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Quantifying the CO_2 Emissions of Motor Vehicles and the Urban Tree Carbon Sequestration Potential in the Lusaka Central Business District, Zambia

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Abstract

This research was conducted in the Central Business District (CBD) of Lusaka, the total area of the CBD is 2.7 km². The aim of this study was to quantify the CO2 emissions of motor vehicles contributing to the negative impacts of climate change and urban tree CO_2 sequestration potential in the Lusaka CBD. Specific objectives of this study were to: Assess the amount of carbon emitted by the daily motor vehicle fleet in the CBD of Lusaka; assess the amount of green spaces required to offset the current motor vehicle CO_2 related emissions in the CBD of Lusaka. The research design for this study was a field survey. The daily urban fleet in the CBD of Lusaka was physically counted from the four main entry points during pick hours. On the other hand, the research took into consideration the fact that the CBD has a few trees in selected places, therefore all trees with a diameter greater than 5cm were considered for carbon capture. The data for both categories was subjected to mathematical models to estimate the CO_2 emissions as well as amount sequestered. The data collected indicate that there were 17 plant species and 424 individual trees in the CBD of Lusaka. Among tree species, *Trichilia emetic* had the highest number of plants up to 174 followed by *Delonix regia* having 70 plants. The most dominant species of plant in the central business district of Lusaka are *Trichilia emetic* and *Delonix regia* as a result of planting activities promoted by the government in the previous years. Despite the earlier mentioned species having high numbers of individual plants, *Afzelia quanzensis* recorded the highest carbon sequestration of up to 2.868 tons. Total Carbon sequestered by plants in the CBD of Lusaka is 15.729 tons. The projected amount of carbon that will be sequestered the following year is 17.353 tons. This indicated that the amount sequestered by plants every year is 1.757 tons. The results obtained from Lusaka CBD also indicated that the daily motor vehicle fleet consumed approximately 3174.212 litres of fuel which release about 19.656 tons of CO_2.

