https://dx.doi.org/10.4314/dujopas.v9i2b.16
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
**Dutse Journal of Pure and Applied Sciences (DUJOPAS)**, *Vol. 9 No. 2b June 2023*

# Assessment of Aircraft Carbon Emission in Nigerian Airspace towards Climate Change Mitigation

[1]Luka Fitto Buba, [1]Shakir Akintola Akinsanya, [2]Mansur Abdul Mohammed*

[1]Department of Environmental Management,
Bayero University, Kano,
Nigeria.

[2]Department of Geography,
Bayero University Kano
P.M.B. 3011 BUK, Nigeria

Email: mamohammed.geog@buk.edu.ng

## Abstract

*Global effects of climate change due to greenhouse gas emission are increasing this need to be given more attention. Also further improvements required for the global long-term demand of air transportation and reduction the net greenhouse gas emissions as a contributor to climate change mitigation. This study aimed at examining the carbon emission from domestic air traffic operations in Nigerian with view to mitigating climate change impact from aviation sector. in line with International Civil Aviation Organization resolution A38-18 of 2013 targeting annual emission reduction by at least 2% from 2021 to 2050. Carbon Emission Calculation Methodology was adapted in assessing total carbon dioxide emission by some Nigerian domestic airline in 2019. Cluster and purposive sampling methods were used in selecting the aircrafts. Results indicate B737 as the most commonly used aircraft in domestic routes with 44.9% fleet in the period. 71.5% of routes had fuel consumption to Carbon dioxide emission ratio of 1:3. Azman air had the highest percentage (83%) of the commonest aircraft type (B737s). Again it had 5,984 domestic trips on a cumulative distance of 3,521,218 kilometers with total carbon dioxide emission of 55,729,531 kg$CO_2$. Pearson correlation analysis indicated positive relationship between great circle distance, fuel consumption and carbon dioxide emission on each route and collectively with a high level of significance ($r = 0.798$, $P = 0.001$). Sustainable improvement of airspace infrastructures to reduce flying time and carbon dioxide emission. Environmental economics market based measures should be applied to aviation operations to ensure environmental sustainability*

**Keywords**: Aircraft, Carbon Emission Calculator, Airspace, Environment, Climate Change

## INTRODUCTION

The aviation sector accounts for about 2% of the total greenhouse gas emission globally (Kwong-sang *et al*., 2015). Globally, increasing concerns due to climate change have led to innovations and resolutions for reducing greenhouse gas (GHG) emissions from all sectors of the global economy. Despite the historical reduction of fuel burn and pollutant emissions from aviation, further improvements are required for the global long-term demand of air transportation and neutral or reduced net GHG emissions targeted for carbon dioxide ($CO_2$) as a contributor to climate change to be met, Intergovernmental Panel on Climate Change

*Author for Correspondence

(IPCC, 2006). $CO_2$ has received much attention for its prevalence at high atmospheric altitude and its harmful effects through absorption and reemission of infrared radiation thereby affecting climate for centuries (Wuebbles, 2006).

Different countries and regional blocs have set ambitious goals for $CO_2$ and other GHG emission mitigation. The Obama administration in USA set 17% reduction target for 2020 and 83% reduction target by 2050 (United States Government Accountability Office, 2010). In June 2009, the European Union (EU-27) set a 21% reduction target compared to 2005 levels, to be achieved in 2020, European Environment Agency (EEA, 2012). International Civil Aviation Organization (ICAO) global aspirational goal is based on a fuel efficiency improvement of 2% reduction per annum. (EEA, 2012). In 2019, commercial aviation contributed approximately 2.5% of total human induced $CO_2$ emissions, which was 12% of all transport emissions with at least 915 million tonnes of $CO_2$ produced by flights (Air Transport Action Group, 2020). Niedzielski *et al*. (2021) reported that there is significant relationship between aviation sector, GHG emission and revenue from environmental taxes and gross domestic products. $CO_2$ as a leading contributor to climate change motivates action to mitigate aviation's emissions (Solomon, 2007). It is very pertinent to establish well-informed national policy regarding decision in the availability of data on trends and absolute level of GHG emission from aviation sector (Gossling *et al*., 2016; Larsson *et al*., 2018)

