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ABSTRACT

This study presents a comparative assessment of Nigeria's greenhouse gas emissions within the African continent from 1970 to 2024, using data from the Emissions Database for Global Atmospheric Research (EDGAR). Nigeria's emissions were evaluated using multiple indicators, including total emissions, per-capita emissions, emission intensity per GDP, emission density, and compound annual growth rate (CAGR). Nigeria ranked third among Africa's top ten emitters in 2024, with total emissions of 350.56 $MtCO_2e$. However, its long-term CAGR of 1.34% was comparatively low, reflecting its already substantial emissions base in 1970. Nigeria's contribution to Africa's total GHG emissions showed a weak and statistically insignificant declining trend. A moderate positive correlation was observed between Nigeria's per-capita emissions and the African average ($r = 0.465$). The conventional Mann-Kendall test indicated a strong negative trend in Nigeria's per-capita emissions, but this was not statistically significant after accounting for serial autocorrelation. GHG emissions per GDP declined significantly for both Nigeria and the African average from 2009 to 2024, with Nigeria showing a slightly steeper decline. Despite improvements in per-capita emissions and emission intensity, Nigeria's relatively high emission density and continued fossil fuel dependence remain persistent challenges. The findings highlight the importance of multidimensional indicators in evaluating climate performance. They also support Nigeria's position under the Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC) principle in international climate negotiations.

Keywords: Greenhouse gas emissions; Nigeria; Comparative analysis; Emission intensity; Per-capita emissions; Emission density; CBDR-RC (Common but Differentiated Responsibilities and Respective Capabilities)

1.0 INTRODUCTION

Climate change is one of the defining environmental and developmental challenges of the 21st Century, with anthropogenic greenhouse gas (GHG) emissions constituting the principal driver of the observed increase in global atmospheric concentrations of climate-forcing gases (Solomon et al., 2007). Although the sources and magnitudes of emissions differ substantially among countries and regions, the consequences of climate change are increasingly experienced through changes in temperature and precipitation regimes, sea-level rise, droughts, floods, ecosystem degradation, and disruptions to agricultural and socioeconomic systems. The geographical distribution of emissions, however, is highly uneven, reflecting differences in population, economic structure, energy systems, industrialization, land-use practices, technological development, and historical patterns of resource exploitation. Consequently, assessments of national climate responsibility and mitigation requirements increasingly require consideration not only of absolute emissions, but also of emissions in relation to population, economic output, land area, and development trajectories.

Africa presents a particularly important case in this regard. The continent has historically contributed a relatively small proportion of global anthropogenic GHG emissions compared with highly industrialized regions, while simultaneously being among the regions considered particularly vulnerable to the impacts of climate change. At the same time, Africa's emissions are neither spatially nor sectorally homogeneous. Recent continent-wide assessments demonstrate substantial contributions from fossil-fuel combustion, agriculture, land-use change and forestry, biomass burning, and other human activities, with considerable uncertainty associated with several components of the African GHG budget. Ernst et al. (2024), for example, found that land-use change constituted one of the largest components of Africa's GHG budget during the recent assessment period, while fossil-fuel emissions were also substantial. Their findings demonstrate that an assessment based solely on energy-related carbon dioxide emissions may provide an incomplete representation of the continent's overall GHG profile.

The heterogeneity of African emissions is further demonstrated by recent research examining convergence in per-capita GHG emissions. Evidence from 54 African countries indicates the existence of multiple convergence patterns rather than a single continental emissions trajectory. Countries tend to form different "clubs" characterized by relatively similar long-term per-capita emission dynamics, and these patterns vary across sectors. The particularly heterogeneous behaviour of agricultural emissions further illustrates the importance of accounting for differences in national economic and environmental structures when interpreting African GHG trends (Apeaning and Labaran, 2024). Thus, treating Africa as a homogeneous emissions region can obscure important differences among individual countries and may lead to misleading conclusions concerning national emission performance.

Nigeria is especially important within this continental context. As one of Africa's largest economies and most populous countries, Nigeria occupies a strategically important position in discussions concerning the continent's future energy consumption, economic development and climate policy. Its large population and expanding economic activity create substantial potential for increases in energy demand and associated emissions, while its petroleum-dominated energy and export structure introduces additional complexities into its emissions profile. Nigeria's position as a major oil and gas producer is particularly relevant because petroleum production can generate emissions through extraction, processing, transportation, energy consumption and, importantly, the flaring of associated natural gas. Research on Nigeria has established the persistence of gas flaring as an important environmental issue and has demonstrated links between petroleum-sector activities, fossil-fuel use and greenhouse gas emissions. For example, studies covering several decades have identified the persistence of gas flaring in Nigeria and its relationship with economic and energy-sector conditions (Hassan and Kouhy, 2013; Okoye et al., 2022; Nwankwo et al., 2023).

Gas flaring is particularly significant because it illustrates why Nigeria's emissions should be interpreted within the context of its economic structure rather than simply through aggregate emission totals. Nwanya (2011) identified the environmental and energy implications of gas flaring in Nigeria, emphasizing the continued environmental consequences of the practice. Similarly, Hassan and Kouhy (2013) examined changes in carbon dioxide emissions associated with gas flaring in Nigeria's upstream petroleum industry over an extended period and found that the size of the industry and environmental factors were important determinants of flaring-related emissions. More recent empirical evidence also indicates persistent relationships among gas flaring, fossil-fuel use and economic performance in Nigeria (Okoye et al., 2022). These findings suggest that Nigeria's emission trajectory cannot be understood

adequately without considering the interaction between resource extraction, energy use, economic growth and technological efficiency.