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1. Introduction

Green-house gas emissions (GHG) in particular carbon dioxide (CO_2) were the main focus of this study, because it makes up quite a large proportion of the transport sector's emissions. Globally, the transport sector contributes 23% of CO_2 as a result of fuel combustion, and road traffic is responsible of close to 75% of all emissions in this sector (Grote *et al*, 2016). In the United Kingdom (UK), the transport sector contributes 99% of all green-house gas related emissions (Grote *et al*, 2016). The contributing factors to the increase in GHG emissions in urban areas are many. Most of all the increase in population, more than half of the world's population currently resides in urban areas. The transport systems are now overburdened by the high demand for movement during peak hours. Projections indicate that towns and cities will consist of 80% of urban inhabitants by 2030 (Grote *et al*, 2016). Congestion is one of the end results making the situation worse (Grote *et al*, 2016). Motor vehicle pollution and GHG emissions are quite pronounced in developing countries, this is because the technology levels for vehicles are typically lower, and there is also a time difference between when new technologies first appear in already developed countries and the time when they reach developing countries that often import second hand vehicles (Sims, 2014). Current line of approach is considering green spaces to mitigate the negative effects resulting from these GHG emissions. Several assessments have been undertaken regarding the benefits that come with vegetation. Provisioning (food and water production); Regulation (absorbing and storing of carbon or the mitigation of climate change); Supporting services (cycling of nutrients) and cultural services (the beauty of nature, spiritual use) (Sun, 2018; Pansit, 2019). Despite this widely recognised role played by vegetation in urban areas in the direct provision of ecosystem services, this role is often ignored/overlooked and very few studies have been carried out. Without doubt, trees themselves have been considered to be very important because of their promising ability to provide ecosystem services to urban communities (Sun, 2018). A strong link exists between urbanisation and global climate change. The losses of habitat, the loss of biodiversity, climate change, pollution, land use change are all environmental challenges resulting from urbanisation. This occurs through unsustainable consumption of resources, generation of waste to a level that the environment can't afford to absorb as well as enhanced green-house gas emissions (Nero, 2017). Therefore, urban areas are considered strongly affect the ecological processes and the biogeochemical cycles as well as change regional and global climate. Ecosystems and biodiversity are affected by urban development and climate change but at the same time, urban areas can play an important role in reducing the adverse effects of climate change and biodiversity loss (Nero, 2017). In urban areas sometimes, trees are considered as not growing in the right place and not much value is placed on them this is because their ecosystem services can't be quantified and understood. They are easily brought down in order to put up development structures such as buildings, highways etcetera, that are viewed to present benefits that are tangible economically (Pansit, 2019). One of the targets of the United Nation sustainable development goal number 11: make cities and human settlements inclusive, safe, resilient and sustainable (UNDP, 2015), is to reduce negative environmental impacts of urban areas, provide access for all, to green and public spaces and preservation of nature in urban areas because it is apparent that the solution to the challenges faced in urban areas of biodiversity conservation, climate change mitigation and adaptation to its adverse effects is nature based (Nba) (Nero, 2017). The aim of nature-based solutions is to improve and ensure reliable urbanisation, restore degraded ecosystems, implement climate change mitigation and adaptation practices for improvements in risk management and resilience. Nature based solutions are believed to be energy resource efficient and resilient to change. However, there is need to adapt them to locally prevailing conditions in order to ensure a win-win outcome (European commission, 2015). With regards to climate mitigation, studies undertaken on urban spaces include those of Jo (2002) where he quantified carbon (C) emissions from the consumption of energy and the storage of carbon and sequestration by urban green spaces for three cities in South Korea. From his findings, he estimated that woody plants stored an amount of carbon equivalent to 6.0 – 59.1% of total carbon emissions within the cities. The amount of total carbon offset annually amounted to 0.5-2.2% (Russo *et al*, 2015). In other assessments undertaken in Hangzhou, Asia by Zhao *et al* (2010) it was shown that China's urban forests offset 19% of carbon emitted annually by industrial businesses through absorption and kept an amount of carbon equivalent to 1.75 times the amount of carbon emitted from the use of energy in the city. Another study by Escobedo *et al* (2010) in North America of two cities in Florida in the United States of America (USA) indicates that urban trees captured 3.4% and 1.8% of the total carbon emissions in Gainesville and Miami Dade respectively. A similar study done by Mcpherson and Kendell (2014) found that the total amount of CO_2 which was emitted in modelled large scale tree planting in Los Angeles, USA was slightly greater than the CO_2 stored by these trees over a period of 40 years (Russo *et al*, 2015). A study by Nero *et al*, (2018) in Kumasi Ghana, indicates that urban trees in Africa are often not given attention with regards to their attributes and ability to contribute to the well-being of individuals. It is apparent that 1.2 million tonnes of carbon are captured in aboveground components of trees in Kumasi (Nero *et al*, 2018). Generally, the total carbon in the above ground vegetation of Kumasi accounts for 0.2% of total of above ground carbon stored but vegetation only represents 0.1% of the area's land mass (Nero, 2017). In Zambia, management of urban trees (green spaces) date back to colonial time of the British rule before independence. Development plans of urban green spaces in most towns were strategically located to separate residential areas of colonial masters from those of the local people and these were wide tracks of green spaces (Muwowo, 1979; in Handavu, 2011). Urban green spaces in Zambia have received little attention. However, studies undertaken focus more on values and how to adapt and use benefits to guide decision making process. Developing countries in sub-Saharan Africa are in a better position to grow their cities with enough urban trees to protect ecological areas considered sensitive. This is simply because they are still in the process of urbanizing and can therefore incorporate urban green spaces in at planning stage. This will allow for mitigation of environmental challenges being faced by already established urban areas in other parts of the world. In 2014 the government of Zambia announced that it would not limit the age of motor vehicles imported into the country (ZIPAR, 2014). The argument was that limiting the age of motor vehicles imported would disadvantage the majority of Zambians. This saw an increase in motor vehicle imports occurring with increase in motor vehicle age while decreases in general road and environmental worthiness. Older vehicles are potentially more prone to pollution emission and road crashes than newer vehicles. The average age of Zambia's motor vehicle fleet increased from 13 years in 2006 to 17 years in 2014. This increase is expected to continue probably reaching 20 years considering the economic challenges faced by the country (ZIPAR, 2014). In addition to the aforementioned, it is not known how much motor vehicle carbon related emissions are released to the atmosphere by this increase in motor vehicle fleet. On the other hand, vegetation or carbon stocks can be an important line of approach to mitigate the negative impacts resulting from these emissions. However, in most urban environments, trees are sometimes seen as a displaced structure and they are given less value because their services are not easily quantifiable. They are usually eliminated in order to give way to development structures such as roads, highways, buildings and many more considered to bring tangible benefits economically (Pansit, 2019). The aim of this study was to quantify the CO_2 emissions of motor vehicles contributing to the negative impacts of climate change and urban tree CO_2 sequestration potential in the Lusaka Central Business District. Specific objectives of this study were to:

1. Assess the amount of carbon emitted by the daily motor vehicle fleet in the Central Business District of Lusaka

2. Assess the amount of green spaces required to offset the current motor vehicle CO_2 related emissions in the Central Business District of Lusaka.

2. Literature review

2.2 Urban areas as hotspots of environmental challenges

One of the largest global problems faced today is poor air quality. Out-door air pollution causes 3.3 million annual premature deaths and related illnesses. In the United States of America, transportation is responsible for a larger amount of air pollution. In 2012, more than 75% carbon monoxide (CO), 60% of nitrogen oxide (NOx) were emitted from on and off-road vehicles. Motor vehicle emissions in large urban areas account for as much as 90% local emissions (Gately *et al*, 2017). Carbon dioxide is one important GHG as well as an important driver of the adverse effects of climate change. At the moment the accumulation of GHGs in the atmosphere has become an environmental problem of concern. Notably, the total amount of CO_2 emitted in the atmosphere will be directly proportional to the rise in temperature. Some important factors that have led to the accumulation of CO_2 in the few past years are attributed to rapid population increase, energy use and emissions from motor vehicles. Currently half of the world's population is living in cities and in Europe alone, it is estimated that around 70% of the population, approximately 350 million people–live in urban settlements of more than 5000 inhabitants (Russo *et al*, 2015). Predictions indicate that by 2030, 5 billion out of the 8.5 billion people in the world will be living in the urban areas. The anthropogenic activities and transportation sector contribute more than 80% of all CO_2 emissions into the urban environment. Increasing population as well as urbanization in the world are a big cause of CO_2 and other GHGs that are affecting the global climate. As urbanization increases globally, it is becoming important to better understand the changes in carbon content of these urban ecosystems. Although, cities are a primary source of CO_2 emissions, natural and planted vegetation in urban forests and green spaces can sequester and store carbon dioxide (Russo *et al*, 2015).