In 2010, ICAO adopted resolution A37-19 on climate change which set voluntary goals for international aviation emission to have a global annual average fuel efficiency improvement 2% until 2020. Also a global aspirational goal of 2% annual fuel efficiency improvement from 2021 to 2050. This research employed air traffic data to assess $CO_2$ emission (measured in ICAO's $kgCO_2/km$ standard) in the airspace from every domestic flight from the airborne time at its departure airport to the landing time at destination airport within the Nigerian airspace (Bradley, 2009). The total carbon emission by a Nigerian representative domestic airline with the most commonly used aircraft type in 2019 was equally investigated. The research provides a template for domestic airlines operation carbon emission to be transparently measured (in $kgCO_2/km$) per flight to determine the direct impact of air traffic operations on climate change. It would encourage airline operators to focus their corporate social responsibilities on environmental protection initiatives and guide aviation regulators and government on applying environmental economics Market-Based Measures (MBM) to the aviation industry (ICAO, 2010b).

## MATERIAL AND METHODS

### Study area

The study area is the domestic air routes in the Nigerian airspace (otherwise known as KANO Flight Information Region (FIR) with a territorial area coverage of 988,885 square kilometers over Nigerian land mass (of 923,763 square kilometers) and adjourning territorial water up to 250 nautical miles off the coastline (Fig. 1). This is bounded by N'DJAMENA FIR (Chad republic) in the North East, the BRAZAVILLE FIR (DR Congo) in the South East, the Niamey FIR (Niger Republic) in the North and North West and the ACCRA FIR (Ghana) in the South, South West and the West.

