 384. The sample

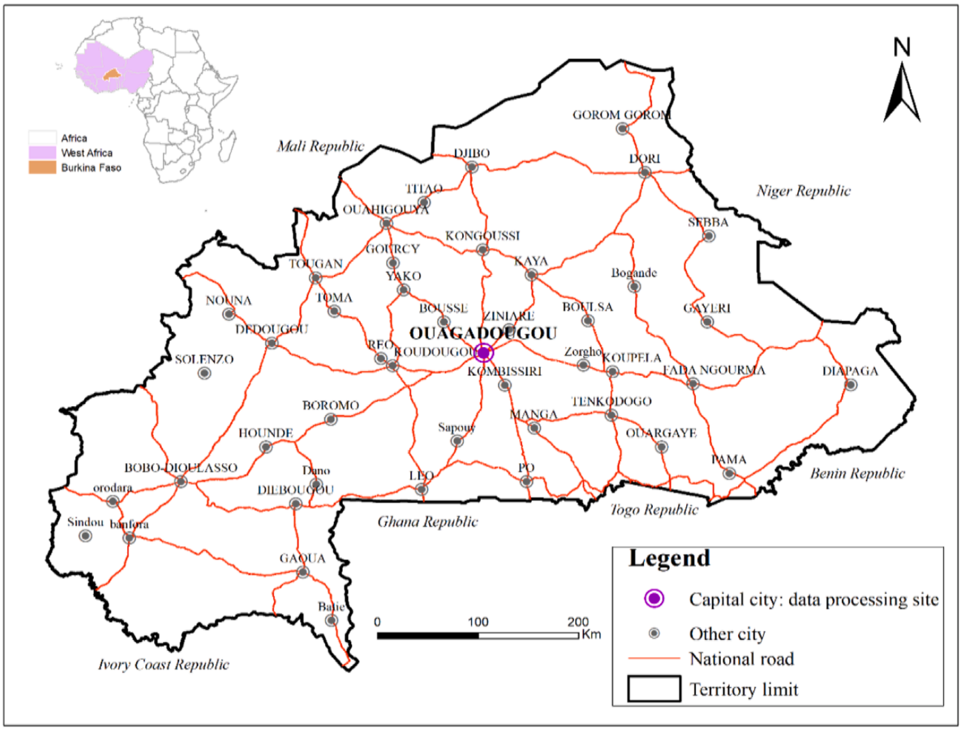

Fig. 1. Study area.

distribution detail has taken into account he proportional shared of the vehicle powered engine (diesel or gasoline) population **(Table S1).** The summary is therefore split by vehicle and fuel type according to the population detail, which revealed the dominance of two wheelers and gasoline vehicles (Table 1).

3.3. *Emission factor estimation*

The emission factor is a coefficient that quantifies the emissions or removals per unit activity with combined information on the extent to which human activity occurs (EEA, 2023). In the transport sector, a mass of carbon dioxide emitted per unit of fuel consumed is considered an emission factor, which depends on fuel type, vehicle activity, technology, and emission reduction regulations at regional and country levels (EEA, 2023; Keita et al., 2021). However, in Burkina Faso as well as in many African countries, information on specific emission factors is not available for each fuel/activity (Gitarskiy, 2019; Jim Penman et al., 2006; Paustian & Van Amstel, 2006). Therefore, the estimation is based on country-specific information on process conditions, and fuel qualities (Gitarskiy, 2019). Thus, several operations were performed to obtain the actual amounts of gas emission factor using the Testo 350-XL gas analyzer (Testo North America, 2019). The vehicle combustion data was collected from the Motor Vehicle Control Center (CCVA) by real-time measurements with a time step of a second over two minutes maximum corresponding to the average time during which the emission values are stable for data recording. The data obtained in ppm units from the measurement are normalized concerning the excess air during the process as shown below:

CO_2 *(ppm)=* CO_2 *(%) *10,000* *Step1*
CO_2 (Normalized air excess) = CO_2 (ppm)*20.9/(20.9-O_2(%)); *Step2*
CO_2 (mg/m3) = CO_2(Normalized) * Density of CO_2; *Step3*
CO_2(g/kWh) = CO_2(mg/m3) * Sp/(1000*LCV); *Step4*
CO_2(g/kg) = CO_2(mg/m3) * Sp/1000 *Step5*
*Where: **LCV**= Lower Calorific Value; **Sp**= Smoke Power*

Notes: Fuel density of 850 kg/m^3 for diesel, and 750 kg/m^3 for gasoline is used.

To control the data uncertainties, the Testo 350-XL gas analyzer is first calibrated using the censors' instruction manual. The engine exhaust emissions measurement is made based on the Senegalese standard NS 05–060 (https://faolex.fao.org/docs/pdf/sen54266.pdf) in the absence of a national standard on vehicle's emission control procedures in Burkina Faso. In addition, the benches for the vehicle's emission control procedures of the European standards (European Union, 2019) are used to know the technology of the vehicles surveyed using the manufacturing year. Therefore, the measurement accuracy was ±2ppm error, either 0.3 % of the volume with an average response time of ≤30 s.

3.4. *Vehicle activity data, fossil fuel demand, carbon dioxide emission*

In the transport sector, energy consumption depends on factors such as travel distance, fuel efficiency, or economy. The more a vehicle traveled, the higher the fuel consumption. Thus, the travel distance constitutes an activity data. In this study, the annual travel distance is the activity data, and were collected together with fuel efficiency or economy at the Motor Vehicle Control Center (CCVA) with the owners of the surveyed vehicles on which the measurements were carried out during the vehicle control. Then, the vehicle importation and, its registration document in the country were exploited. The travel distance from the vehicle visit card delivered by CCVA at its previous visit and, the total mileage information from the vehicle dashboard during the measurement is collected. Then, the calculation of the average annual distance is made between two visits as follows:

$$\boldsymbol{D_{ij}} = \sum_{jit} (\boldsymbol{d_{1t}} - \boldsymbol{d_{0t}}), \tag{2}$$

where **D** is the annual travel distance in km, **d0** is the initial distance from the first visit, and **d1** is the distance traveled at the second visit, **t** is the year; **i** is the vehicle type, **j** is the fuel type.

The fuel efficiency or fuel economy data information was obtained from the compliance documents and from all the sample sizes of the vehicles that were measured during the survey. Thus, the fuel demand and consumption have been estimated using the Long-Range Energy Alternatives Planning (LEAP) model (Huang et al., 2011), is applied to estimate and project the future energy demand using the vehicle population growth rate **(Table S2)** method in the context of business-as-usual condition up to 2040 (Kenworthy-Groen, 2012), Eqs. (3) and (4):

$$\boldsymbol{E_t} = \sum_{jit} \boldsymbol{Vijt * dijt * feijt} \tag{3}$$

where: **E** is the energy demand, **V** is the vehicle population; **d** is the average annual distance traveled in km, **fe** is the fleet's average on-road fuel economy. **t** is the calendar year; **i** is the vehicle type, **j** is the fuel type.

$$\boldsymbol{N_{it}} = \boldsymbol{N_{i0}} + \boldsymbol{k_i.tv} \tag{4}$$

Where: $\boldsymbol{N_{it}}$ is vehicle type ***i*** population size at time ***t***; $\boldsymbol{N_{i0}}$ = initial vehicle type ***i*** population size, $\boldsymbol{k_i}$ is the growth rate of ***i*** vehicle population, and ***tv*** is time intervals.

The energy demand used the vehicle growth rate considering the context of business as usual since the country did implement any policies in road transportation and urban mobility. The growth rate calculation used the vehicle fleet data of previous year (Eq S1). The vehicle fleet projection **(Table S3)** used the recent growth, 2018 to 2019 (Eq S2).

Carbon dioxide (CO_2) emission

For the carbon dioxide assessment purpose, an equation adapted from Chavez-Baeza and Sheinbaum-Pardo (2014) was used

$$\mathbf{CO_{2t}} = \sum_{jit} \mathbf{V}ijt * \mathbf{d}ijt * \mathbf{fe}ijt * \mathbf{EF}jt \tag{5}$$

where: $\mathbf{CO_2}$ is the $\mathbf{CO_2}$ emissions, **V** is the vehicle population. **d** (km) is the fleet average annual vehicle distance traveled, **fe** is the fleet average on-road, **EF** is the emission factor (g/Km), **i** is vehicle type, **j** is fuel type, and **t** is the year**.**

Table 1
Vehicle sample categories and per fuel type in 2019 in the central region.