2.3 Urban Heat Island

An occurrence where the surface and atmosphere changes as a result of urbanisation leading to the overall difference in urban climate becoming warmer than the surrounding areas is what is referred to as urban heat island (UHI). UHI also refers to the attributes of the urban area in which the temperature of at night is warmer than the surrounding environment. Warmer temperatures in the urban environment are attributed to several factors which include the modification of the natural surface, the heat and the pollution released from the anthropogenic activities in the urban environment (Ridha, 2017; Li, 2020). Heat island effect is attributed to the growth and expansion of cities and urban areas. It is directly connected to issues of energy use efficiency, the environment and ultimately human health and comfort. Most commonly urban areas associated with high population density, buildings, high energy consumption and very few green spaces. Research indicates that a high presence of traffic, pavements and few green spaces to contain air moisture have a contributing effect negatively on urban heat island (Ridha, 2017).

2.4 Urban trees and ecosystem services

The services that come with urban trees (green infrastructure) which include provision of clean air, fresh water, food, soil, regulating climate and sequestering carbon have been classified by the millennium ecosystem assessment (MEA, 2003) as: (1) provisioning services for example; food, fibre, fuel, materials and drinking water (2) cultural services for example; aesthetic and psychological benefits, recreational activities and health benefits and a sense of place (3) regulating services for example; storm water regulation, pollution clean-up, carbon storage and sequestration and local climate modification (4) supporting services for example;

soil formation, pollination (MEA, 2003: Pakzad *et al*, 2015). Apparently there are a few studies undertaken globally on carbon storage and sequestration of urban trees. However, this gap has been filled up by research or studies that have looked at urban ecosystem services in general. In Europe, ecosystem services are being considered in many different projects such as the BiodivERsa research and dissemination project Urban Biodiversity and Ecosystem services (URBES) including the FP7 project: transitioning towards Urban Resilience and Sustainability (TURAS). All of these projects address ecosystem services provided by urban trees (Schroder *et al*, 2013). In the global assessment of urbanization, biodiversity, and urban ecosystem services, the sequestration of carbon by urban trees is considered as one of the most important services that contribute to the well-being of communities. Urban trees in this case are found in parks, open spaces, residential gardens, or along streets. Urban trees are very important but are also highly vulnerable to urban sprawl and compaction. Ensuring a variety distribution of urban vegetation is necessary as a strategy to mitigating climate change in urban areas. Vegetation protects, restores and sequesters carbon in the above and below-ground biomass (Schroder *et al*, 2013). Urban trees are now gaining recognition more precisely in the area of climate change adaptation and mitigation globally. For example, there is an increase in the acceptance and approval of policies among city authorities that further and encourage the planting of trees, preservation of trees in urban areas and the current technologies of green roofs and buildings. Urban trees provide many benefits and services. These include the sequestration of GHG emissions, air quality improvement, protection from floods, heat regulation and reduction in energy use, and runoff water quality improvement. Some of the social benefits realised from urban trees include improved health of urban communities and recreation benefits (Velascoa *et al*, 2015).

2.5 Urban trees and sustainable development goals

The need for urban trees is also recognised in the sustainable development goals (vision 2030). Generally, there are nine sustainable development goals that seek to highlight the importance and necessity of urban trees to both humans and the environment in the urban areas. We can begin by looking at sustainable development goal number 11-sustainable cities and communities, recognises the role of green spaces and urban forests. Goal number 3-Good health and well-being, it is apparent that a high number of urban trees in a community postpones the average onset of health problems. Goals number 6 and 13-clean water and sanitation and climate action related to climate action, trees are important in the hydrological cycle to which targets 6.6 talks about protecting and restoring water related ecosystems. number 9, 12 and 13-industry innovation, responsible consumption and production and climate action, the benefits that come from trees (timber, fibre) are important in building quality, reliable, sustainable and resilient infrastructure (UNDP, 2015). Lastly are sustainable development goals number 5 and 11-gender equality and sustainable cities and communities. Talks about adaptive design and management of urban forests and parks to include the perception and needs of the community specifically focussing on the women needs and perceptions by giving means of shelter, privacy and other types of daily needs they express as important (UNDP, 2015).

2.6 Estimating Carbon Sequestration by urban trees

Urban trees/forests are a significant sink of CO_2 as well as storage. Urban forests, defined as the sum of all woody and associated vegetation in and around dense human settlements are able to absorb and keep significant quantities of CO_2 around urban areas (Schroder *et al*, 2013). Many methodological approaches exist for estimating tree biomass and carbon content of trees. Some of these approaches are a combination of tree inventory with tree biomass regression models. Depending on the level of analysis, estimation of tree biomass for carbon stock analysis involves the selection and application of allometric equations for the estimation of individual tree biomass and summation of individual tree biomass. An allometric equation to be used maybe selected depending on several factors which include the climate or rainfall pattern of a particular region (e.g. tropical or temperate), species type etcetera. Commonly used allometric equations for tropical and temperate regions are those developed by Brown (1997) and Woody Biomass Inventory and Strategic Planning Project WBISPP (2000) respectively.