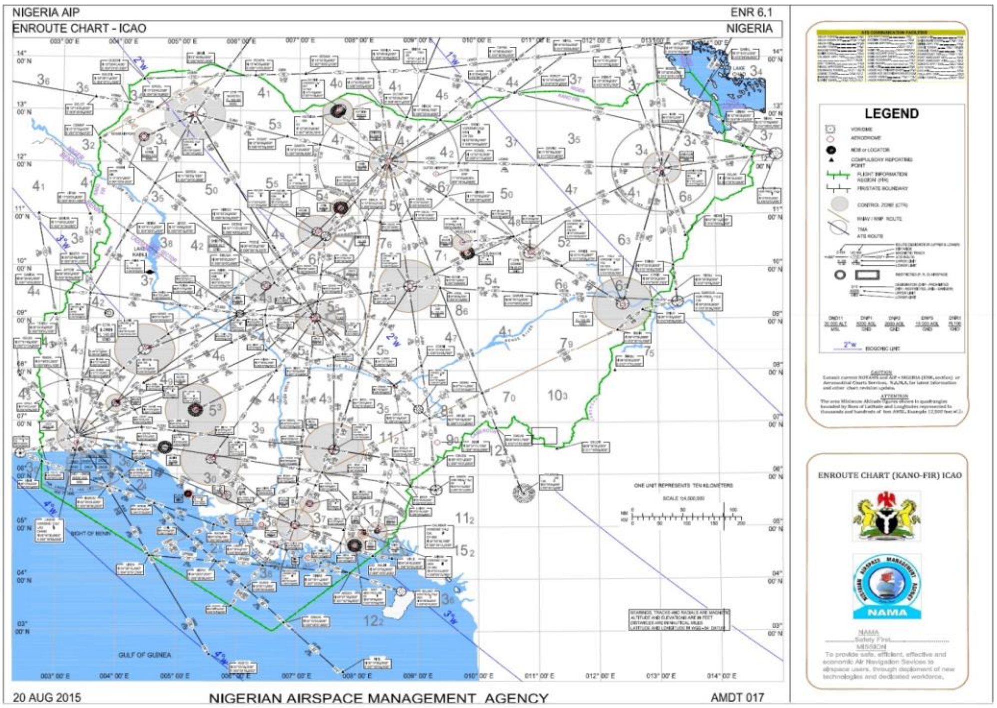


Figure 1: Nigerian Airspace showing the air routes and adjourning airspaces

**Source of data**

The International Civil Aviation Organization (ICAO) Carbon Emission Calculator Methodology (CECM) Version 10 (2017) was adapted for this study. The software applies the Great Circle Distance (GCD) between the Aerodrome Reference Point (ARP) geographical coordinates of two airports to compute the carbon emission on the air route based on the data inputted. Data were sourced from the Air Traffic Control (ATC) system of the Nigerian Airspace Management Agency. Nigerian Civil Aviation Authority (NAMA) published data; In Primary and secondary data were used in this study. Primary data collected include aircraft call sign, aircraft type, registration number, departure airport code, destination airport code, departure time and landing time. Secondary data includes airline standard operating procedures, the NCAA 2019 executive flight summary report, aircraft performance and other information on domestic aircraft operation within Nigeria airspace. Cluster sampling (a probability technique) and purposive sampling (a non-probability technique) were applied. Cluster sampling was used to examine the 2019 Nigerian domestic Airline Operating Companies (AOCs) to analyse their fleet aircraft types. Purposive sampling technique was then applied to an airline (cluster) with an aircraft type most common among the domestic operators. The data was analyzed using Microsoft Excel and SPSS version 20. Correlation and regression analysis were run for the variables to determine the significance level between Great Circle Distance on a route, fuel consumption on the route and the equivalent $CO_2$ emission on the routes respectively and collectively. The entire routes carbon emission daily, weekly and the year 2019 of a representative domestic airline was then calculated to serve as template for calculating each airline's actual $CO_2$ emission daily, monthly and annually.
ternational Air Transport Association (IATA) and ICAO (2010c) database were also consulted.

**Carbon Emission Measurement**

Direct carbon emission measurement in the airspace for each flight was impractical. Hence, emission was calculated from the quantity of fuel combusted in the airspace (from take-off time to landing time) based on the chemistry of aviation fuel combustion and the variation in the aircraft types on the route. Studies have shown that for every 1 gram of aviation fuel burnt; approximately 3.157 gram of $CO_2$ is usually emitted (IPCC, 2006b; Bradley, 2009; ICAO, 2016b). The ideal exothermic chemical reaction for the combustion of aviation fuel is represented by the chemical equation:

$$25O_2 + 2C_8H_{18} \text{ ----------}\rightarrow 16CO_2 + 18H_2O + \text{energy}$$

This research had a sequential approach; each stage is completed prior the commencement of the next stage. The fuel quantity consumed and equivalent $CO_2$ emission by scheduled domestic flight on a unit trip from take-off time at runway of departure airport to the landing time at destination airport within the Nigerian airspace in 2019 were calculated.

## RESULTS AND DISCUSSION

### Fuel Consumption and Carbon Emission by Domestic Flight in 2019

The ICAO CECM was applied to each of the twenty-one (21) city pair routes in Nigeria with scheduled domestic flights in 2019 to calculate the GCD, fuel consumed on each route and the equivalent $CO_2$ emission. The 'A' on each route represents the first leg while the 'B' represents the return leg. Due to the use of GCD as the distance between each city pair, distance was always constant between the first and return legs (A and B). However, the trip fuel quantity consumed might differ between the first leg (A) and return leg (B) due to type of Air Traffic Management (ATM) procedure used by at the Air Traffic Control (ATC) units at airports concerned, prevailing weather condition, navigational facility or volume of traffic at the destination airport, which might lead to holding of succeeding traffic (ICAO, 2016b).

The mean values of fuel quantity/trip and $CO_2$ emission/trip on each of the return routes ($\frac{A+B}{2}$) was calculated and presented in Table 1. The International Air Transport Association (IATA) three letter codes of respective Nigerian airports (programmed in the ICAO CECM software) are used to represent each airport.