The relationship between economic growth and environmental pressure is particularly important for developing economies such as Nigeria. Economic development generally requires increases in energy consumption, infrastructure, transportation, industrial activity and material production, all of which can increase emissions when development remains dependent on carbon-intensive energy systems. However, the relationship is not necessarily proportional. Improvements in energy efficiency, technological change, structural transformation and the substitution of low-carbon energy sources can allow economic output to increase more rapidly than emissions. This phenomenon is commonly described as decoupling. Tapio (2005) developed a framework for distinguishing different degrees of coupling and decoupling between economic activity and environmental pressures, emphasizing the importance of distinguishing between absolute and relative changes in the variables.

The question of decoupling is particularly relevant to Africa because the continent must simultaneously address climate change and substantial development deficits. Evidence from 25 African countries over 1990–2017 suggests some evidence of relative decoupling between economic growth and production-based carbon emissions, although the evidence is less robust when consumption-based emissions are considered. Apraku et al. (2021) argue that indigenous knowledge constitutes a body of knowledge existing within, constructed, or acquired by local people over a reasonable period of time and transferred from one generation to another, and that such knowledge is critical for the existence and survival of local residents in coping with climate change impacts on agriculture. This distinction is important because reductions in emissions intensity do not necessarily imply absolute reductions in emissions. An economy can become less emissions-intensive while its total emissions continue to increase if economic output grows sufficiently rapidly. Consequently, examining GHG emissions relative to GDP provides useful information concerning the carbon efficiency of economic activity, but it should be interpreted alongside absolute and per-capita emission measures.

Energy structure constitutes another important determinant of national emissions. Studies of African oil-producing countries have demonstrated significant relationships among GHG emissions, energy consumption and economic growth. Yusuf et al. (2020), examining six African OPEC countries including Nigeria, Algeria, Angola, Equatorial Guinea, Gabon and Libya over 1970–2016, showed that the relationship between GHG emissions, energy consumption and economic output varies across oil-producing economies. Such findings reinforce the importance of comparative analysis. Countries with similar resource endowments may nevertheless exhibit different emission trajectories because of differences in energy efficiency, industrial structure, population growth, economic diversification and environmental policy.

The importance of comparative analysis is further strengthened by the limitations of interpreting emissions through a single indicator. Total GHG emissions provide an indication of a country's overall contribution to the continental emissions burden and are therefore relevant for understanding aggregate mitigation potential. However, total emissions are strongly influenced by population size and economic scale. A large country can have high total emissions while maintaining relatively low emissions per person. Conversely, a smaller country may have relatively low aggregate emissions but considerably higher emissions per person or per unit of economic output. Per-capita emissions therefore provide an alternative perspective by relating the emissions burden to population, while GHG emissions per unit of GDP provide information about the carbon intensity or efficiency of economic production. Similarly, emissions per unit of land area provide information concerning the spatial concentration of emissions and can be particularly relevant when comparing countries with substantially different land areas.

The need to distinguish among these indicators is especially important in assessing Nigeria's position within Africa. A ranking based solely on total emissions may portray Nigeria as one of the continent's principal emitters, whereas a ranking based on per-capita emissions, emissions intensity or emission density may produce a substantially different picture. Indeed, the use of multiple indicators can reveal whether a country's relatively large aggregate emissions are primarily a consequence of its population and economic scale or whether they also reflect relatively high emissions intensity. Such distinctions are essential for evaluating national environmental performance and for avoiding simplistic interpretations of climate responsibility.

This issue also has implications for the broader debate concerning equity and differentiated climate responsibilities. Climate policy requires countries to reduce emissions while simultaneously recognizing substantial differences in

historical emissions, current economic capacity, population, development needs and technological capabilities. For developing countries, particularly those in Africa, climate mitigation is therefore closely intertwined with the challenge of maintaining economic development and improving living standards. Nigeria's climate-policy position must consequently be understood in relation to both its growing contribution to contemporary African emissions and its development requirements. Recent scholarship examining Nigeria's climate legislation and nationally determined contributions highlights the continuing relevance of the principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC) in interpreting Nigeria's climate obligations (Izoukumor, 2025).

Within this context, the temporal dimension of emissions becomes particularly important. A country's current emission level does not necessarily describe its historical or developmental trajectory. Two countries may have similar emissions in a particular year while following very different long-term pathways. One may have experienced sustained growth, another may have undergone stabilization, while a third may be experiencing a prolonged decline. Long-term time-series analysis can therefore identify structural changes that cannot be detected through cross-sectional comparisons of a single year. The availability of increasingly comprehensive national and sectoral GHG datasets has facilitated such analyses. Recent work on the Emissions Database for Global Atmospheric Research (EDGAR) has emphasized the value of consistent spatial and temporal emission inventories for understanding how emissions evolve across countries and sectors. Crippa et al. (2024), for example, demonstrated the importance of spatially explicit and temporally consistent emission information for supporting mitigation analysis and atmospheric modelling.

Comparative analysis is also necessary because the principal drivers of GHG emissions differ considerably among African countries. South Africa's emissions profile is strongly influenced by its energy-intensive and coal-dependent economy, whereas petroleum and gas production are particularly important in Nigeria and Algeria. Other countries have emission profiles strongly influenced by agriculture, land-use change, forestry or biomass energy. The recently developed African regional GHG budget underscores the importance of these sectoral differences, demonstrating that land-use processes, fossil-fuel activities, biomass burning and other sources make different contributions across the continent (Ernst et al., 2024). Therefore, Nigeria's position should ideally be assessed against countries with substantial emissions while recognizing that the underlying sources and socioeconomic contexts may differ.