3. Materials and methods
3.2 Study area location and description
3.2.1 Location

Lusaka is the capital and largest city of Zambia, located in the south central part of the country. It is a sprawling city located in a productive farming area of agro ecological region IIa. Its geographical coordinates are 15°25'S, 28°17'E, on a 1,300m plateau above sea level. The total population of Lusaka district is 1,747,152 (2010 census). Lusaka has a good climate, the summers are warm and sunny interspaced with cooling thunderstorms and mild winters with enough sunshine. The average maximum day temperature in January is 26°C dropping to an average minimum of around 23°C in July. It gets hot around October when there are no rains. The average annual precipitation is 836 mm.

3.2.2 Description

The Lusaka CBD lies around Cairo road covering approximately 2.7 km^2 of area, there are four main highways radiating from the center which include the Great North Road, the Great East Road, Kafue road and Lumumba Road. The main environmental problems facing Lusaka include deforestation, degradation of the environment, as well as air and water pollution.

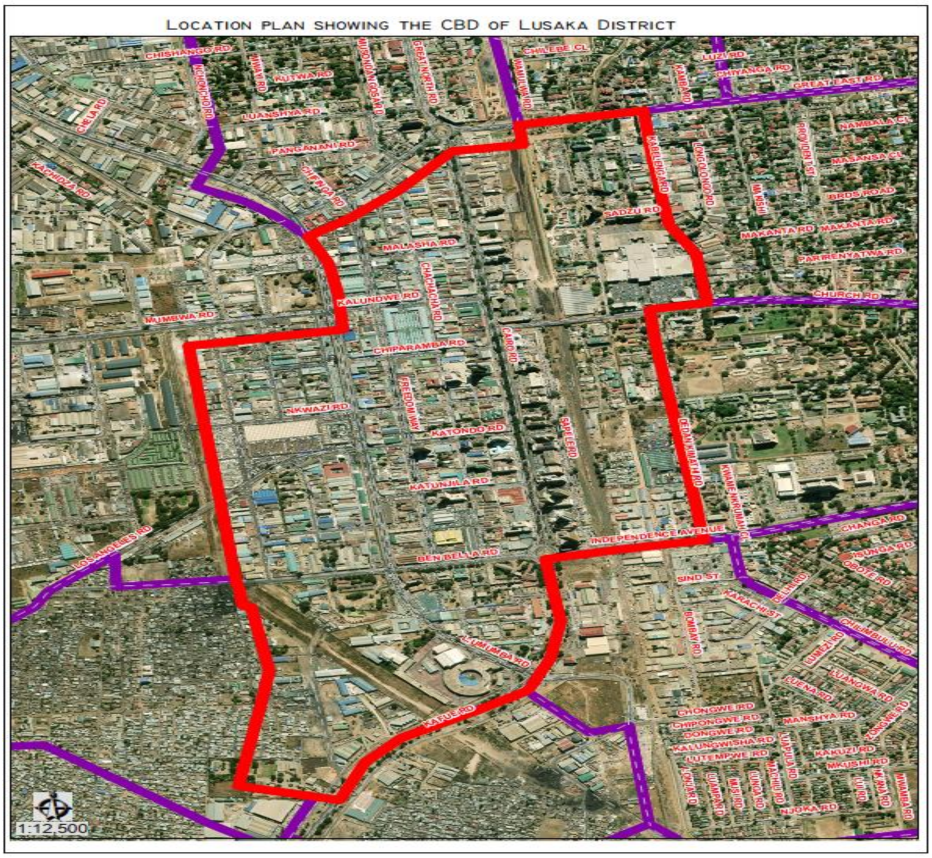

Figure 3. 1: Map of the Central Business District (Source: Google maps, 2021).

Unplanned growth has led to insufficient water resources, inefficient solid waste management, undeveloped water born sanitation systems and inadequate toxic waste disposal systems.

Originally planned as a garden city, Lusaka has become a sprawling metropolis with many multi-storey buildings, high-walled suburbs and busy shanty towns. Areas originally planned for greenery were built up as the city expanded. Cairo road is the city's main through fare and the principle business, retail and service area. It was a section of the Great North road and it was so named because it was a link in Cecil Rhode's dream of a Cape to Cairo road through British colonies in Africa. The city center includes several blocks west of Cairo road, where New City Market and Kamwala Market, a major shopping area as well as the Zintu community Museum are located. Further east lies the government area, including the state house and the various ministries.

3.3 Research design

The research design for this study was a field survey.

3.3.1 Data collection

The daily urban fleet in the CBD of Lusaka was physically counted from the four main entry points during pick hours. This gave a better estimate for average total number of vehicles entering the CBD on a daily basis. The following information was recorded: the type of vehicle, number of each type of vehicle, fuel used (diesel or petrol), distance to the central part of the CBD.

The following sampling technique was employed for green spaces

Considering the presence of trees only in a few places of the central business district, all trees with a diameter greater than 5cm were considered for carbon capture. A hand held global positioning system (GPS) was used to record the location of the areas with vegetation. It is also important to state that the study used non-destructive methods to get the actual measurements. The following information for trees was collected: species, number of each species, species diameter (DBH; 1.3 m above ground level), tree height, and health condition of each measured tree following the method described by Nowak (2008).The survey's focus was for carbon sequestration estimates on trees of >5cm, given the fact that shrubs, herbs contribute relatively less to carbon storage (Davies *et al*., 2011: Pansit, 2019).