**Table 1: Average Estimates on Return Routes**

| S/N | City Pair | Great Circle Distance (km) | Average Fuel Quantity/Trip (kg) | $CO_2$ Emission/ Trip (kg) | Fuel:$CO_2$ Emission Ratio |
|---|---|---|---|---|---|
| 1 | KAN-ABV | 364 | 2516.4 | 6307.4 | 01:03 |
| 2 | KAN-LOS | 832 | 4287.8 | 11515 | 01:03 |
| 3 | ABV-LOS | 510 | 2937.8 | 8348.4 | 01:03 |
| 4 | ABV-MIU | 710 | 3995.7 | 10259.6 | 01:03 |
| 5 | ABV-YOL | 566 | 3388.6 | 8710 | 01:03 |
| 6 | CBQ-ABV | 463 | 2954.9 | 7587 | 01:03 |
| 7 | ABV-PHC | 446 | 3151.5 | 7968.8 | 01:03 |
| 8 | ABV-QOW | 398 | 2849.2 | 6623.2 | 01:02 |
| 9 | ABV-IBA | 404 | 2140.5 | 6350 | 01:03 |
| 10 | ABV-ILO | 309 | 1830 | 5460 | 01:03 |
| 11 | ABV-AKR | 290 | 612.1 | 3330.3 | 01:05 |
| 12 | ABV-SKO | 488 | 2898.2 | 8580 | 01:03 |
| 13 | ABV-ABB | 317 | 2215 | 5715 | 01:03 |
| 14 | ABV-GOM | 422 | 2695.1 | 7291.7 | 01:03 |
| 15 | LOS-KAD | 634 | 2975.1 | 11910 | 01:04 |
| 16 | LOS- ILO | 243 | 525.3 | 2860 | 01:05 |
| 17 | LOS-PHC | 436 | 2733.1 | 4287.6 | 01:02 |
| 18 | ABV-QUO | 468 | 1696.7 | 8550 | 01:05 |
| 19 | LOS-QUO | 558 | 2771.2 | 8175 | 01:03 |
| 20 | LOS-BNI | 251 | 1714.8 | 6240 | 01:04 |
| 21 | ABV-KEB | 491 | 3135.8 | 8483.9 | 01:03 |

Results of Pearson correlation analysis to test the association between equivalent $CO_2$ emissions,
GCD and trip fuel quantity consumed are shown in Table 2. Result in table 2 above shows significant positive relationship exist between GCD covered and $CO_2$ emission with correlation coefficient value of $r = 0.877$. In addition, there was significant association between GCD and fuel consumption correlation coefficient value $r = 0.843$. This implies that increase in great circle distance will increase the values of $CO_2$ emission and vice versa.

**Table 2: Correlation between $CO_2$ Emission, Great Circle Distance and Fuel Quantity Consumed**

| Parameter | Distance Covered | $CO_2$ Emission | Fuel Consumption |
|---|---|---|---|
| Distance Covered | 1 | | |
| $CO_2$ Emission | 0.877** | 1 | |
| Fuel Consumption | 0.843** | 0.798** | 1 |

**Correlation is significant at the $P < 0.01$

Results also show significant association between fuel consumption and $CO_2$ emission ($r$ = 0.798, $P$ = 0.000). Figure 2 shows that great circle distance the coefficient of determination $r^2$ values is 0.71 which revealed that great circle distance can explain the changes in fuel quantity per trip to 71 percent leaving the remaining 29 percentage for other factors to explain