Type	Population	P/Gasoline	P/Diesel	S/Gasoline	S/Diesel	Sample	Share
Private Cars	147,823	113,712	34,111	36	11	47	12.24 %
Vans	54,374	3806	50,568	1	16	17	4.43 %
Trucks	26,803	0	26,803	0	8	8	2.08 %
Bus (Public)	16,636	665	15,971	0	5	5	1.30 %
Tractors/Trailor	64,190	0	64,190	0	20	20	5.21 %
Motorbikes	921,400	921,400	0	287	0	287	74.74 %
Total	**1,231,226**	**1,039,583**	**191,643**	**324**	**60**	384	100 %

3.5. Nitrogen dioxide (NO_2) emissions estimation

The capital city's tropospheric NO_2 concentration has been used to assess atmospheric air pollution. Nitrogen oxides (NO_2 and NO) are important trace gases in the Earth's atmosphere, present in both the troposphere and the stratosphere (Cheng et al., 2023; NASA, 2018). They enter the atmosphere because of anthropogenic activities, notably fossil fuel combustion and biomass burning (Bucsela et al., 2013), in the presence of sunlight, a photochemical cycle involving ozone (O_3) converts NO into NO_2 and vice versa in a few minutes. Thus, NO_2 concentrations in cities are due to urban transportation and mobility. Launched in October 2017, this satellite is used to monitor atmospheric air pollution, and provides two types of data, Near Real-Time (NRTI) and Offline (OFFL) (Bucsela et al., 2013; Yin et al., 2022). The offline high-resolution (*1113.2* m) imagery of NO_2 concentrations with cloud radiance fractions of <10 % is used. The data was retrieved from the Google Earth Engine dataset (https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S5P_OFFL_L3_NO2). Thus, data from January 1, 2019, to December 31, 2022, has been extracted to assess NO_2 emission over the city of Ouagadougou. The estimation is based on the OMI model of tropospheric Air Mass Factor (AMF) calculation (Perliski & Solomon, 1993). We used the NO_2 profiles simulated by the Global Modeling Initiative (GMI) chemistry transport model with a horizontal resolution of 1° x 1.25°. We considered the total vertical column of NO_2, which is the ratio of the slant column density of NO_2 and the total air mass factor. The formula used to calculate the tropospheric NO_2 is as follows (Perliski & Solomon, 1993; Rotman et al., 2001):

$$\mathbf{VCD}_{trop} = \frac{\boldsymbol{SCD}_{trop}\ -\ SCD_{strat}}{\boldsymbol{AMF}_{trop}} \tag{6}$$

where $\boldsymbol{SCD}_{trop}$ *= Slant tropospheric column density,* $\boldsymbol{SCD}_{strat}$ *=Slant stratospheric column density, and* $\boldsymbol{AMF}_{trop}$*=Tropospheric Air Mass emission factor.*

$$\boldsymbol{AMF}_{trop} = \frac{\boldsymbol{SCD}_{trop}}{\boldsymbol{VCD}_{trop}}, \tag{7}$$

Separation of stratospheric and tropospheric columns is achieved by the local analysis of the stratospheric field over unpolluted areas.

4. Results

4.1. Fossil fuel consumption by the transport sector in 2019 and demand scenario to 2040

The annual average travel distance per vehicle and the average fuel efficiency or economy, the main factors that contribute to fuel consumption, are presented below (Table 2).

It shows that gasoline vehicles are more fuel efficiency and travelling more distance per fuel used than diesel vehicles. With one liter, a gasoline vehicle could travel an average distance of 11.38 km, while a diesel vehicle can reach an average distance of 10.25 km for private cars. The country road transportation is mainly based on gasoline and diesel-powered vehicles. The consumption has increased from 441.3 million liters in 2010 to 1286.2 million liters in 2019 for the whole economic sector. The consumption is made up of 42 % gasoline and 58 % for diesel. Thus, in 2019, the transport sector consumed a huge amount of 1153.24 million liters accounting for 89.66 % of the whole general consumption in the country. The share consumption per fuel type and vehicle category shows a disparity. Gasoline is the most consumed with a shared of 71 % (Fig. 2)

Table 2
Parameters of the fossil fuel consumption estimation.

Vehicle Type	**Average annual Distance**	**Average Fuel efficiency** (Km/liter)
Private Cars Gasoline	4387.67	11.38
Private Cars Diesel	6219.9	10.25
Vans Gasoline	12,392.08	12.5
Vans Diesel	16,563.15	9.7
Trucks Diesel	22,014.58	6.29
Bus (Public) Diesel	13,599.68	5.22
Tractors/Trailer Diesel	21,605.06	4.8
Motorbikes Gasoline	5223.25	37.87

The fuel consumption depends on the fleet availability, and vehicle distance traveled which highlights urban mobility dominated by individual means of transportation with 84 % using shared transport. Each person uses at least one mode of transport, either a motorcycle, private car, or bus transport respectively 48 %, 34 %, and 2 % (Fig. 2, B). The remaining fleet of vehicles (16 %), provides transportation for goods in urban freight mobility. The existing diesel vehicles are dominated by Vans, Trucks, and Bus. Vans are for urban logistic mobility while Trucks and Trailor are for freight transportation within cities.

The projected diesel fuel demand scenario from 2019 to 2040 indicates a huge quantity of fossil fuel that will be consumed in the coming years. The share consumption by 2040 in total diesel fuel is 517. 69 million liters with 66 % for Trailor and 16 % for tractors, and Bus for 3 %. This difference can be explained by the increase in travel distance, the vehicle fuel efficiency/economy, the average rate of the vehicle type fleet annual growth, and, the low-level public transport development. Bus has a low annual growth rate (2 %), then, shall consume less fuel with a shared need of 3 % (Fig. 3).

Thus, there is an average need for diesel fuel of 24.65 million liters each year for diesel vehicle type during the scenario period. The need dominated by Trailor and Truck vehicles is due to urban freight and logistics.

By 2040, gasoline fuel of 729.456 million liters will be consumed by motorbikes, private cars, and vans. Thus, 69 % of gasoline will be consumed by private cars, while 30 % is for motorbike, (Fig. 4). That difference is due to travel distance despite the high number of motorbikes, fuel economy, and, the strong growth of private vehicles compared to motorcycles. A total amount of 1247.141 million liters of fossil fuels will be consumed in 2040 with an annual need of 59.387 million liters/year. The needed share by the fuel type in 2040 is 41 % for diesel and 59 % for gasoline vehicles. This difference in fuel-shared consumption is explained by the vehicle's travel distance, and vehicle number. The increase in average annual distance by gasoline vehicles is due to urban mobility and transportation which is dominated by individual shared modes of mobility.

With business as usual, the private car and motorbike will still be the main mode of mobility with 93 % in 2040. This huge consumption of fossil fuels is the main source of greenhouse gas emissions.

4.2. Gases emission per vehicle and fuel type in 2019 and its scenario from to 2040

The vehicle's emission factors depend on the fuel type and the combustion during a period. The assessment revealed that private vehicles and vans using gasoline have higher emission factors of CO_2 and CO compared to those using diesel for the same type of vehicle, while the NOx emission factor is higher for private vehicles and trucks using diesel (Table 3).

The emission factor is used together with the activity data to estimate the amount of the gases emitted. The assessment indicates that CO_2 is the main gas from transport. In 2019, there was a total of 1 034 513.84 tons of CO_2 (1034.5 $GgCO_2$), with a shared emission of 36 % for Gasoline and 64 % for diesel. In the business-as-usual condition, an average annual CO_2 production of 213.71 thousand is simulated from 2019 to 2040. A total emission of 4 486 559.34 tons (4486.64 GgCO2) by 2040 is expected with a share of 62 % for gasoline and 38 % for diesel. The reversal of CO_2 emissions by energy type is due to the strong growth of gasoline vehicles with >53 % of CO_2 emissions for private vehicles (28

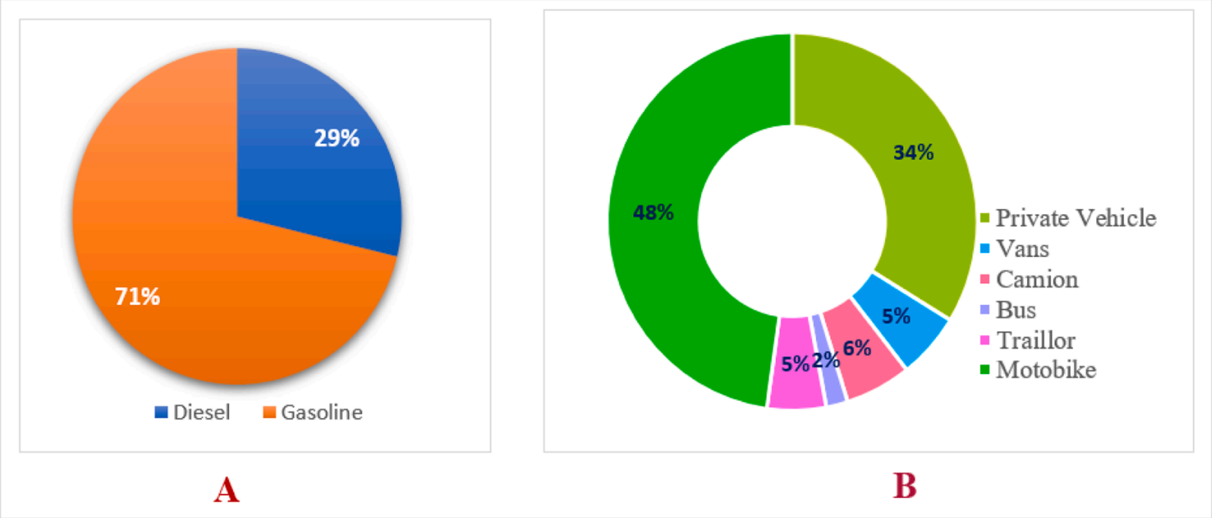

Fig. 2. Share of fuel type consumed by the transport sector in 2019: A) fuel type, and B) per vehicle category.