Secondary data: Secondary data was collected from written sources such as books and journals, other sources of information included the Lusaka City Council (LCC).

3.4 Data analysis

3.4.1 Quantifying motor vehicle carbon emissions

A mathematical model was used to estimate the CO_2 emissions (EM) of each type of vehicle. The average fuel consumption and run in kilometres was also considered for all vehicles to calculate the total fuel consumption and the total emissions (equation 1,2). Other required data included the specific gravity, calorific power and the emission factor for both petrol and diesel.

$$Fc = Ac \times V \times Rd \quad (1)$$ (Kakouei*et al*, 2012)

Where:
Fc = Fuel consumption (diesel or petrol) (L)
Ac = Average fuel consumption (L/km)
V = Number of each type of vehicle
Rd = Amount of running per day by the vehicle (k)

$$EM\ (CO2) = Fc \times SG_F \times CP_F \times EF_F \quad (2)$$

Where:
SG_F = specific gravity of the used fuel

CP_F = Calorific power of the fuel (kcal/kg)
EF_F = Emission factor of the fuel (tco2/T)

3.4.2 Quantifying Tree Biomass and Carbon Sequestration

Considering the climatic zone for the study area, this research used the improved allometric model for tropical trees given by Chave *et al* (2015).The following steps show how to estimate Tree Biomass (TB) based on plot inventories:

The first step is the selection and application of an allometric biomass function for the estimation of individual tree biomass,
The second step involve summation of individual tree AGB to estimate plot AGB, and
The third and last step involves calculation of an across-plot average to hectare based (Houghton, 2005).
The biomass of trees was estimated by summing up above ground biomass (AGB) and root biomass (RB) (Chave *et al*, 2015).

AGB was calculated following Chave's *et al*, (2015) allometric equation 3:

$$AGB\ (kg) = 0.0673 \times (pD^2H)^{0.976} \ldots\ldots\ldots\ldots (3)$$

Where:
D (cm) = diameter at breast height
P (g/cm^3) = wood specific density
H (m) = height of the tree
The data for wood specific density is available from the Food and Agriculture Organisation (FAO) website.

The Root biomass was estimated as provided by Cain *et al*, (1997) from root-shoot ratios (R/S) by taking 0.26 of above ground biomass. The result for tree biomass estimation was adjusted by a factor of 0.8 to account for reported difference between forest and urban trees (Nowak, 1994). This is so because urban trees were observed to have lesser biomass than the forest trees based on estimations made on trees of the same diameter at breast height.

Root Biomass (RB) and Tree Biomass was estimated as follows (Equation 4,5,6):

$$RB\ (\text{kg}) = AGB\ (\text{kg}) \times 0.26 \ldots\ldots\ldots\ldots (4)$$

$$TB\ (\text{kg}) = (\text{AGB} + \text{RB}) \times 0.80 \ldots\ldots\ldots\ldots (5)$$

Carbon estimation: according to Pearson et al, (2005), 50% of any plant's biomass is carbon. Therefore, carbon storage = Biomass x 50% or Biomass/2............................ (6)

Estimating Annual Rate of Sequestration

According to Schneider *et al* (2013) estimating tree diameter and tree height in year x + 1, an annual increment value of 1.19 cm/year and 1.05 cm/year, respectively is added to the existing tree diameter and height. The results obtained are used to compute above ground biomass for the preceding year.

4. Research Findings

4.1 Carbon dioxide emitted by the daily motor vehicle fleet in the CBD of Lusaka

Table 4.1 below shows the chemical properties of fuel used in the motor vehicles around the central business district of Lusaka (IPCC, 2006). Table 4.2 below shows the average fuel consumption, the average number of vehicles as well as the average distance travelled. This data was later used to quantify the potential CO_2 emissions contribution and fuel consumption shown in table 4.3. The increase in population is a contributing factor to the increase in urban trips. The increase in motor vehicles turns out to be a major problem for the central business district of Lusaka. Often, there is a high concentration of buses and private cars on the roads to the CBD, during pick hours in the morning as well as in the evening. As indicated in table 4.2, private cars and buses are the most popular means of transportation in the central business district of Lusaka.

Table 4. 1: Chemical properties of fuels used in selected motor vehicle in the CBD

Type of fuel	Specific gravity (Kg/cuM)	Calorific power (Kcal/kg)	Emission factor (tCO2/TJ)
Diesel	885	10700	71.4
Petrol	737	11464	69.3

Table 4. 2: Average fuel consumption, number of vehicles and distance travelled

Type of vehicle	Average number	Average distance (km)	Average consumption (lit/km)
Taxis	2037.5	1.64	0.1
Buses	3564.5	1.64	0.25
Private cars	4734	1.64	0.1
Light truck	666.25	1.64	0.28
Heavy duty truck	516	1.64	0.35

4.1 Contribution of taxis to CO_2 emission

Taxis are a third most populous means of transportation in the Lusaka CBD. Table 4.3 below indicates that, taxis make use of about 334.15 litres of fuels within the CBD. The average CO_2 emission of taxis is 1.956 tons. Contribution of buses to CO_2 emission. Buses are the second most important means of transportation in the CBD of Lusaka. Table 4.3 below shows that buses consume on average a total of 1461.445 litres of fuel within the CBD. This has a potential to emit about 8.557 tons of carbon, making buses the highest emitters. Contribution of private cars to CO_2 emissions. Private cars are the most popular means of transport in the CBD of Lusaka. Table 4.2 below shows that private cars consume an average of 776.376 litres of fuel which make a contribution of 4.546 tons of carbon. Private cars are second largest emitters of CO_2.