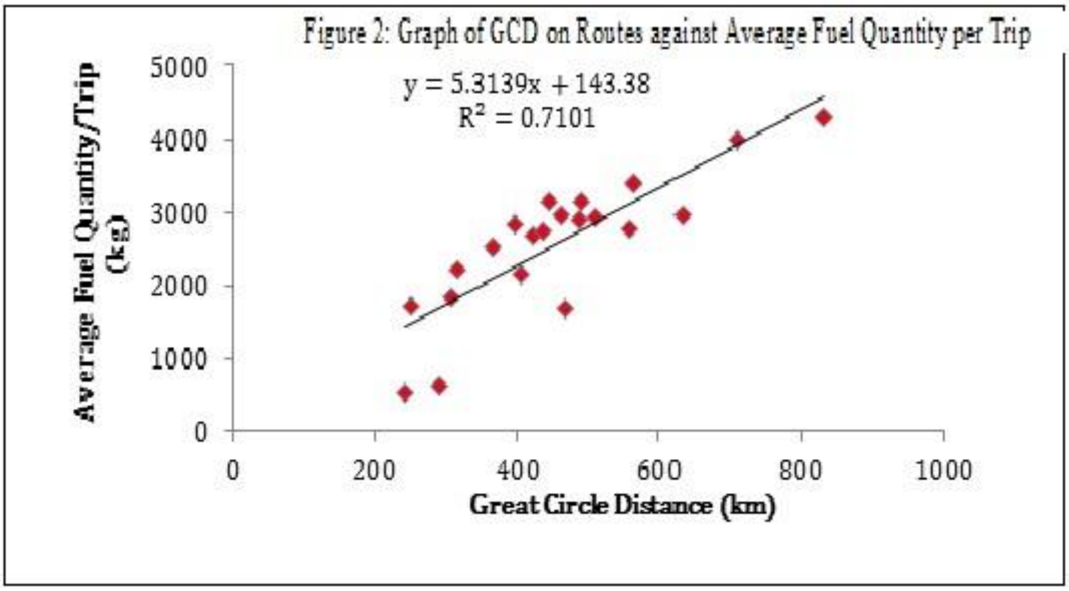


**Fig. 2: CGD on Routes against mean Fuel Quantity per Trip**

The coefficient of determination (Fig.3) revealed that the $r^2$ values is 0.76 which means that great circle distance explained the changes in the $CO_2$ emission by 76 percent leaving the remaining 24 percent to be explained by others factors. This implies that great circle distance is directly related to $CO_2$.

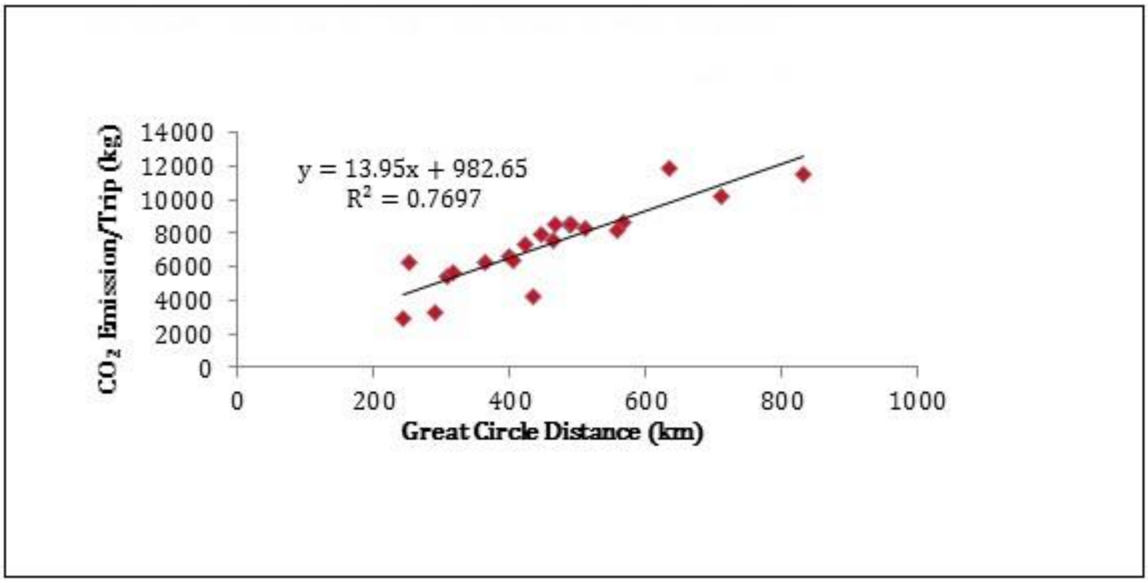


**Fig. 3: GCD on Routes against Equivalent $CO_2$ Emission per Trip**

Table 3 shows the step wise multiple linear regression analysis for prediction of equivalent $CO_2$ emission from GCD and trip fuel quantity consumed. A multiple regression was run to predict $CO_2$ from Great Circle Distance (Dist) and Trip Fuel quantity Consumed (Fuel) of the average estimates on return routes. These variables were statistically significant to predict $CO_2$, F (2, 95) = 32.19, $P < 0.05$, $R^2 = 0.782$. Statistically, both variables added significantly to the prediction $P < 0.05$.

Fifteen (15) out of the twenty-one (21) routes were complied with the 1:3 fuel to $CO_2$ ratio, while two routes each were of the 1:2, 1:4 and 1:5 fuel to $CO_2$ ratios respectively. The aircraft types used on routes account for this.