Despite the growing body of research on African carbon emissions, important gaps remain. Much of the existing literature focuses on relationships between emissions and selected explanatory variables such as energy consumption, economic growth, fossil-fuel use or institutional factors. Other studies examine either specific countries or groups of countries, while recent continental research has emphasized convergence, decoupling or sector-specific emission patterns. These approaches have generated valuable insights, but there remains a need for an integrated empirical assessment that places Nigeria's long-term GHG emission trajectory directly within the broader African context using multiple complementary indicators. In particular, there is value in simultaneously examining Nigeria's absolute emissions, per-capita emissions, emissions relative to GDP, emission density and share of continental emissions, while comparing its trajectory with both the African average and other major emitting countries.

Such an approach is important because Nigeria's position cannot be adequately characterized by asking simply whether its emissions are "high" or "low." A more meaningful question is high relative to what benchmark? Its total emissions can be compared with those of other major African emitters; its per-capita emissions can be compared with the continental average; its GHG/GDP ratio can be used to assess emissions intensity relative to economic output; and its emission density can provide insight into the spatial dimension of its emissions. Examination of changes in these indicators over time can further reveal whether Nigeria is becoming relatively more or less emissions-intensive and whether its development trajectory is converging toward or diverging from those of other African countries.

The present study therefore undertakes a comparative analysis of Nigeria's greenhouse gas emissions within the African continent over the period 1970–2024. The study uses a long-term country-level GHG emissions dataset to examine Nigeria's position from multiple dimensions, including total emissions, per-capita emissions, emissions relative to GDP, emission density and Nigeria's percentage contribution to African emissions. Comparative analysis is undertaken against the African average and selected major African emitters to identify similarities, differences and changes in emission trajectories. Statistical analyses of temporal trends and relationships are employed to complement graphical comparisons and provide quantitative evidence concerning the direction, magnitude and strength of observed patterns.

The study is motivated by the premise that Nigeria's contribution to Africa's GHG emissions should be interpreted in relation to its demographic size, economic scale, land area and development trajectory rather than through absolute emissions alone. Such an approach provides a more nuanced assessment of whether Nigeria represents a relatively high- or low-emission economy within Africa and whether its emissions trajectory is becoming more or less carbon-intensive over time. The findings are expected to contribute to the growing literature on African climate mitigation by providing a country-focused but continentally contextualized assessment of Nigeria's emissions performance. More importantly, the study can help distinguish between the scale of Nigeria's emissions, the intensity of its economic activity, and the per-capita distribution of its emissions, thereby providing a stronger empirical basis for discussions concerning mitigation priorities, sustainable development and Nigeria's position in African and international climate-policy debates.

Despite the growing literature on African greenhouse gas emissions, convergence and the relationship between emissions, energy consumption and economic growth, there remains a need for a multidimensional assessment of Nigeria's relative position within the continent's GHG emissions landscape. Existing studies have demonstrated substantial heterogeneity in African countries' emission trajectories and convergence patterns, but comparatively less attention has been given to integrating absolute emissions, per-capita emissions, emissions relative to economic output and spatial emission intensity within a single country-focused comparative framework. This gap is particularly important for Nigeria because its large population, economic scale and petroleum-based economy can produce a high absolute emissions profile that may differ substantially from its position when emissions are normalized by population, GDP or land area. The present study therefore addresses this gap by examining Nigeria's GHG emissions over 1970–2024 and benchmarking its trajectory against the African average and other major African emitters using multiple emission indicators and statistical trend analyses.

Specific Research Objectives

Objective 1: To examine the temporal trends and changes in Nigeria's total greenhouse gas emissions and compare its emission trajectory with those of the African continent and other major African emitters from 1970 to 2024.

Objective 2: To assess the temporal pattern of Nigeria's per-capita greenhouse gas emissions relative to the average per-capita emissions of the rest of Africa and selected major African emitters from 1970 to 2024.

Objective 3: To evaluate changes in Nigeria's greenhouse gas emission intensity relative to economic output and compare its trajectory with the average emission intensity of the rest of Africa from 2009 to 2024.

Objective 4: To determine the greenhouse gas emission density of Nigeria and compare it with that of other major African emitters in relation to their respective land areas.

Objective 5: To determine Nigeria's relative position within the African greenhouse gas emissions profile and identify the principal similarities, differences and trends that characterize its emission trajectory in comparison with other African countries.

2.0 METHODOLOGY

2.1 **Study Area**

Nigeria is a country of 923,770 km^2 located in West Africa (Figure 1). It's territory (latitude 4^0N to 14^0N. longitude 3^0E and 15^0E of the Greenwich Meridian) spans three primary climatic zones: a tropical monsoon climate in the south, a tropical savannah across much of the central belt, and a Sahelian, semi-arid hot climate in the north. The agro-ecological zones identified in Nigeria are; Sudan Savanna, Sahel Savanna, Montane Forest, Mangrove and Coastal Vegetation, Lowland Rainforest, Guinea Savanna, Freshwater Swamp Forest, Derived Savanna, Jos Plateau (Federal Ministry of Environment, 2019).