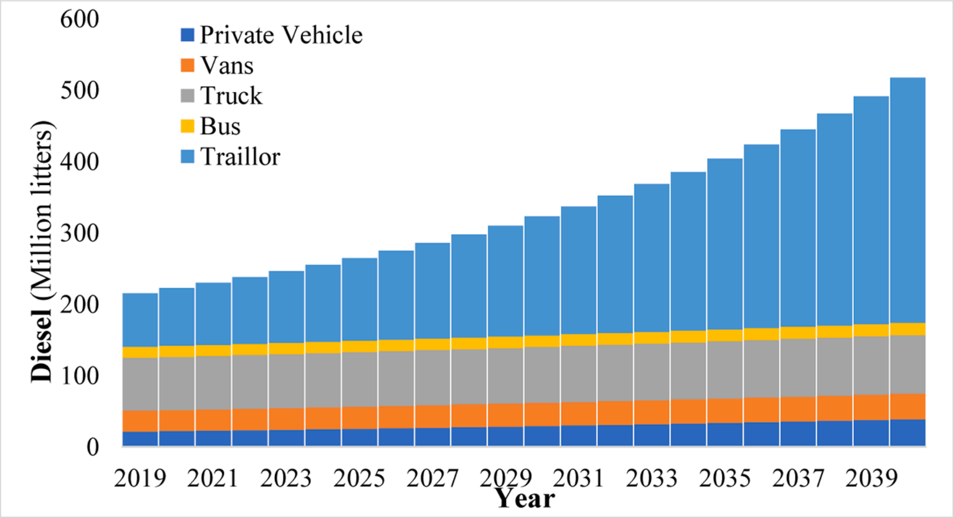

Fig. 3. Diesel demand scenario from 2019 to 2040 by road transport and urban mobility.

%) and Motorbikes (25 %) (Fig. 5).

In the absence of strong politique of public transport development, this situation can contribute to exacerbating the negative externalities of urban mobility such as pollution, traffic accidents, and urban sprawl.

4.3. Nitrogen dioxide emissions estimation

The tropospheric Nitrogen dioxide emission is particularly important in cities due to urban transportation and mobility. The monthly average emission analyzed from the satellite daily data indicates the variation over time from 2019 to 2022. The highest monthly emissions are from April to June and from November to January (Fig. 6).

It therefore shows the seasonal variation of the emission. Indeed, the period from April to June and from November to January corresponds to the dry season. Thus, the prominent level of emission occurs during the dry hottest months between April and June and during the cold months between November and January. During these periods, the ground layer of the atmosphere (troposphere) of Ouagadougou city is loaded with dust. This could therefore influence NO_2 co-emitted in conjunction with other harmful pollutants such as diesel PM, VOC (volatile organic compounds) air toxics, heavy metal, etc. The year 2021 has the highest NO_2 emissions rate with a peak emission in May (1.89e-05 mol/m^2) while 2020 has the lowest rate of emission with the lowest emission in February (1.00e-5 mol/m^2). The variation of the emission is seasonal. It can be explained by the characteristics of each season or the level of emissions. The high NO_2 level occurs during the warm summer months. The high solar radiation in summer can speed up the chemical reactions. The spatial distribution of the average annual tropospheric NO_2 pollution in Ouagadougou city varies like the temporal distribution (Fig. 6). The highest concentration is around the city's central business center (CBD) where the Airport is located and other economic activities. So, trip origin and/or destinations such as the airport, the city's markets, leisure centers, and social and educational centers, are the main factors contributing to urban mobility, which then leads to NO_2 emissions. In addition to this urban mobility generation centers, urban freight movement, or urban logistics contribute to the gas emission. Based on the atomic mass of NO_2 and its chemical formula, the emission value (56 µg.m^{-3}) over the city of Ouagadougou (Fig. 7) is higher than the recommended World Health Organization (WHO) annual exposure standard of 40 µg.m^{-3}.

Thus, within the four years (2019 to 2022), the average national NO_2 emission level (Fig. 7a), shows that the city of Ouagadougou is the main

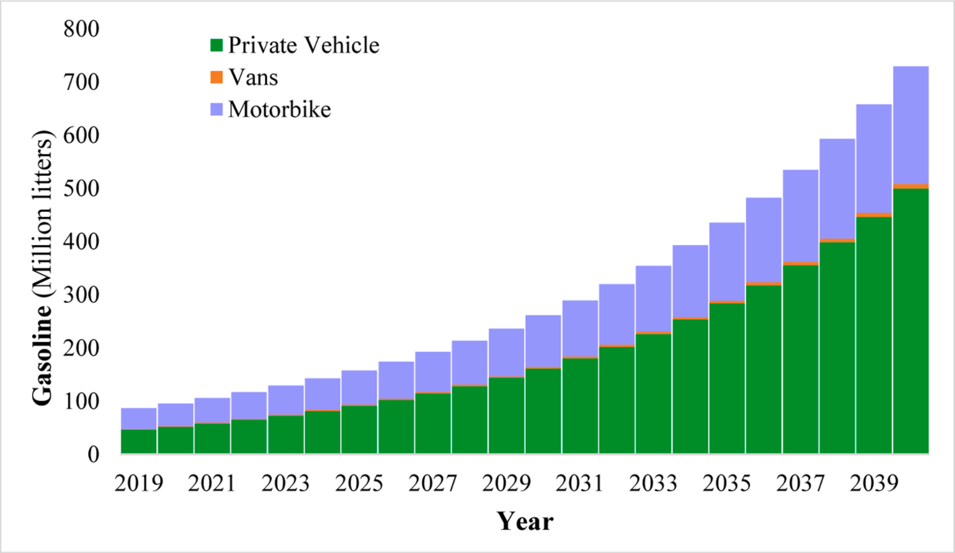

Fig. 4. Gasoline demand scenario from 2019 to 2040 by road transport and urban mobility.

Table 3
Emission factor per vehicle, type of gases, and fuel.

Vehicle's type	EF CO_2 (kg/liter)	EF CO (kg/liter)	EF NOx (kg/liter)	Fuel density (kg/liter)	Fuel type
Bus	3.7135	0.012	0.029	0.85	**Diesel**
Trailer	3.8441	0.021	0.05	0.85	
Vans	3.8172	0.08249	0.002	0.85	
Tractor/ Truck	3.8135	0.024	0.022	0.85	
Private Vehicle	3.623	0.0421	0.022	0.85	
Average	**3.7623**	**0.0363**	**0.025**	**0.85**	
Motorbike	3.25	0.00245	0.0028	0.75	**Gasoline**
Vans	3.27	0.029	0.0111	0.75	
Private Vehicle	3.3	0.021	0.0009	0.75	
Average	**3.27**	**0.0175**	**0.0049**	**0.75**	

center of atmospheric Air pollution. The average NO_2 emissions in 2019 and 2020 (Figs. 7b and 7c) have lower NO_2 concentrations than the average emissions in 2021 and, 2022 (Figs. 7d and 7e).