Table 3: Regression analysis of Equivalent $CO_2$ Emission from Great circle distance and Fuel consumed

| Steps | Equations (y = mx + c) | r | $R^2$ | SEE | F | P Value |
|---|---|---|---|---|---|---|
| Distance | $CO_2$ = 982.654 + (13.95) Dist | 0.877 | 0.77 | 1157.83 | 63.503 | 0 |
| Fuel | $CO_2$ = 2184.02 + (2.01) Fuel | 0.798 | 0.637 | 1454.38 | 33.29 | 0 |
| Dist & Fuel | $CO_2$ = (11.24) × Dist + (0.510) × Fuel + 909.59 | 0.884 | 0.782 | 1158.58 | 32.19 | 0 |

$CO_2$ Carbon dioxide, r is the correlation coefficient, $R^2$ is the coefficient of determination

**Total Quantity of Carbon Emission by a Domestic Airline Company in 2019**

Emission from an aircraft on a route is usually based on different factors. A major factor is the aircraft type flown on the route. The total quantity of carbon emission (measured in kg$CO_2$/km) by a domestic airline company with the highest percentage number of the commonest aircraft type used by the operated domestic airline companies in 2019 was analysed. Sixty nine (69) serviceable domestic aircraft operated in 2019 as detailed in Table 4.

**Table 4: Nigerian Domestic Airline Serviceable Aircraft Types in 2019**

| Airline | Aircraft Type | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | A340 | B737 | B747 | DH8D | Do-328 | ERJ-145 | CRJ-1000 | CRJ-900 | MD-83 | ATR 42/72 | |
| Air Peace | - | 10 | 3 | - | 1 | 7 | - | - | - | - | 21 |
| Arik Air | - | 5 | - | 4 | - | - | 1 | 4 | - | - | 14 |
| Aero | - | 4 | - | - | - | - | - | - | - | - | 4 |
| Azman | 1 | 5 | - | - | - | - | - | - | - | - | 6 |
| Max Air | - | 3 | 2 | - | - | 1 | - | - | - | - | 6 |
| Dana Air | - | 2 | - | - | - | - | - | - | 4 | - | 6 |
| Overland | - | - | - | - | - | 1 | - | - | - | 5 | 6 |
| Ibom Air | - | - | - | - | - | - | - | 3 | - | - | 3 |
| Medview | - | 2 | 1 | - | - | - | - | - | - | - | 3 |
| **Total** | 1 | 31 | 6 | 4 | 1 | 9 | 1 | 7 | 4 | 5 | 69 |
| % | 1.4 | 44.9 | 8.7 | 5.8 | 1.4 | 13 | 1.4 | 10.1 | 5.8 | 7.2 | 1.4 |

The percentage aircraft types' distribution from Table 4 for the domestic airlines serviceable fleet in 2019 is represented in Figure 5.

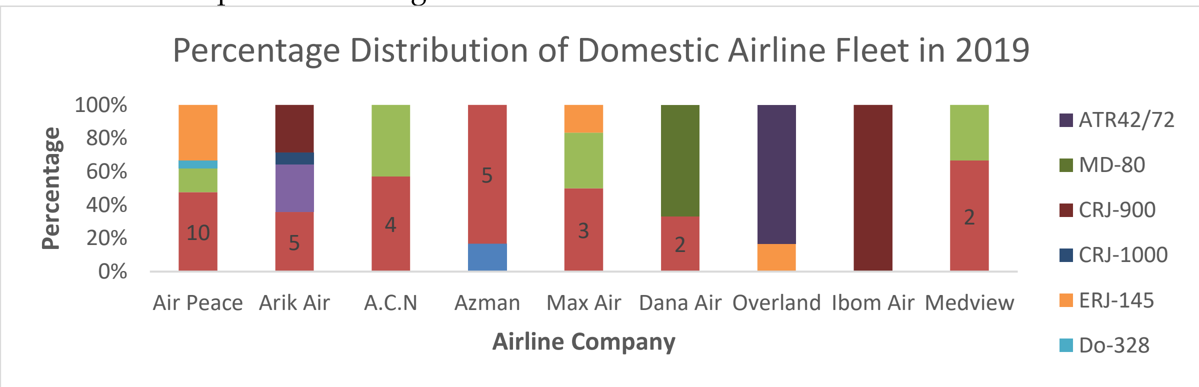

Figure 5: Percentage Distribution of Domestic Airline Fleet in 2019

The B737 (300 and 500 series) have a total 45.9% of the domestic airline fleet capacity, making it the most common aircraft type in the year. Azman Air had the highest percentage representation (83%) of the 2019 most common aircraft type (B737s) used in Nigeria. Hence, Azman air operation on all its domestic routes in 2019 was assessed for the airline's total $CO_2$ emission as detailed below on weekly operation on all its nine operational routes in 2019.