Table 4. 3: Average CO_2 emission contributions of motor vehicles and their fuel consumption

Type of vehicle	Fuel consumption (L)	CO_2 emission (tons)
Taxis	334.15	1.956
Buses	1461.445	8.557
Private cars	776.376	4.546
Light trucks	306.057	1.792
Heavy duty trucks	296.184	2.805
Total	**3174.212**	**19.656**

4.2 Green spaces available to offset the current motor vehicle related CO_2 emissions in the CBD of Lusaka?

Table 4.4 below shows the standard wood densities of tree species found in the CBD of Lusaka. Table 4.5 below show the physiological data of selected tree species and their carbon sequestration potential.

Table 4. 4: Represents the standard wood densities of selected tree species in the CBD.

No.	Vernacular name	Scientific name	Wood density g/cm^3	Reference
1		*Acacia sieberana*	0.49	www.worldagroforestry.org
2		*Afzelia quanzensis*	0.67	www.worldagroforestry.org
3		*Anisophyllea boehmii*	0.75	http://datadryad.org
4		*Brachystegia boehmii*	0.52	www.worldagroforestry.org
5		*Delonix regia*	0.51	www.worldagroforestry.org
6		*Diplorhynchus condylocarpon*	0.67	http://datadryad.org
7		*Eucalyptus glandis*	0.60	www.worldagroforestry.org
8		*Gmelina arborea*	0.41	http://datadryad.org
9		*Grevillea robusta*	0.51	http://datadryad.org
10		*Hibiscus*	0.57	http://datadryad.org
11		*Julbernardia globiflora*	0.76	www.worldagroforestry.org
12		*Mangifela indica*	0.52	http://datadryad.org
13		*palm*	0.4	http://datadryad.org
14		*Piliostigma thonningii*	0.75	www.worldagroforestry.org
15		*Pseudolachnostylis maprouneifolia*	0.62	www.worldagroforestry.org
16		*Syzygium cordatum*	0.59	www.worldagroforestry.org
17	Musikili	*Trichilia emetica*	0.6	www.worldagroforestry.org

Table 4. 5: Shows the number of trees, average DBH, Height and potential Carbon capture

No.	Vernacular name/ common name	Scientific name	Number of tree	Average DBH (cm)	Average Height (meter)	Organic carbon stored (ton/ species)	Annual sequest-stratin (ton/ species)
1	Mutubatuba	*Acacia sieberana*	5	42.335	12.2	0.303	0.344
2	Mwande	*Afzelia quanzensis*	4	102.655	13.25	2.868	3.132
3	Mufungo	*Anisophyllea boehmii*	4	72.814	11	1.388	1.548
4	Mubombo	*Brachystegia boehmii*	25	54.837	9.972	0.462	0.543
5	Flamboyant	*Delonix regia*	70	65.199	8.691	0.563	0.637
6	Mulya	*Diplorhynchus condylocarpon*	8	55.346	12.125	0.925	1.01
7	Gum tree	*Eucalyptus glandis*	2	54.113	13	0.86	0.949
8	Yemane	*Gmelina arborea*	12	106.554	12.167	1.546	1.738
9	Silky oak	*Grevillea robusta*	12	38.993	10.467	0.235	0.252
10		*Hibiscus*	17	56.341	10.5	0.638	0.712
11	Mwanza	*Julbernardia globiflora*	4	97.085	12.75	2.582	2.852
12		*Mangifela indica*	6	35.651	8.933	0.17	0.2
13		*palm*	35	34.105	10.103	0.142	0.17
14	musekese	*Piliostigma thonningii*	8	50.89	12.388	0.675	0.773
15	Mukunyu	*Pseudolachnostylis maprouneifolia*	26	50.567	9.535	0.504	0.573
16	Mutoya	*Syzygium cordatum*	12	73.344	13.933	1.407	1.544
17	Musikili	*Trichilia emetica*	174	43.848	9.464	0.461	0.376
	Total number of trees		424	**Total carbon sequester**		15.729	17.353

Findings for the T test

The T test conducted was on two different classes or populations (motor vehicles and plant species). The population mean for the first class was 2303.65 (motor vehicles). The population mean for the second class was 24.941 (plants). The population standard deviation for the first class was 1639.753 while for the second class was 40.648. The calculated degree of freedom was 19.999946843 rounded off to the nearest whole number 20. The alpha is 0.025, therefore the critical T value on the T distribution table is 2.0860. Meanwhile the calculated T value was -3.107 which falls in the rejection region. Since the T value falls in the rejection region, it's concluded that the null hypothesis has been rejected.