5. Discussion

5.1. *Do the results of gas (CO_2) emissions factors in road transport align with GHG inventory guidelines?*

The GHG inventory depends on principles of geographic area, time series, sectors, and gas categories (Eggleston et al., 2006; Paustian & Van Amstel, 2006). CO_2 emissions from road transport are attributed to where vehicle fuel consumption is recorded most. Therefore, the focus of this study was to establish gas (CO_2) emissions factors in road transport using a detailed technology-based method known as the bottom-up approach (tiers 2 and 3) by IPCC guidelines (Paustian & Van Amstel, 2006). The Tier 2 methods apply to country-specific emission factors that need to be developed, using country-specific information on process conditions, fuel qualities, and abatement technologies (Eggleston et al., 2006; Gitarskiy, 2019). The result of the emission factor revealed an average emission of 3.7623 kg/l for diesel vehicles and 3.27 kg/l for the gasoline vehicle. Thus, compared to the average emission factor calculated by the United States Environmental Agency (EPA) using IPCC guidelines to set the national emission standards (Eggleston et al., 2006; EPA, 2023; Federal Register, 2010), that recorded 8887 g of CO2/gallon of gasoline (≈ 2.221 kg/l) and, 10,180 g of CO2/gallon of diesel (≈ 2545 kg/l). Comparatively, the difference with this research findings can be

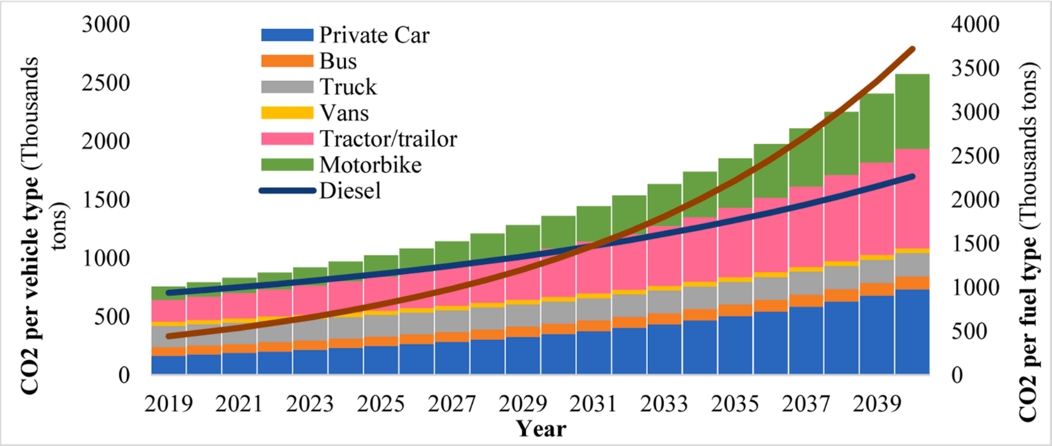

Fig. 5. CO_2 emission scenario by vehicle and fuel type from 2019 to 2040.

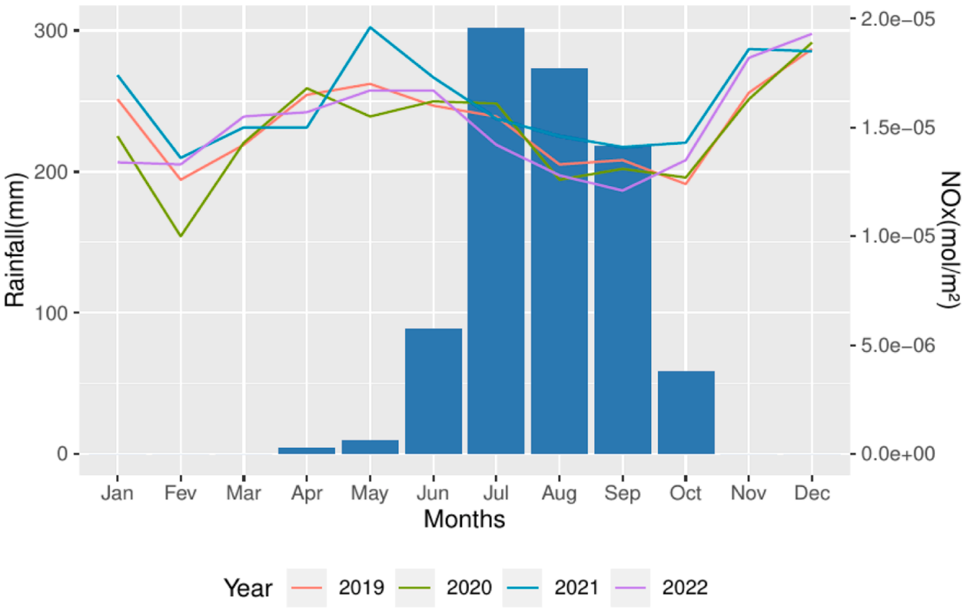

Fig. 6. Tropospheric nitrogen dioxide (NO2) concentration over a time in Ouagadougou.

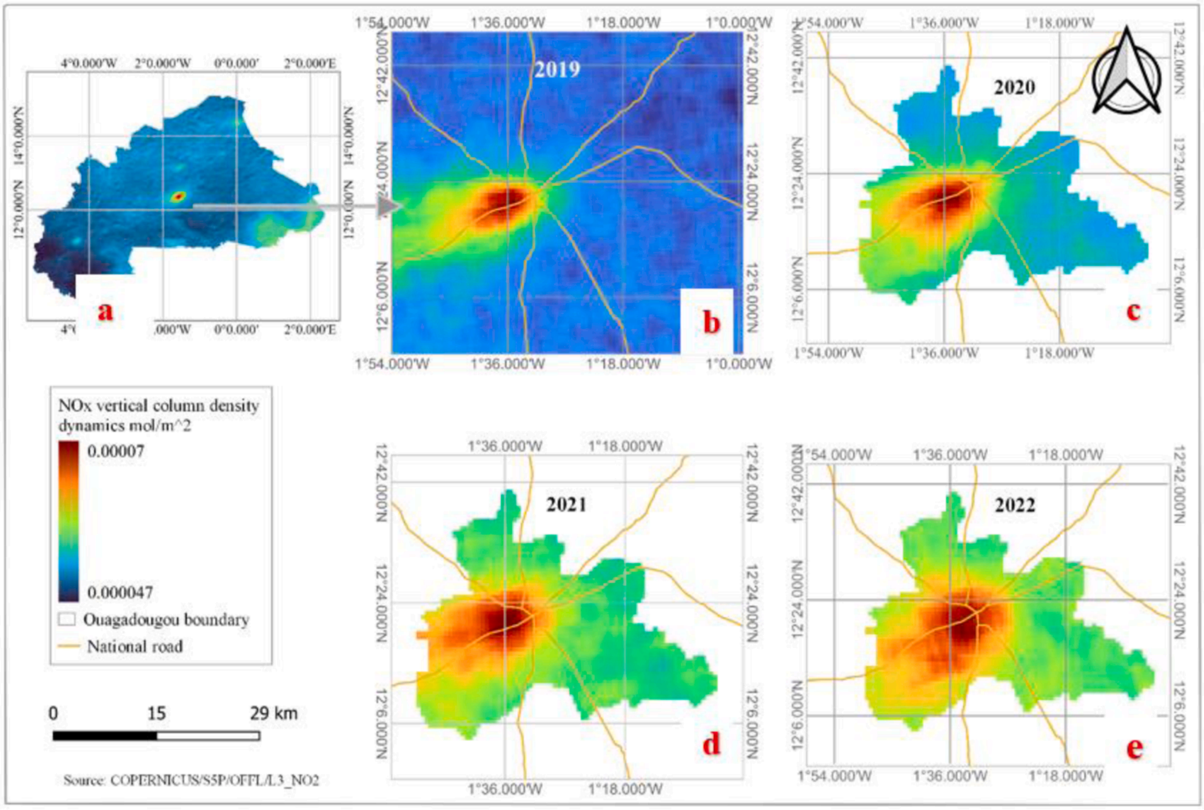

Fig. 7. Spatial and temporal dynamic of NOx emission over the city of Ouagadougou with OMI satellite data from 2019 to 2022.

explained by the age of the vehicle fleet. The average age of the vehicle fleet in Burkina Faso was 17 years old in 2020 according to the General Directorate of Studies and Sectoral Statistics (DGESS) of the Ministry of Transport, Urban Mobility and Road Safety (MTUMSR, 2019). About 19 % of the vehicle's fleet are between 15 and 20 years and 25 % are above 30 years (Figure S1). Therefore, the vehicle can become less fuel efficient and gas emissions with age, since modern cars are designed aerodynamically with engine specs to suit fuel efficiency. Furthermore, the fuel efficiency and gas emission economy vary with the intensity of daily vehicle use, cumulative mileage, the ambient temperature (Greene et al., 2017) including the way of the vehicle's maintenance. Thus, the computation of gas emissions is aligned with the IPCC GHG inventory guideline (Eggleston et al., 2006; Jim Penman et al., 2006) for the establishment of the specific emission factor, which is highly recommended by UNFCC in each country's national MRV tool to reflect the really of the country economy and the NDC reports (Singh et al., 2016;

UNFCC, 2014). In general, it revealed that emission factors from diesel engines are significantly higher than gasoline powered vehicles, which means that diesel vehicles have a lower CO2 emissions economy than their gasoline counterparts (Sullivan et al., 2004). Using the specific emission factor, the amount of 103 4513.84 tons of CO2 (1034.5 $GgCO_2$) was calculated in 2019, which revealed the significant contribution of road transport and urban mobility to gas emissions in Burkina Faso. The measurement uncertainties during the data recording were ±2 %, which were taken into account in data processing. Based on the approach of on-site measurements on urban air pollution, previous research revealed a high rate of city's air pollution, where vehicle traffic flows which therefore confirmed the high contribution of urban mobility to air pollution in the city of Ouagadougou (Nana et al., 2012; Yaguibou et al., 2018). Those studies were focused on urban air pollution and, did not include estimation of gas emission factors, but aligned with the findings on urban air pollutions.