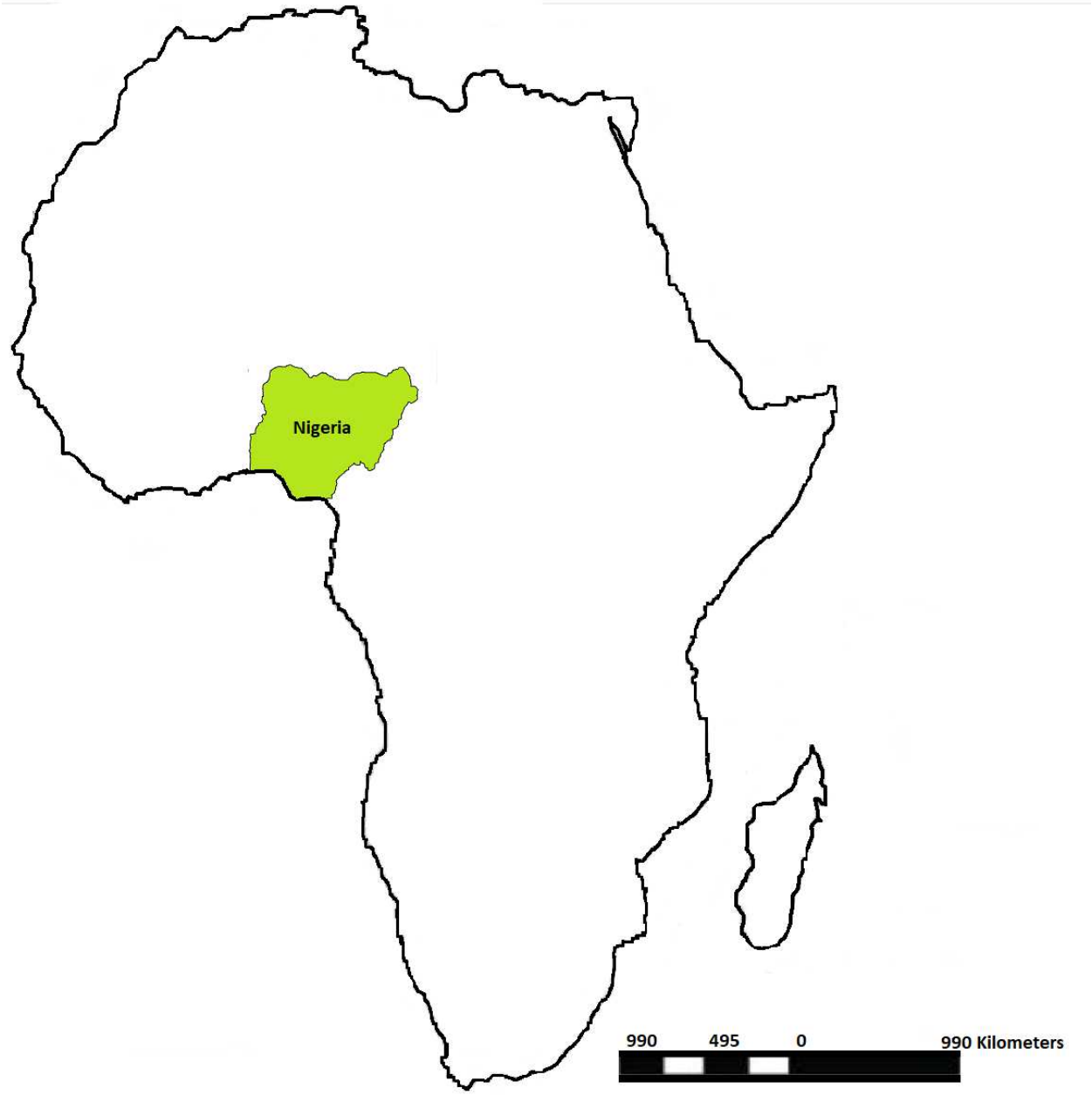


Fig 1 Spatial context of Nigeria within Africa

This spatial arrangement produces a pronounced south-to-north decline in average annual precipitation. The southern belt experiences intense rainfall during the wet season, which runs from March through October, with annual totals typically exceeding 2,000 mm and in places like the Niger Delta, figures can surpass 4,000 mm. In 2024, the nation's Gross Domestic Product (GDP) was valued at approximately N372.82 trillion (NBS, 2025) with a GHG total emission of 350.5554 $MtCO_2eq/yr$ in year 2024 ranking 3rd in Africa after South Africa and Egypt (Crippa et al., 2025).

2.2 **Research Design and Data Source**

Secondary data were obtained from the Emissions Database for Global Atmospheric Research (EDGAR) of the European Commission (Crippa et al., 2025). This data (available at https://edgar.jrc.ec.europa.eu/report_2025) which covers the period 1970 to 2024 (known as EDGAR_2025_GHG) is the 2025 data release of the EDGAR Community GHG emissions database, which results from a new agreement between the Joint Research Centre (JRC) and

International Energy Agency (IEA) to collaborate more closely on collecting and providing consistently harmonised CO_2 emissions data from fossil fuel combustion. Available data formats are PDF and CSV but only the CSV copy was used in the research for ease of analysis in MS EXCEL environment and other statistical tools.

For each country and sector, this dataset offers estimated emissions of the three principal greenhouse gases; CO_2 (fossil only), CH_4, N_2O and fluorinated gases. Accounted for in these datasets are CO_2 emissions from forest land (Rossi et al., 2023), deforestation, drainage of organic soils, other land use and their conversion (Grassi et al., 2022). Wildfire GHG emissions are also included using the Global Wildfire Information System (GWIS) estimates. The datasets are aggregated using Global Warming Potential (GWP) values from IPCC AR5 (GWP-100 AR5). Values in GHG totals by country are expressed in $MtCO_2eq/yr$. Values in GHG by sector and country are expressed in $MtCO_2eq/yr$. Values in GHG per GDP by country are expressed in $tCO_2eq/kUSD/yr$. Values in GHG per capita by country are expressed in $tCO_2eq/cap/yr$. The raw dataset comprises GWP values for 211 sovereign nations and non-country aggregates.

The sectors captured in the GHG country dataset are defined as presented in Table 1:

Table 1: Sectors Definition in the EDGAR_2025_GHG dataset

Sector	**Definition**
Power Industry	Facilities that generate electricity and heat, including both public utilities and private producers.
Industrial combustion	Fuel burned to support manufacturing and industrial operations.
Buildings	Stationary fuel combustion from small-scale, non-industrial sources such as residential and commercial premises.
Transport	Fuel combustion from mobile sources, covering road vehicles, railways, shipping, and aviation.
Agriculture	Emissions arising from agricultural soils, burning of crop residues, livestock digestion, manure handling, and indirect N_20 releases from farming activities.
Fuel exploitation	Activities related to the extraction, processing, and refinement of fossil fuels. Non-combustion emissions from industrial activities, including the manufacture of cement, iron and steel, aluminium, chemicals, and solvents, among others.
Processes	Non-combustion emissions from industrial activities, including the manufacture of cement, iron and steel, aluminium, chemicals, and solvents, among others.
Waste	Emissions generated from the disposal of solid waste and the treatment of wastewater.