5. Discussion

The background of this study highlights that the anthropogenic carbon emissions as well as atmospheric CO_2 are a significant GHG. Predictions indicate that by 2030, 5 billion out of the 8.5 billion people in the world will be living in the urban areas. The anthropogenic activities and transportation sector contribute more than 80% of all CO_2 emissions into the urban environment. Increasing population as well as urbanization in the world are a big cause of CO_2 and other GHGs that are affecting the global climate (Russo *et al*, 2015). The results got from the Lusaka CBD show that the daily motor vehicle fleet consumed approximately 3174.212 litres of fuel which released about 19.656 tons of CO_2. Table 4.2 above shows that the category with the highest number of vehicles that enter the central business district is private cars followed by buses. While in terms of emissions, table 4.3 shows that buses have the highest record. The high number of private cars in the CBD confirms the lack of proper public transportation means recorded in other regions such as Iran (Kakouel *et al*, 2012).

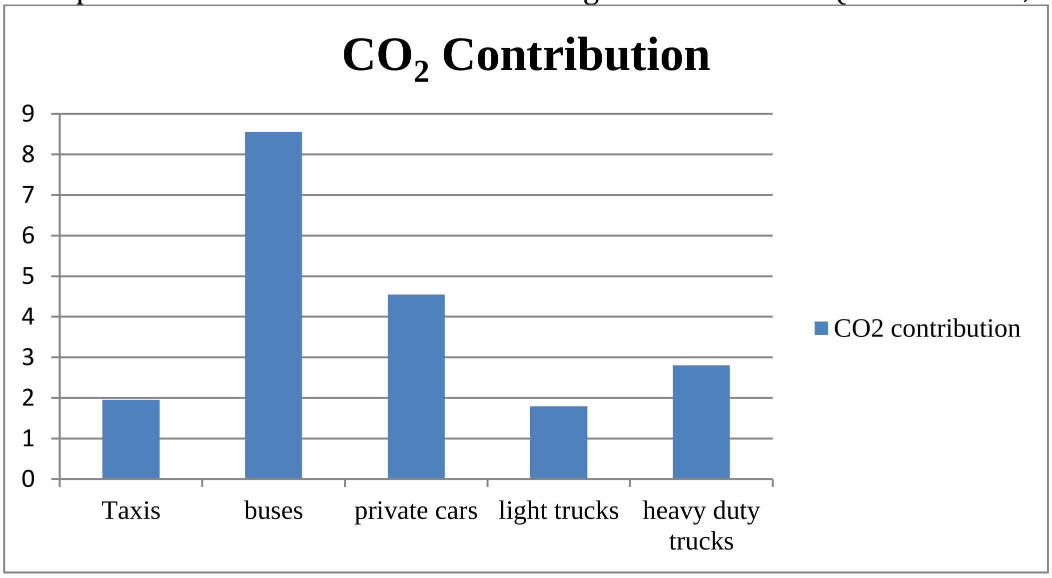

Figure 5. 1: Potential contribution of motor vehicles to CO_2 emissions

During the assessment of carbon sequestration and storage, important information collected include: Tree species, DBH, Height which was used to estimate biomass. Studies undertaken at global level have incorporated these parameters for a broader scope when calculating for carbon storage by urban trees (Schroder *et al*, 2013). The data collected indicate that there were 17 plant species and 424 individual trees in the CBD of Lusaka. Table 4.5 above gives a summary of average diameters, tree height and carbon sequestered. *Trichilia emetic* had the highest number of plants up to *174* followed by *Delonix regia* having 70 plants. Despite the earlier mentioned species having high numbers of individual plants, *Afzelia quanzensis* recorded the highest carbon sequestration of up to 2.868 tons.