5.2. Urban mobility and fossil fuel demand: does urbanization impact fuel consumption and air pollution?

The study revealed the high dependence of road transportation and urban mobility on fossil fuel consumption, about 89 % of the imported fuel sold in Burkina Faso in term of gasoline and diesel. The finding in fossil fuel consumption can be compared to the Burkina Faso 2015 National Determined Contribution (NDC) report, which highlighted that 74.00 to 83.00 % of hydrocarbon imports are consumed by the transport sector (Burkina Faso, 2022). The quality of the fuel, the power of the engine, and the quality of the traffic road are the main factors influencing CO_2 emission and air pollution in the country's major cities (Burkina Faso, 2022; Nana et al., 2012). Previous studies reported comparable results of high energy demand by the transport sector. In 2008, 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 & Sheinbaum-Pardo, 2014) demonstrated the high dependence of the transport sector on fuel consumption. Thus, the vehicle's fleet, the fleet growth rate, and the country's urban transport policy influence the amount of fuel consumed and, gases emissions. In addition to the aforementioned factors, urbanization, and its related features such as urban form of settlement and population density have been increasingly acknowledged as contributors to travel demand and transport energy consumption in recent years (Rodrigue et al., 2016). Thus, the future scenarios of the energy demand use the vehicle's fleet growth rate since this reflect the country's economic (GDP) and the population dynamics. The energy demands and consumption in road transport and urban mobility depends on the urban form and the city's growth (Kaza, 2020; Proost & Van Dender, 2012b)

Global energy consumption for transport reached 28 % of total end-use energy in 2010 (Heubaum & Biermann, 2015), of which around 40 % was used in urban transport. Rapid urbanization causes a huge demand for motorized vehicles and increases the motor vehicle fleet due to people's relocating and needs for personal transportation (Padam & Singh, 2011). For example, Burkina Faso is facing an ever-increasing fleet of motor vehicles in the cities, due to its rapidly urban growth resulting in the city expansion and sprawling. The two main cities of the country, Ouagadougou and Bobo Dioulasso represent almost 62 % of the national urban population(INSD, 2022; UN-HABITAT, 2019). This situation highly contributing the vehicle fleet growth leading to traffic congestion and air pollution in urban area. The intensification of fossil fuel demand and consumption is due to rapid urbanization and the growth of the country's GDP (Bakirtas & Akpolat, 2018; Kaza, 2020). Higher per capita income is typically associated with an increased demand for passenger transport, and urban regions are expected to account for 81 % of global GDP, up from 60 % in 2015 by 2050 (Girod et al., 2013). In Oman City, about 76 % of registered vehicles as of 2014 were private cars with approximately one private car per household (Amoatey & Sulaiman, 2017). The growth of automobile production (4.3 %) is faster than the growth of the human population (2 % per annum) (Amoatey & Sulaiman, 2017) during 2000 and 2009. This confirms the influences of urban development on vehicle's fleet growth. Due to the extremely limited public transportation system, traffic congestion and emissions from vehicles are high during working days because most individuals use private vehicles as the only means of transportation. Comparably, in Ouagadougou city, 84 % of shared mobility in 2019 is composed of private vehicles which are dominated by motorbikes, and private cars, and are projected to dominate with 93 % by 2040 in a business-as-usual scenario. This is the reason for the huge consumption of fossil fuels and consequently contributes to atmospheric pollution and climate change impact enforcement. Furthermore, traffic congestion has economic, social, and health impacts in urban areas (Chavez-Baeza & Sheinbaum-Pardo, 2014; Leila & Noureddine, 2014). The situation is expected to worsen in the coming years due to the rapid growth of the urban population in Burkina Faso.

The major source of cities' air pollution is urbanization due to rapidly growth population, and industries development (Duan et al., 2024). The air pollution related to nitrogen and nitrogen oxide found as a compound in fossil fuel are the result of fossil fuels combustion process in the urban mobility(Kaza, 2020; Mesjasz-Lech, 2016). The Satellite-based estimation of surface NO_2 concentrations over east-central China with a comparison of POMINO and OMNO2d data has shown that cities of this region are polluted from satellite, and ground measurements respectively (He et al., 2016; Qin et al., 2020). Despite the absence of ground-level measurement in Ouagadougou city, the satellite assessment confirmed the NO_2 concentration over the Central Business Division (CBD) with an average emission of 1.89 mol/m^2. It corresponds to 56 $\mu g.m^{-3}$ which is beyond the World Health Organization's annual standard of exposure or exhibition (10 μg.m-3) (WHO, 2021). The same findings have been highlighted by a study carried out in Ouagadougou city in 2009 with an average emission of 52.2 μg.m-3 of NO_2 (Nana et al., 2012). Since the pollution of NO_2 in the city is due to road traffic or fuel fossil fuel consumption, it is therefore urgent to develop sustainable urban mobility to reduce the risk of exposure to air pollution and urban climate mitigation.

5.3. Emission factor and GHG assessment implication for effective sustainable road transport and urban mobility in Burkina FASO

Using emissions factors to assess GHG in road transportation sector provides a specific characteristics and comprehension of urbanization and the urban transport systems. Since the GHG assessment relies on vehicle's activity data including fuel consumption, and travel distance, the emission factor allows estimate it with application to different spatial and temporal scale of the city (Sánchez-Balseca et al., 2023). This makes emission factor a flexible method that facilitates road transportation and urban mobility environmental impact studies in detail and at larger scale. Highly recommended by UNFCC for each country's national MRV tool improvement, emission factor is suitable for environmental regulation framework and provide policymakers an historical data to guide policies in road transportation sector like targets in emissions reduction, and urban planning and cities transportation infrastructure development. Thus, developing a sustainable road transport, strategies to lower GHG emissions is required to make cities environmentally friendly and livable that balance economy growth and quality of life. In light of this study outcomes, it is crucial for road transportation and urban mobility planners to adopt strategies implementation of sustainable mobility. We suggest implementing sustainable urban mobility inspired by Mexico City, sustainable passenger road transport scenarios that have been implemented to reduce air pollutant emissions such as (CO, NOx, NMVOC (non-methane volatile organic compounds), and PM_{10}) and GHGs while promoting better mobility and quality of life (Chavez-Baeza & Sheinbaum-Pardo, 2014). The mitigation scenario should consider increasing fuel efficiencies and introducing innovative technologies for car emission controls and the development of "BRT" to facilitate a modal shift from private car trips to a Bus Rapid Transport system as implemented in developed countries. Recognizing this positive impact of urban mobility GHG reduction, Burkina Faso has to take an urgent action for sustainable urbanization and mobility development that balance economic growth with quality of life in cites. These environmentally friendly action through the promotion of sustainable urban transport and mobility, could contribute achieving SDG 11, which in synergy with other SDG, could contribute to the achievement of many SDGs in urban area for climate resilience in Burkina Faso (Kiribou et al., 2024). Moreover, this road transportation and urban mobility specific emission factor gives a great opportunity for policymakers to implement new policies including technological advancements such as the adoption of electric vehicles, improvement of public transportation, or the limitation of the ages of imported vehicles. It is also important to encourage the scrapping of old vehicles in order to renew the fleet. This can be done by establishing an allowance for the scrapping of old vehicles to encourage the renewal of the fleet and setting the new vehicle lifecycle (duration) at the moment of releasing on circulation. These integrated actions could make successful the implementation of the National Strategy for Urban Mobility for 2022–2026, which consist of reducing the environmental and carbon footprint of urban mobility.