Source: Crippa et al., 2025.

2.3 **Data Preparation**

This data was screened first by removing blank rows of records before applying filters (in MS EXCEL environment) to retain only sovereign African countries. Data for Sudan and South Sudan were combined as provided in the original database. The GHG dataset for Nigeria is made up of CO_2, CH_4, N_2O and fluorinated gases (F-gases) from the sources identified in Table 2.

Table 2: GHGs comprising each of the sectors in Nigeria for which GWP were obtained

Country	**Sector**	**Substance**
Nigeria	Agriculture	CO_2
Nigeria	Agriculture	GWP_100_AR5_CH_4
Nigeria	Agriculture	GWP_100_AR5_N_2O
Nigeria	Buildings	CO_2
Nigeria	Buildings	GWP_100_AR5_CH_4
Nigeria	Buildings	GWP_100_AR5_N_2O
Nigeria	Fuel Exploitation	CO2
Nigeria	Fuel Exploitation	GWP_100_AR5_CH_4

Nigeria	Fuel Exploitation	GWP_100_AR5_N_2O
Nigeria	Industrial Combustion	CO_2
Nigeria	Industrial Combustion	GWP_100_AR5_CH_4
Nigeria	Industrial Combustion	GWP_100_AR5_N_2O
Nigeria	Power Industry	CO_2
Nigeria	Power Industry	GWP_100_AR5_CH_4
Nigeria	Power Industry	GWP_100_AR5_N_2O
Nigeria	Processes	CO_2
Nigeria	Processes	GWP_100_AR5_CH_4
Nigeria	Processes	GWP_100_AR5_F-gases
Nigeria	Processes	GWP_100_AR5_N_2O
Nigeria	Transport	CO_2
Nigeria	Transport	GWP_100_AR5_CH_4
Nigeria	Transport	GWP_100_AR5_N_2O
Nigeria	Waste	GWP_100_AR5_CH_4
Nigeria	Waste	GWP_100_AR5_N_2O

Source: Adapted from Crippa et al., 2025.

2.4 Trend Analysis

Temporal trends in emissions were evaluated using time-series analysis from 1970 to 2024 (and 1990 to 2024 in some cases). Annual emission trajectories were examined for Africa as a whole, Nigeria, and selected major emitters. Percentage growth rates and long-term changes were computed to identify periods of rapid increase or decline. All analyses were conducted using Microsoft Excel and PAST Version 4.13 (Hammer et al., 2001).

2.41 Ranking of Nigeria in Africa's GHG emission

The most fundamental insight drawn from this is whether Nigeria's share of Africa's total GHG emissions has:

- increased,
- decreased, or
- remained relatively stable.

An increasing share suggests that Nigeria is becoming a more significant contributor to Africa's emissions, whereas a declining share indicates that other African countries are contributing proportionately more to the continent's total emissions. This reveals Nigeria's changing position in Africa's emissions landscape. Nigeria's share of African countries' GHG emission from 1970 to 2024 ($MtCO_2eq/yr$) is calculated using:

Country Share (%) = (Country Emissions / Total African Emissions) × 100

2.42 Comparison of Nigeria GHG emission and African Average GHG emission

The GHG total ($MtCO_2eq/yr$) by country as provided in the EDGAR database was used for this analysis. The record (row of data) for Nigeria was isolated and then the average values of GHG of all the other African countries were obtained for the period 1970 to 2024 using the AVERAGE function in MS EXCEL. A line graph of the GHG total by country for Nigeria is plotted against the average for other African countries. Comparing Nigeria's total greenhouse gas (GHG) emissions with the average emissions of other African countries serves several important scientific and policy purposes. The comparison provides context for interpreting the country's emissions profile. The principal reasons include:

Establishing Nigeria's Relative Position in Africa

The comparison indicates whether Nigeria emits more or less GHGs than the average African country**,** thereby placing its emissions within the continental context. This contextualization is particularly important because total emissions alone provide little insight without a reference point.

Identifying Regional Leadership or Responsibility

Nigeria is Africa's most populous country and one of its largest economies. Comparing its emissions with the African average helps determine whether Nigeria contributes disproportionately to the continent's total GHG emissions and

therefore bears greater responsibility in achieving Africa's climate mitigation objectives under the Paris Agreement (UNFCCC, 2015).

Informing Resource Allocation and International Support
International organizations and climate finance institutions often consider comparative emission assessments when prioritizing:

- climate finance,
- capacity-building initiatives,
- technology transfer, and
- mitigation projects.

Countries with emissions substantially above regional averages may receive greater attention for targeted mitigation interventions.

Providing Statistical Context
From a scientific perspective, comparing Nigeria's emissions with the continental mean helps determine whether the country's emissions represent the "typical" African country or whether they deviate significantly from the regional norm. This enhances the interpretation of descriptive statistics and strengthens comparative analyses.

2.43 Comparison of Nigeria per capita GHG emission and African Average GHG emission

Available values in GHG per capita by country in the EDGAR dataset runs from 1970 to 2024. The GWP values was presented in $tCO_2eq/cap/yr$. The record for Nigeria was isolated from the dataset that has filtered out non-African countries. The average of these values was plotted against the GWP values of Nigeria to obtain a line chart in MS Excel environment. Insights provided by this comparison is relevant in the area of carbon convergence, climate justice, and economic development.