**Table 5: Respective Routes $CO_2$ Emission Analysis for Azman Air in 2019**

| Route | Return Flight | No. of Trips | $CO_2$ Emission/Trip | $CO_2$ Emission in 2019 | Trip Distance | Distance covered in 2019 |
|---|---|---|---|---|---|---|
| KAN-LOS | 695 | 1390 | 11,513.50 | 16,003,765 | 832 | 1,156,480 |
| KAN-ABV | 377 | 754 | 6,307.40 | 4,755,780 | 364 | 274,456 |
| KAN-KAD | 9 | 18 | 3,465.60 | 62,381 | 200 | 3,600 |
| ABV-LOS | 686 | 1372 | 8,348.35 | 11,453,936 | 510 | 699,720 |
| ABV-MIU | 326 | 652 | 10,259.60 | 6,689,259 | 710 | 462,920 |
| ABV-GMO | 129 | 258 | 7,291.70 | 1,881,259 | 422 | 108,876 |
| ABV-KEB | 133 | 266 | 8,483.90 | 2,256,717 | 491 | 130,606 |
| LOS-PHC | 311 | 622 | 7,815.40 | 4,861,179 | 436 | 271,192 |
| LOS-KAD | 326 | 652 | 11,909.90 | 7,765,255 | 634 | 413,368 |
| **Total** | **2992** | **5,984** | **75395.35** | **55,729,531** | **4599** | **3,521,218** |

(i) Total $CO_2$ Emission in 2019 ($kgCO_2$) = ∑ (Carbon Emission on each of the routes)
= ∑ (Number of trips X $CO_2$ Emission Per Trip)
= ∑ (d)
= 55,729,531 $KgCO_2$

(ii) Average $CO_2$ Emission ($kgCO_2$/km) Per Trip = $\frac{Total\ CO2\ Emission\ in\ 2019}{Total\ Distance\ covered\ in\ 2019}$

$$= \frac{\sum (d)}{\sum (f)}$$

$$= \frac{55{,}729{,}531}{3{,}521{,}218}$$

= 15.83$kgCO_2$/km

Azman Air had a total of Five Thousand Nine Hundred and Eighty-Four (5,984) domestic flight trips on a cumulative distance of Three Million Five Hundred and Twenty-One Thousand Two Hundred and Eighteen Kilometers (3,521,218km). There was a total $CO_2$ emission of Fifty-Five Million Seven Hundred and Twenty-Nine Thousand Five Hundred and Thirty-One kilogram of $CO_2$ (55,729,531$kgCO_2$). The number of trips observed (5984) shows 99.8% accuracy when compared to the tabulated (5998) number of trips recorded for the year by the Nigerian Civil Aviation Authority's 2019 executive summary on international and domestic flight operations. This implies that for every kilometer (1km) of operation in 2019, an average of 15.8kg $CO_2$ was emitted by an Azman air B737 aircraft. This represent the environmental opportunity cost of the aviation business of the airline in 2019.

## CONCLUSION AND RECOMMENDATION

This study has shown that type of aircraft used for domestic operation on a route and distance determines the fuel consumption and $CO_2$ emission in the airspace. The fuel quantity consumed by a flight on a route and the equivalent $CO_2$ emitted conforms to the stoichiometric 1 to 3.157 of fuel: $CO_2$ emission ratio in 71% of the routes. The $CO_2$ emission by a Nigerian domestic airline on each of its flight, its entire route daily, weekly, monthly and annually can be assessed through the Carbon Emission Calculator Methodology. Therefore, airline operation produced $Co_2$ in to the atmosphere also distance covered, fuel consumption are directly related with rate of $CO_2$ emission.

Based on the findings obtained in this study, it is therefore, recommended that airlines should use modern aircraft with $CO_2$. Single aircraft with lower seat capacity and low fuel consumption like E145 and ATR72 should be used for short distance route, while aircraft with high capacity should be used for long distance. This would allow economies of scale in aviation business. Domestic airlines should make environmental program as their corporate social responsibilities (CSR) while, environmental economics market based approaches are introduced by government. Green areas may be built and managed by airlines within an airport and/or within city centres which will help to sequester the GHG emitted from the aircraft. Future versions of the CECM software design may be designed to accommodate departure time, landing time and cruising speed of an aircraft. Also, the Nigerian Civil Aviation Regulation on environmental protection regulations should be domesticated in every aviation operational unit and collectively in every airport.

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