Beside the importance of this study for sustainable mobility implementation in Burkina Faso, one of the limits is inherent ot uncertainties in satellite data of NOx vehicular assessment. The NO_2 estimate is based on satellite data which has radiance measured in the 400–450 nm visible wavelength region and used to create a total slant column between detector (700 nm) and ground. It then separates the stratospheric component from the tropospheric component using a model or clean tropical measurement (Qin et al., 2020). The use of information from radiance transfer models and chemical transport models to calculate an air mass factor to convert a slant tropospheric column to a vertical column can be a big source of uncertainty (Yin et al., 2021). Operational tropospheric vertical column measurements have a low bias in urban and highly polluted regions due to an air mass factor bias. This can be solved using a hybrid approach of regional or global models and vertical observational when available (Meng et al., 2010; Yin et al., 2022). It has been shown in Pandora and OMI, NO_2 with regional AMF, but it needs more observations of free tropospheric NO_2 concentrations over land and time (Yin et al., 2021). Then, the data retrieval in a wet season over the Ouagadougou city, where we noticed lower levels of NO_2 observed, can be due to the cloud effect (Qin et al., 2020), even though 10 % of free cloud algorithm is applied to remove clouds effects. Despite this limit, satellite assessment-based estimation has highlighted NO_2 emission over cities at the global level (Amritha et al., 2024; Dong et al., 2023).

6. Conclusion

This study has highlighted the necessity of a new urban mobility policy to reach sustainable urban transport in the cities of Burkina Faso. Given the immensity of the motorized vehicle fleet dominated by individual modes of mobility (84 %) in 2019, road transport and urban mobility contribute significantly to air pollution and GHG emissions. This implies that the road transport and urban mobility legislation have not seriously taken enough account of the environmental regulation and protection in Burkina Faso. In general, the emission factors from diesel engines are significantly higher than a gasoline engine, which means diesel vehicles have a lower CO_2 emissions economy than their gasoline counterparts. This has resulted in a total of 103 4513.84 tons of CO_2 (1034.5 $GgCO_2$) emitted in 2019 with a high contribution from diesel vehicles. In the business-as-usual condition, the amount of 4 486 559.34 tons (4486.64 GgCO2) of CO2 will be emitted by 2040.

In light of all these findings including the satellite NO_2 pollution, a regular study on urban environmental pollution in the transport sector would update activity data and the emission factor. Thus, the establishment of this specific emission factor can improve the country's nationally determined contribution (NDC) report to UNFCC and could facilitate the investigation of improving urban planning with sustainable mobility and transportation implementation in African countries. It will therefore be necessary to conduct the cost projection study to mitigate the road transportation sector in this context of urban climate change resilience. This study can form the basis for the development of policies geared towards reducing and capping GHG emissions associated with road transportation and urban mobility. It also justifies the need for policy to regulate the age of imported vehicles and active development of public transport systems. This could lead to the development of sustainable transport by satisfying people's needs while taking care of the urban environment and urban climate adaptation.

Abbreviations

AMF: Air mass factor
DGTTM: General Directorate of Land and Maritime Transportation;
GHG: Greenhouse Gas
IPCC: Intergovernmental Panel on Climate Change
LEAP: Long-Range Energy Alternatives Planning
OMI: Ozone Monitoring Instrument
UNFCC: United Nations Framework Convention on Climate Change
CCVA: Motor Vehicle Control Center;
SDAGO: Greater Ouaga Development Master Plan
WASCAL: West African Science Service Center on Climate Change and Adapted Land Use
ADB: African Development Bank
US-EPA: United States Environmental Agency
Google Earth Engine data extraction source code link: https://code.earthengine.google.com/660c7e9b94acd5956138a4012d94f2a7

CRediT authorship contribution statement

Issaka Abdou Razakou Kiribou: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tiga Neya:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology. **Bernard Nana:** Writing – review & editing, Writing – original draft, Validation, Methodology. **Kehinde Ogunjobi:** Writing – review & editing, Validation, Supervision, Resources, Methodology. **Tizane Daho:** Writing – review & editing, Supervision, Resources, Methodology. **Y. Woro Gounkaou:** Writing – review & editing, Validation, Resources, Methodology, Data curation. **Faith Mawia Muema:** Writing – review & editing, Writing – original draft, Validation. **Dejene W. Sintayehu:** Writing – review & editing, Validation.

Declaration of competing interest

This work does not have any competing interest to declare. No conflict of interest

Acknowledgment

This study was supported by the West African Science Service Centre on Climate Change and Adapted Land Use **(WASCAL)** research grants for the MSc program through the German Ministry of Education (BMBF) collaboration. Therefore, we are incredibly grateful to this institution and BMBF. Thanks also go to the Laboratory of Environmental Physics and Chemistry for the collection of the emission data, and the Ministry of Transportation, Urban Mobility, and Road Safety of Burkina Faso for collaboration and data acquisition.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.urbmob.2025.100106.

References

Abdul, S., Bukhari, R., & Ali, M. (2021). *Sample size determination using Krejcie and Morgan table*. https://doi.org/10.13140/RG.2.2.11445.19687.

Albuquerque, F. D. B., Maraqa, M. A., Chowdhury, R., Mauga, T., & Alzard, M. (2020). Greenhouse gas emissions associated with road transport projects: Current status, benchmarking, and assessment tools. *Transportation Research Procedia, 48*, 2018–2030. https://doi.org/10.1016/J.TRPRO.2020.08.261

Amoatey, P., & Sulaiman, H. (2017). Options for greenhouse gas mitigation strategies for road transportation in Oman. *American Journal of Climate Change, 06*(02), 217–229. https://doi.org/10.4236/ajcc.2017.62011

Amritha, S., Varikoden, H., Patel, V. K., Kuttippurath, J., & Gopikrishnan, G. S. (2024). Global, regional and city scale changes in atmospheric NO_2 with environmental laws and policies. *Sustainable Cities and Society, 112*, Article 105617. https://doi.org/10.1016/J.SCS.2024.105617

Anenberg, S. C., Mohegh, A., Goldberg, D. L., Kerr, G. H., Brauer, M., Burkart, K., et al. (2022). Long-term trends in urban NO2 concentrations and associated paediatric asthma incidence: Estimates from global datasets. *The Lancet Planetary Health, 6*(1), e49–e58. https://doi.org/10.1016/S2542-5196(21)00255-2

Arioli, M., Fulton, L., & Lah, O. (2020). Transportation strategies for a 1.5°C world: A comparison of four countries. *Transportation Research Part D: Transport and Environment, 87*, Article 102526. https://doi.org/10.1016/J.TRD.2020.102526

Bakirtas, T., & Akpolat, A. G. (2018). The relationship between energy consumption, urbanization, and economic growth in new emerging-market countries. *Energy, 147*, 110–121. https://doi.org/10.1016/J.ENERGY.2018.01.011

Bamas, S. M. M. (2003). Les transports urbains à Ouagadougou : Diagnostic et perspectives. *Pays Enclavés, 11*(1), 59–90. https://www.persee.fr/doc/payen_0989-6007_2003_ant_11_1_935.

Barker, T., Bashmakov, I., Bernstein, L., Bogner, J.E., Bosch, P.R., Dave, R. et al. (2007). *Technical summary, contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change*. https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg3-ts-1.pdf.

Bucsela, E. J., Krotkov, N. A., Celarier, E. A., Lamsal, L. N., Swartz, W. H., Bhartia, P. K., et al. (2013). A new stratospheric and tropospheric NO2 retrieval algorithm for nadir-viewing satellite instruments: Applications to OMI. *Atmospheric Measurement Techniques, 6*(10), 2607–2626. https://doi.org/10.5194/AMT-6-2607-2013

Faso, Burkina (2022). *Burkina FASO first NDC (Updated submission) | UNFCCC*. UNFCC. https://unfccc.int/documents/497293.

Cascetta, E., & Henke, I. (2023). The seventh transport revolution and the new challenges for sustainable mobility. *Journal of Urban Mobility, 4*, Article 100059. https://doi.org/10.1016/J.URBMOB.2023.100059

Chavez-Baeza, C., & Sheinbaum-Pardo, C. (2014). Sustainable passenger road transport scenarios to reduce fuel consumption, air pollutants and GHG (greenhouse gas) emissions in the Mexico City Metropolitan Area. *Energy, 66*, 624–634. https://doi.org/10.1016/j.energy.2013.12.047

Cheng, S., Cheng, X., Ma, J., Xu, X., Zhang, W., Lv, J., et al. (2023). Mobile MAX-DOAS observations of tropospheric NO2 and HCHO during summer over the Three Rivers' Source region in China. *Atmospheric Chemistry and Physics, 23*(6), 3655–3677. https://doi.org/10.5194/ACP-23-3655-2023

DCycle. (2024). What are the emission factors in the carbon footprint. *DCycle*. https://www.dcycle.io/post/learn-about-the-benefits-and-updates-of-emission-factors-and-their-customization.