Benchmarking Development Trajectory and Carbon Convergence: Comparing Nigeria's per capita emissions against the African average is a crucial exercise for understanding its stage of economic development and its alignment with the continent's broader carbon trajectory. A key concept in environmental economics is the "carbon convergence hypothesis," which posits that as developing economies grow and industrialize, their per capita carbon emissions will eventually converge toward the levels of more developed nations (Muhammad et al., 2026). By comparing Nigeria's per capita trends with the African average, one can assess whether Nigeria is following this expected path and how it compares to other countries in the region. Secondly, the comparison can reveal if Nigeria is on a higher or lower emissions path relative to the continental average. This divergence points to unique national factors shaping Nigeria's emissions profile.

Assessing Equity and Climate Justice: The analysis of per capita emissions is fundamental to the principle of "Common But Differentiated Responsibilities and Respective Capabilities" (CBDR-RC), a cornerstone of international climate negotiations.

Academic research underscores that allocation schemes for emissions reduction have very different implications for developing countries based on their unique characteristics, including per capita emissions (Winkler et al., 2002). This comparison allows for an equity-based assessment of Nigeria's position and future commitments.

2.44 Comparison of Nigeria Emission per GDP to Average Africa Emission per GDP

The EDGAR dataset for Emission per GDP has GWP values in $tCO_2eq/kUSD/yr$ and it's for the period 1990 – 2024. Record (row of data) for Nigeria was isolated after filtering out non-African countries. The AVERAGE function in MS Excel was to determine the average values for the other African countries from 1990 to 2024. These values are then plotted against that of Nigeria in a line chart. Comparing Nigeria's greenhouse gas emission intensity (GHG per GDP) against the African average from 1990 to 2024 is a valuable exercise for understanding its unique position within the continent's climate and development narrative. The significance of this comparison can be understood through several key analytical lenses:

Benchmarking Economic Efficiency and "Decoupling": This comparison acts as a benchmark to reveal whether Nigeria is a regional leader or laggard in carbon efficiency. If Nigeria's GWP per GDP is lower than the African average, it suggests a more carbon-efficient economy; if higher, it highlights a significant area for policy intervention. For a developing economy like Nigeria, one of the most critical indicators of sustainable development is "decoupling"; achieving economic growth without a corresponding rise in emissions (Ul-Durar, 2025). Comparing Nigeria's trend against the continent's shows whether its development pathway is becoming relatively cleaner or more carbon-intensive over time.

Revealing Structural Economic Realities: A higher intensity often reflects an economy reliant on energy-intensive sectors, such as oil extraction or heavy industry (Susilowati et al., 2025). For Nigeria, the petroleum sector is a major economic driver, and this comparison would help quantify its impact on the nation's overall carbon footprint relative to other African countries with more service-based or agricultural economies. This comparison can help contextualize whether Nigeria's emissions are driven more by industrial activity or by the use of inefficient, traditional fuels.

Informing Policy and International Negotiations: The principle of CBDR-RC (Common But Differentiated Responsibilities and Respective Capabilities) is central to climate negotiations (Avathari, 2025). This comparison provides data to support Nigeria's position that, while its total emissions may be growing, its per-GDP footprint may still be far lower than that of industrialized nations, arguing for its right to develop. A country's energy intensity and CO_2 intensity are key drivers of its overall emissions.

2.45 Comparison of Nigeria with African Top 10 Emitters (1970 – 2024)

The data ($MtCO_2eq/yr$) for year 2024 was used to filter the GHG dataset for African countries in descending order of magnitude. The first ten records (representing the first 10 emitters in year 2024) was isolated to develop a line chart for each of the countries.

Comparing line graphs allows the examination of how emission pathways have evolved over more than five decades. It also helps to assess whether Nigeria is converging toward or diverging from other major emitters. Additionally, understanding which countries contribute most to Africa's emissions helps identify where mitigation efforts could have the greatest continental impact.

2.46 Comparison of Nigeria GHGs Emission Density with African Top 10 Emitter (1970 – 2024)

The emission density of Nigeria and African top 10 emitters for the period was obtained by dividing the total GHG emission for each of the countries by their total surface area over the period 1970 to 2024. The data obtained ($tCO_2eq/yr/km^2$) was then plotted in MS Excel to show how Nigeria compares with high emitters in Africa. This metric also serves as a powerful analytical tool for understanding its emissions profile. It helps to normalize a country's total emissions by its physical size, revealing spatial patterns and sector-specific issues that other metrics might miss.

This metric also provides an indication of land-use efficiency by assessing the greenhouse gas emissions generated per unit of land area. As highlighted in previous research, the emissions footprint can be used to evaluate the trade-offs between greenhouse gas emissions and land productivity, thereby identifying areas characterized by high emissions but efficient land use (Adlan et al., 2025).

Comparing countries like Nigeria (with a significant fossil fuel industry) to others with large agricultural or service-based sectors provides fairer insights. For example, agricultural practices in West Africa show different emission profiles compared to industrial activities, which emission density can highlight (Guug et al., 2025).

2.47 Comparison of Nigeria GHGs Emission per Capita with African Top 10 Emitter (1970 – 2024)

The comparison of Nigeria's per capita GHG emissions with those of Africa's top ten emitters provides critical insights that significantly enrich the study. By normalizing emissions against population, this analysis addresses fundamental questions of climate justice, policy effectiveness, and the relationship between development and emissions. The findings will offer a nuanced understanding of Nigeria's position within Africa's emissions landscape.

3.0 RESULTS AND DISCUSSION

3.1 Ranking of Nigeria in Africa's GHG emission

The percentage contribution of Nigeria to Africa's GHGs emissions was determined for the period 1970 to 2024 (i.e. 55 annual observations). The result of the plot is shown in Figure 2.