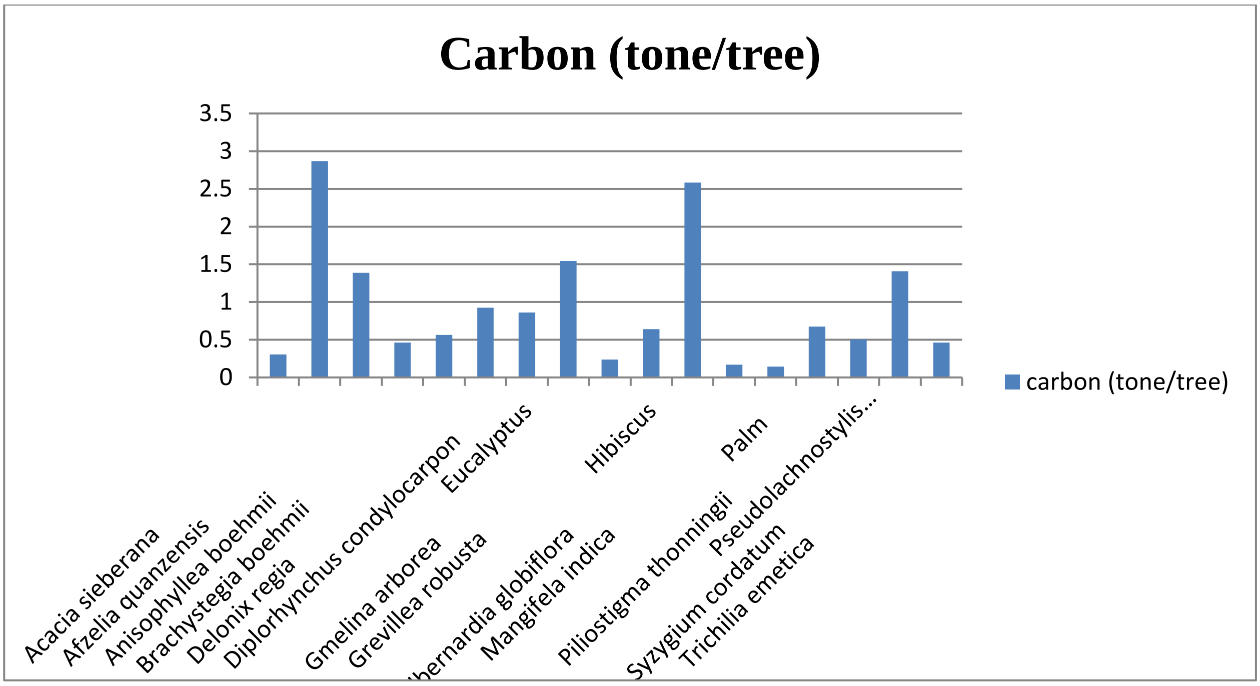

Figure 5. 2: Shows the CO_2 sequestration potential of plant species

Total Carbon sequestered by plants in the CBD of Lusaka is 15.729 tons. The projected amount of carbon that will be sequestered the following year is 17.353 tons. This indicated that the amount sequestered by plants every year is 1.757 tons. These studies have a higher dependence on the inventory of trees, field samples and to some extent on satellite images. Unlike global studies, local studies may lack detailed data on tree species and their annual increment. This restricts the scope of calculation on a higher degree. Under normal conditions, the biomass of trees is estimated using allometric equations which are dependent on DBH and tree height. In certain circumstances, both field inventories and GIS based land cover maps are employed to quantify above ground carbon storage (Schroder *et al*, 2013). Studies undertaken by Tang *et al*, (2016) in Beijing indicate that trees in the streets of Beijing stored 77.1 ± 4.1 Gg C and sequestered 3.1±1.8 Gg C per year. The carbon and sequestration rate when compared to forests that are not in the urban areas of China was found to be about 1/3 ~ ½ in terms of relative quantity (Pansit, 2019). In the same place, Zhao *et al*, (2018), carried out a study to estimate a city wide above ground carbon stored in urban green spaces of China's capital Beijing. The study combined satellite derived vegetation index at a fine resolution of 6m with field survey data of diameter at breast height (DBH) and tree height from 326 field survey plots. An estimate of a total amount of carbon stored in urban trees was found to be 956 Gg in 2014. It is also apparent that carbon density decreased with urban development intensity (Zhao, 2018). Studies undertaken in the tropics where trees are important carbon sink for example in Mexico city and Singapore indicate that in Mexico, 1Mg km^2 of carbon is sequestered per day, in Singapore, trees sequestered 0.8 Mg km^2 per day. This was also attributed to species type as well as the condition of soil. In Italy, Bolzano, the quantity of carbon stored ranged from 134.89 to 179.14 Mg C. The rate of absorption per year estimated was 5.73 to 8.27 Mg C (Pansit, 2019). The USA also has a vast literature on carbon sequestration. In US the total amount of carbon found in trees of the urban was between 597 million to 690 million tons, and the annual rate of carbon sequestration was 18.9 million tons absorption rate per square metre of tree cover of 0.28 kg C/m^2/year. The general idea is that carbon stock varied from place to place and cities with wider, health and large vegetation cover with long life span removed more CO_2 from the atmosphere (Pansit, 2019). In Africa, a study undertaken by Nero (2017) in Ghana, Kumasi which used both field survey and remote sensing techniques indicate that vegetation cover of Kumasi was 33% but declining faster in the years between 2009 and 2014 compared to 1986 and 2001. Trees in the urban area in 2009 and 2014 were significantly correlated to the socio-economic conditions of the city. Urban trees in Kumasi Ghana kept about 3758.1 Gg C: equivalent to 125.7±8 t C/ha in the all study area, this included both vegetation and soils (Nero, 2017).

6. Conclusion and recommendation

6.1 conclusion

Accepting the alternative hypothesis which states that, the carbon dioxide emissions of motor vehicles can-not be significantly sequestered by available plant species is supported by the findings of the tested hypothesis. The most dominant species of plant in the central business district of Lusaka are *Trichilia emetic* and *Delonix regia* as a result of planting activities promoted by the government in the previous years. Total Carbon sequestered by plants in the central business district of Lusaka was 15.729 tons which is way too low when compared to mortar vehicle emissions on a daily basis amounting 19.656 tons. Clearance of vegetated sites to give way to development diminished this ecosystem service. The potential to sequester for carbon is very low, attributed to very few areas of vegetation in the CBD. Vegetation is mainly confined along Cairo road and Freedom way. Other part with vegetation is the areas between Cairo road and the Government complex. In view of the above, the potential for trees in the CBD to sequester all carbon emissions from motor vehicles is not attainable. One of the contributing factors to having the few areas of vegetation in the CBD is due to competing land use.

Recommendations

There is need for enhanced project funding to successfully put into effect mitigation plans such as reforestation, there is need for enhanced policy implementation and management strategies of urban forests, there is need to improve on the age of imported motor vehicle fleet, as a source emission reduction strategy and enhancing management of green spaces is required to successfully reduce carbon and mitigate the adverse impacts of global warming.

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