Dodman, D. (2009). Blaming cities for climate change? An analysis of urban greenhouse gas emissions inventories. *Environment and Urbanization*, 21(1), 185–201. https://doi.org/10.1177/0956247809103016.

Dong, J., Cai, X., Tian, L., Chen, F., Xu, Q., Li, T., et al. (2023). Satellite-based estimates of daily NO2 exposure in urban agglomerations of China and application to spatio-temporal characteristics of hotspots. *Atmospheric Environment, 293*, Article 119453. https://doi.org/10.1016/J.ATMOSENV.2022.119453

Duan, X., Gu, H., Lam, S. S., Sonne, C., Lu, W., Li, H., et al. (2024). Recent progress on phytoremediation of urban air pollution. *Chemosphere, 349*. https://doi.org/10.1016/j.chemosphere.2023.140821

Dubresson, A., & Jaglin, S. (2010). Cities in french-speaking black africa. The era of uncertainty. *Bulletin d'Association de Geographes Francais, 87*(1), 15–25. https://doi.org/10.3406/bagf.2010.8178

EEA. (2023). *EMEP/EEA air pollutant emission inventory guidebook 2023* (6th ed.). Office of the European Union. https://doi.org/10.2800/795737

Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (2006). 2006 IPCC Guidelines for National greenhouse gas inventories. *Genebra, Suíça*, 66(4), 44. https://doi.org/10.1209/epl/i2005-10515-2.

EPA. (2023). *Greenhouse gases equivalencies calculator - Calculations and references | us epa*. United Nations Environmental Agency. https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references.

European Union. (2019). *Regulation (EU) 2019/631 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles - Climate Change laws of the world*. Climate Change Laws of The World. https://climate-laws.org/document/regulation-eu-2019-631-setting-co2-emission-performance-standards-for-new-passenger-cars-and-for-new-light-commercial-vehicles_a8fb.

Federal Register. (2010). *Rules and regulations: Vol. 75, no. 88 (FeEnvironmental protection agency (EPA) and national highway traffic safety administration (NHTSA), ed.; vol. 75, no. 88)*. USA Environmental Protection Agency, EPA. http://epa.gov/climatechange/emissions/.

Freire, M. E., Lall, S., & Leipziger, D. (2014). Africa's urbanization: Challenges and opportunities. *The growth dialogue*, 7; Working Paper N°7 www.growthdialogue.org.

Fu, T., Chang, D., & Miao, C. (2022). Fuel regulation in a developing country: An interventional perspective. *Energy Economics, 113*, Article 106031. https://doi.org/10.1016/J.ENECO.2022.106031

Ghorbani, Y., Zhang, S. E., Nwaila, G. T., Bourdeau, J. E., & Rose, D. H. (2024). Embracing a diverse approach to a globally inclusive green energy transition: Moving beyond decarbonisation and recognising realistic carbon reduction strategies. *Journal of Cleaner Production, 434*, Article 140414. https://doi.org/10.1016/J.JCLEPRO.2023.140414

Girod, B., Van Vuuren, D. P., & Hertwich, E. G. (2013). Erratum: Global climate targets and future consumption level: An evaluation of the required GHG intensity (Environmental Research Letters (2013) 8 (014016)). *Environmental Research Letters, 8*(1). https://doi.org/10.1088/1748-9326/8/1/014016

Gitarskiy, M. L. (2019). the refinement to the 2006 Ipcc guidelines for national greenhouse gas inventories. *Fundamental and Applied Climatology, 2*, 5–13. https://doi.org/10.21513/0207-2564-2019-2-05-13

Giuliano, G., Chakrabarti, S., & Rhoads, M. (2015). Transportation geography. *International encyclopedia of the social & behavioral sciences: Second edition* (pp. 607–615). https://doi.org/10.1016/B978-0-08-097086-8.72071-X

Greene, D. L., Liu, J., Khattak, A. J., Wali, B., Hopson, J. L., & Goeltz, R. (2017). How does on-road fuel economy vary with vehicle cumulative mileage and daily use? *Transportation Research Part D: Transport and Environment, 55*, 142–161. https://doi.org/10.1016/J.TRD.2017.06.004

He, C., Zhang, D., Huang, Q., & Zhao, Y. (2016). Assessing the potential impacts of urban expansion on regional carbon storage by linking the LUSD-urban and InVEST models. *Environmental Modelling & Software, 75*, 44–58. https://doi.org/10.1016/J.ENVSOFT.2015.09.015

Heubaum, H., & Biermann, F. (2015). Integrating global energy and climate governance: The changing role of the International Energy Agency. *Energy Policy, 87*, 229–239. https://doi.org/10.1016/j.enpol.2015.09.009

Huang, Y., Bor, Y. J., & Peng, C. Y. (2011). The long-term forecast of Taiwan's energy supply and demand: LEAP model application. *Energy Policy, 39*(11), 6790–6803. https://doi.org/10.1016/J.ENPOL.2010.10.023

Indian GHG Program. (2015). *India specific road transport emission factors*. https://shaktifoundation.in/wp-content/uploads/2017/06/WRI-2015-India-Specific-Road-Transport-Emission-Factors.pdf.

INSD. (2019). *Cinquième Recensement Général de la Population et de l'Habitation du Burkina Faso*. http://www.insd.bf/contenu/documents_rgph5/Rapport%20resultats%20definitifs%20RGPH%202019.pdf.

INSD. (2022). *Tableau de bord démographique*. https://www.insd.bf/sites/default/files/2024-02/TBD%202022_VF_2023.pdf.

International Transport Forum. (2018). *Corporate partnership board CPB transport CO 2 and the Paris climate agreement decarbonising transport series*. www.itf-oecd.org.

IPCC. (2023a). Climate resilient development pathways. *Climate Change 2022 – Impacts, Adaptation and Vulnerability* (pp. 2655–2808). https://doi.org/10.1017/9781009325844.027

IPCC. (2023b). Transport. *Climate Change 2022 - Mitigation of Climate Change*, 1049–1160. https://doi.org/10.1017/9781009157926.012

Penman, Jim, Gytarsky, Michael, Hiraishi, Taka, Irving, William, & Krug, Thelma (2006). 2006 IPCC guidelines for national greenhouse gas inventories. *Energy, 2*. https://www.ipcc-nggip.iges.or.jp/public/2006gl/.

Kaza, N. (2020). Urban form and transportation energy consumption. *Energy Policy, 136*, Article 111049. https://doi.org/10.1016/J.ENPOL.2019.111049

Keita, S., Liousse, C., Assamoi, E. M., Doumbia, T., N'Datchoh, E. T., Gnamien, S., et al. (2021). African anthropogenic emissions inventory for gases and particles from 1990 to 2015. *Earth System Science Data, 13*(7), 3691–3705. https://doi.org/10.5194/essd-13-3691-2021

Kenworthy-Groen, S. (2012). *A review of traffic growth rate calculations*. http://arrbknowledge.com.

Kiribou, R., Djene, S., Bedadi, Bobe, Ntirenganya, Elie, Ndemere, J., & Dimobe Kangbéni. (2024). Urban climate resilience in Africa: A review of nature-based solution in African cities' adaptation plans. *Discover Sustainability, 5*(1), 1–15. https://doi.org/10.1007/S43621-024-00275-6. *2024 5:1*.

Kirk, M. (1988). The Global Report on Human Settlements. *Population Studies, 42*(3), 519–520. https://doi.org/10.1080/0032472031000143786

Leila, A., & Noureddine, B. (2014). Assessment of the contribution of road traffic to greenhouse emissions: A case of an Algerian City. *Journal of Environmental Protection, 05*(13), 1364–1372. https://doi.org/10.4236/jep.2014.513130

Ma, Y., Zhu, J., Gu, G., & Chen, K. (2020). Freight transportation and economic growth for zones: Sustainability and development strategy in China. *Sustainability, 12*(24), 10450. https://doi.org/10.3390/SU122410450. *2020, Vol. 12, Page 10450*.

Masui, T., Mathur, R., Portugal Pereira, J., Kenneth, B., Virginia Vilariño, M., Zhou, N., et al. (2021). Chapter 4: Mitigation and development pathways in the near-to mid-term 2 3. Marzio Domenico Galeotti. *IPCC AR6 wgiii* (pp. 4–18). IPCC https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SOD_Chapter04.pdf.