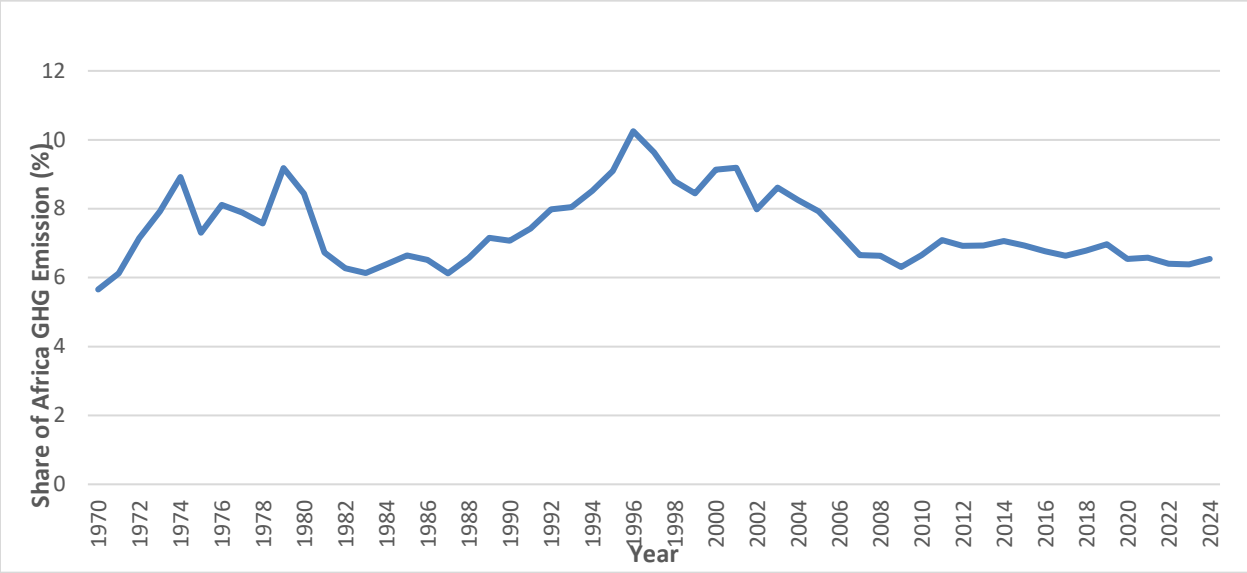


Fig 2 Variation of Nigeria's contribution to Africa's GHG Emission (1970–2024)

The Mann-Kendall trend test (Mann 1945; Kendall 1975; Gilbert 1987) on the data was conducted. The Mann-Kendall test is employed to determine if Nigeria's share has significantly increased, decreased, or remained stable over period. It indicates whether there is a monotonic (consistently increasing or decreasing) trend in the time series. The Mann-Kendall Test Results is given below:

Statistic	Value
Number of observations (n)	55
Mann–Kendall S	−187
Kendall's τ (Tau)	−0.1259
Variance of S	18,975.0
Standardized Z	−1.3503
Two-tailed p-value	0.1769

A Mann-Kendall trend test was performed to evaluate the temporal trend in Nigeria's percentage contribution to Africa's greenhouse gas emissions from 1970 to 2024. The analysis indicated a weak negative trend ($S = -187$; Kendall's $\tau = -0.126$; $Z = -1.350$), which was not statistically significant ($p = 0.177$). Therefore, there is insufficient evidence to conclude that Nigeria's share of Africa's greenhouse gas emissions exhibited a significant monotonic increase or decrease over the study period.

3.2 Comparison of Nigeria GHG emission and African Average GHG emission

The two-time series, Nigeria's total GHG emission and the average GHG emissions for the rest of Africa is given in Figure 3.