Meng, Z.-Y., Xu, X.-B., Wang, T., Zhang, X.-Y., Yu, X.-L., Wang, S.-F., et al. (2010). Ambient sulfur dioxide, nitrogen dioxide, and ammonia at ten background and rural sites in China during 2007–2008. *Atmospheric Environment, 44*(21–22), 2625–2631. https://doi.org/10.1016/j.atmosenv.2010.04.008

Mesjasz-Lech, A. (2016). Urban air pollution challenge for green logistics. *Transportation Research Procedia*, 16, 355–365. https://doi.org/10.1016/J.TRPRO.2016.11.034.

MTUMSR. (2019). *Ministère des transports, de LA mobilité urbaine et de LA Sécurité Routière*. 8–22. http://cns.bf/IMG/pdf/annuaire_statistique_2019_du_secteur_des_transports.pdf.

Mukherjee, R., Rollend, D., Christie, G., Hadzic, A., Matson, S., Saksena, A., et al. (2021). Towards indirect top-down road transport emissions estimation. In *IEEE Computer Society Conference on Computer Vision and Pattern Recognition Workshops* (pp. 1092–1101). https://doi.org/10.1109/CVPRW53098.2021.00120

Nana, B., Sanogob, O., Savadogoa, P., Dahoa, T., Boudad, M., & Koulidiatia, J. (2012). Air quality study in urban centers: Case study of Ouagadougou, Burkina Faso. *FUTY Journal of the Environment, 7*(1). https://doi.org/10.4314/fje.v7i1.1

NASA. (2018). *Sentinel-5P TROPOMI Tropospheric Formaldehyde HCHO 1-orbit L2 5.5km x 3.5km (S5P_L2_HCHO__HiR 2)*. https://disc.gsfc.nasa.gov/datasets/S5P_L2__HCHO__HiR_2/summary.

Padam, S., & Singh, S.K. (2011). Urbanization and urban transport in India: The search for a policy. *SSRN Electronic Journal*. https://doi.org/10.2139/SSRN.573181.

Paustian, K., & Van Amstel, A. (2006). *2006 IPCC Guidelines for National greenhouse gas inventories*. https://www.researchgate.net/publication/40104270.

Perliski, L. M., & Solomon, S. (1993). On the evaluation of air mass factors for atmospheric near-ultraviolet and visible absorption spectroscopy. *Journal of Geophysical Research: Atmospheres, 98*(D6), 10363–10374. https://doi.org/10.1029/93JD00465

Proost, S., & Van Dender, K. (2012a). Energy and environment challenges in the transport sector. *Economics of Transportation, 1*(1–2), 77–87. https://doi.org/10.1016/J.ECOTRA.2012.11.001

Proost, S., & Van Dender, K. (2012b). Energy and environment challenges in the transport sector. *Economics of Transportation, 1*(1–2), 77–87. https://doi.org/10.1016/J.ECOTRA.2012.11.001

Qin, K., Han, X., Li, D., Xu, J., Li, D., Loyola, D., et al. (2020). Satellite-based estimation of surface NO2 concentrations over east-central China: A comparison of POMINO and OMNO2d data. *Atmospheric Environment, 224*. https://doi.org/10.1016/j.atmosenv.2020.117322

Rodrigue, J. P. (2024). The geography of transport systems. *The geography of transport systems* (pp. 1–402). https://doi.org/10.4324/9781003343196

Rodrigue, J. P., Comtois, C., & Slack, B. (2016). The geography of transport systems. *The geography of transport systems*. Taylor and Francis. https://doi.org/10.4324/9781315618159

Rotman, D.A., Tannahill, J.R., Kinnison, D.E., Connell, P.S., Bergmann, D., Proctor, D. et al. (2001). Global Modeling Initiative assessment model: Model description, integration, and testing of the transport shell. *Journal of Geophysical Research: Atmospheres*, 106(D2), 1669–1691. https://doi.org/10.1029/2000JD900463.

Sánchez-Balseca, J., Luis Pineiros, J., & Pérez-Foguet, A. (2023). Influence of travel time on carbon dioxide emissions from urban traffic. *Transportation Research Part D: Transport and Environment, 118*. https://doi.org/10.1016/j.trd.2023.103698

Sims R., R. Schaeffer, F. Creutzig, X. Cruz-Núñez, M. D'Agosto, D. Dimitriu et al.. (2014). *Transport. In: Climate change 2014:Mitigation of climate change. Contribution of working group III to the fifth assessment report of the intergovern-mental panel on climate change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C.Minx (eds*. Mitigation of Climate Change. https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter8.pdf.

Singh, N., Finnegan, J., & Levin, K. (2016). MRV 101: Understanding measurement, reporting, and verification of climate change mitigation. *Understanding measurement* (p. 101). http://www.wri.org/mrv101.www.wri.org/mrv101.

Smart Freight Centre. (2021). *GHG emission factors for road freight vehicles*. www.smartfreightcentre.org.

Steinberger, J., Gasson, B., Hansen, Y., Hillman, T., & Mendez, G.V. (2009). *Greenhouse gas emissions from global cities*. 7297–7302. https://doi.org/10.1021/es900213p.

Sullivan, J. L., Baker, R. E., Boyer, B. A., Hammerle, R. H., Kenney, T. E., Muniz, L., et al. (2004). Co2 emission benefit of diesel (versus Gasoline) powered vehicles. *Environmental Science and Technology, 38*(12), 3217–3223. https://doi.org/10.1021/es034928d

Testo North America. (2019). *testo-350-brochure-US*. https://static-int.testo.com/media/57/39/04d41889ede6/testo-350-brochure-US.pdf.

Uakarn, chanuan, Chaokromthong, K., & Sintao, N (2021). Sample size estimation using Yamane and Cochran and Krejcie and Morgan and Green formulas and Cohen statistical power analysis by G*Power and Comparisions. *APHEIT International Journal of Interdisciplinary Social Sciences and Technology, 10*(2), 76–86. https://so04.tci-thaijo.org/index.php/ATI/article/view/254253.

UNFCC. (2014). *Handbook on MEASUREMENT, reporting and verification for developing country parties*. United Nations Framework Convention on Climate Change. http://unfccc.int/2716.php.

UN-HABITAT. (2019). *Urbanization in Burkina FASO: Building inclusive & sustainable cities*. UN Habitat. https://unhabitat.org/burkina-faso.

UNPA. (2014). *Annual report 2014 | United Nations population fund*. World Population Annual Reports. https://www.unfpa.org/annual-report-2014.

U.S. Energy Information Administration | International Energy Outlook 2016. (2016). *Transportation sector energy consumption figure 8-1. Delivered transportation energy consumption by country grouping,* 2012–40 *(quadrillion Btu)*.

U.S. EPA. (2021). *Emission factor for greenhouse gas inventory*. September 15. US Environmental Protection Agency https://www.epa.gov/sites/default/files/2021-04/documents/emission-factors_apr2021.pdf.

Wang, K., & Zhang, Y. (2012). Application, evaluation, and process analysis of the US EPA's 2002 multiple-pollutant air quality modeling platform. *Atmospheric and Climate Sciences, 02*(03), 254–289. https://doi.org/10.4236/ACS.2012.23025

WHO. (2021). *WHO global air quality guidelines: Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide (World health organization* (2021st ed.). World Health Organization https://www.who.int/publications/i/item/9789240034228.

Yaguibou, W. C., Kohio, N., Kagoné, A. K., Koalaga, Z., & Zougmoré, F. (2018). Influence des aérosols sur la composition à l'équilibre d'un plasma d'air. *Journal International de Technologie, de l'Innovation, de La Physique, de l'Energie et de l'Environnement, 4*(1). https://doi.org/10.18145/JITIPEE.V4I1.167

Yin, H., Sun, Y., Notholt, J., Palm, M., & Liu, C. (2021). *Space borne tropospheric nitrogen dioxide (NO2) observations from 2005 to 2020 over the Yangtze River Delta (YRD), China: 2 variabilities, implications, and drivers*. https://doi.org/10.5194/acp-2021-1089.

Yin, H., Sun, Y., Notholt, J., Palm, M., & Liu, C. (2022). Spaceborne tropospheric nitrogen dioxide (NO&lt;sub&gt;2&lt;/sub&gt;) observations from 2005 to 2020 over the Yangtze River Delta (YRD), China: Variabilities, implications, and drivers. *Atmospheric Chemistry and Physics, 22*(6), 4167–4185. https://doi.org/10.5194/acp-22-4167-2022

Zeng, J., Liu, Y., Ding, J., Yuan, J., & Li, Y. (2024). *Estimating on-road transportation carbon emissions from open data of road network and origin-destination flow data*. https://arxiv.org/abs/2402.05153v1.