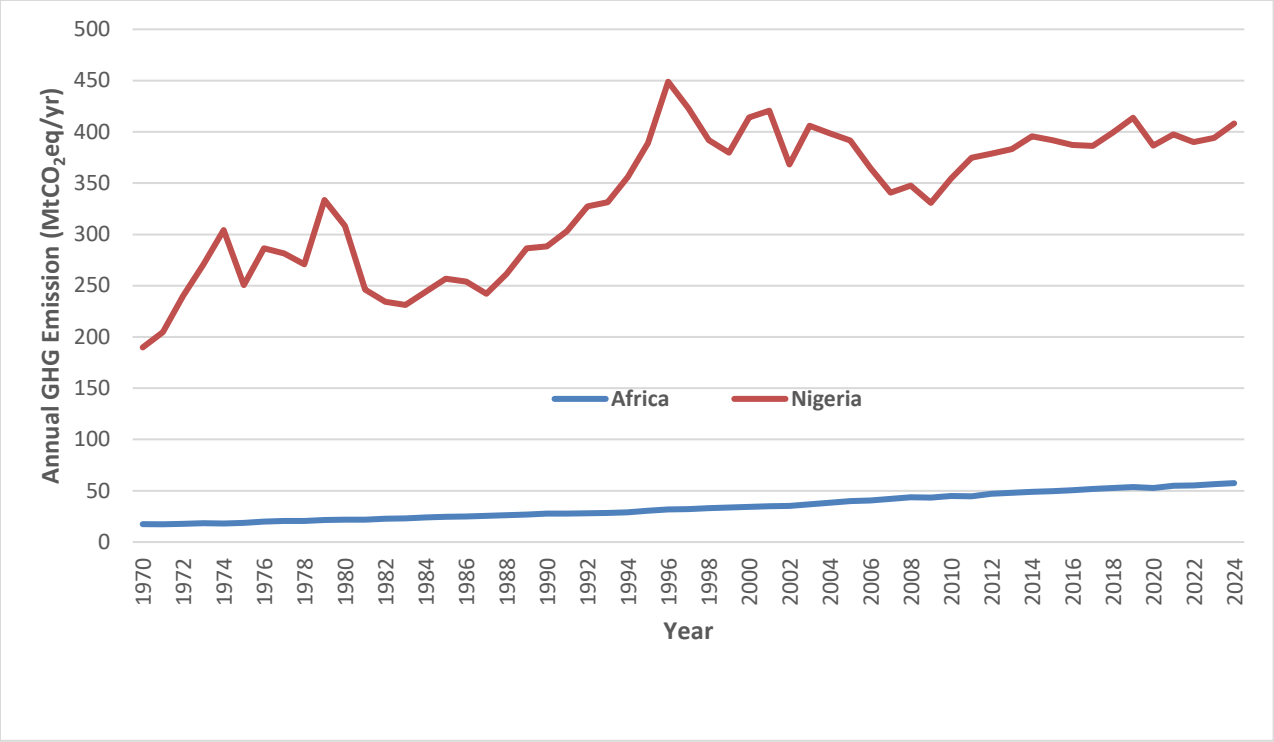


Fig 3 Comparison of Nigeria and African Average GHG emission

In order to test the strength and direction of the linear relationship between Nigeria's emissions and the average for the rest of Africa. The Pearson product-moment correlation analysis (Pearson, 1895) was conducted to examine the relationship between Africa's total greenhouse gas emissions and Nigeria's greenhouse gas emissions during the period 1970–2024. The result of the test, conducted in MSEXCEL environment is given as:

Statistic	Value
Number of observations (n)	**55**
Pearson correlation coefficient (r)	**0.6667**
p-value (two-tailed)	**2.75×10^{-8}**
Coefficient of determination (R^2)	**0.4444**

The analysis revealed a statistically significant, moderately strong positive correlation ($r = 0.667$, $n = 55$, $p < 0.001$), indicating that increases in Africa's greenhouse gas emissions were generally associated with corresponding increases in Nigeria's emissions. The coefficient of determination ($R^2 = 0.444$) suggests that approximately 44.4% of the variation in Nigeria's emissions is linearly associated with changes in Africa's total emissions.

3.3 Comparison of Nigeria per capita GHG emission and African Average GHG emission

A plot of the graph of the Nigeria per capita GHG emission values and the average of the rest of Africa from 1970 to 2024 is shown in Figure 4.

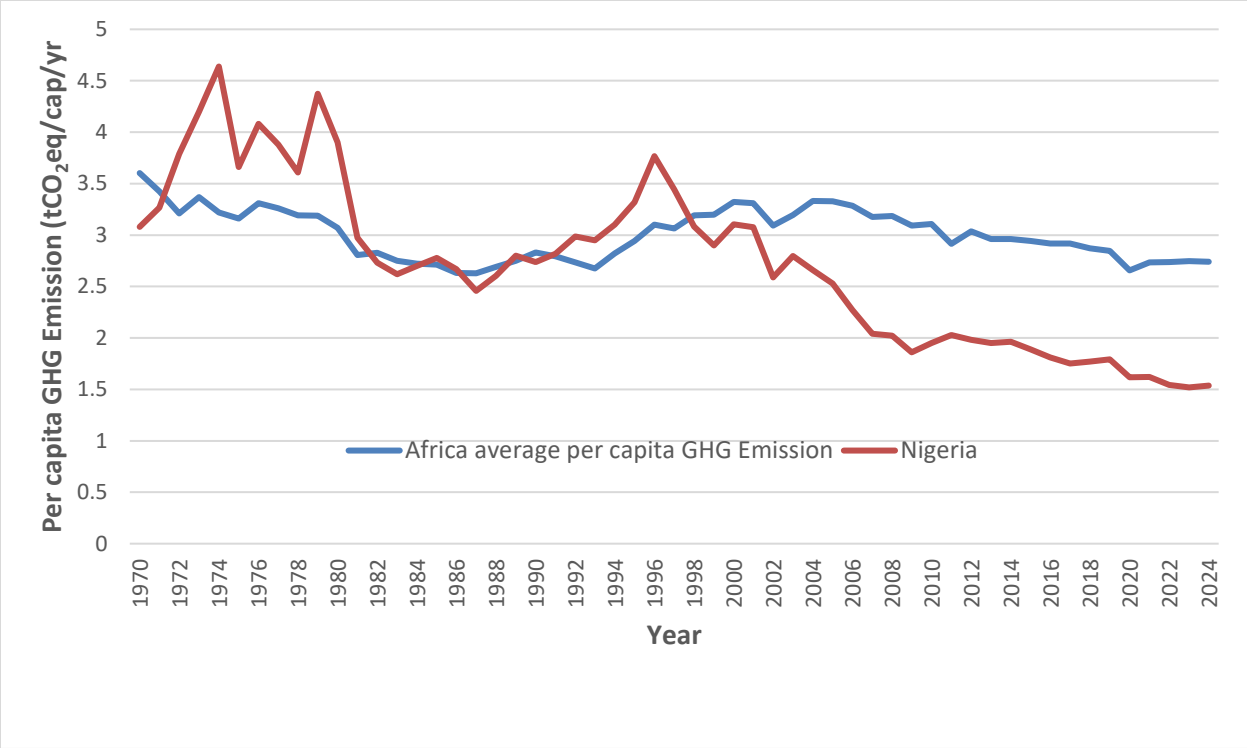


Fig 4 Per capita GHG emission for Nigeria and the Average for the rest of Africa

In order to provide more meaningful insight, the difference between the values average GHG emission per capita for Africa and that of Nigeria (value of African average – value for Nigeria for the same year) for the 55 years was computed and used for the analysis. A graphical representation of this difference is shown in Figure 5.

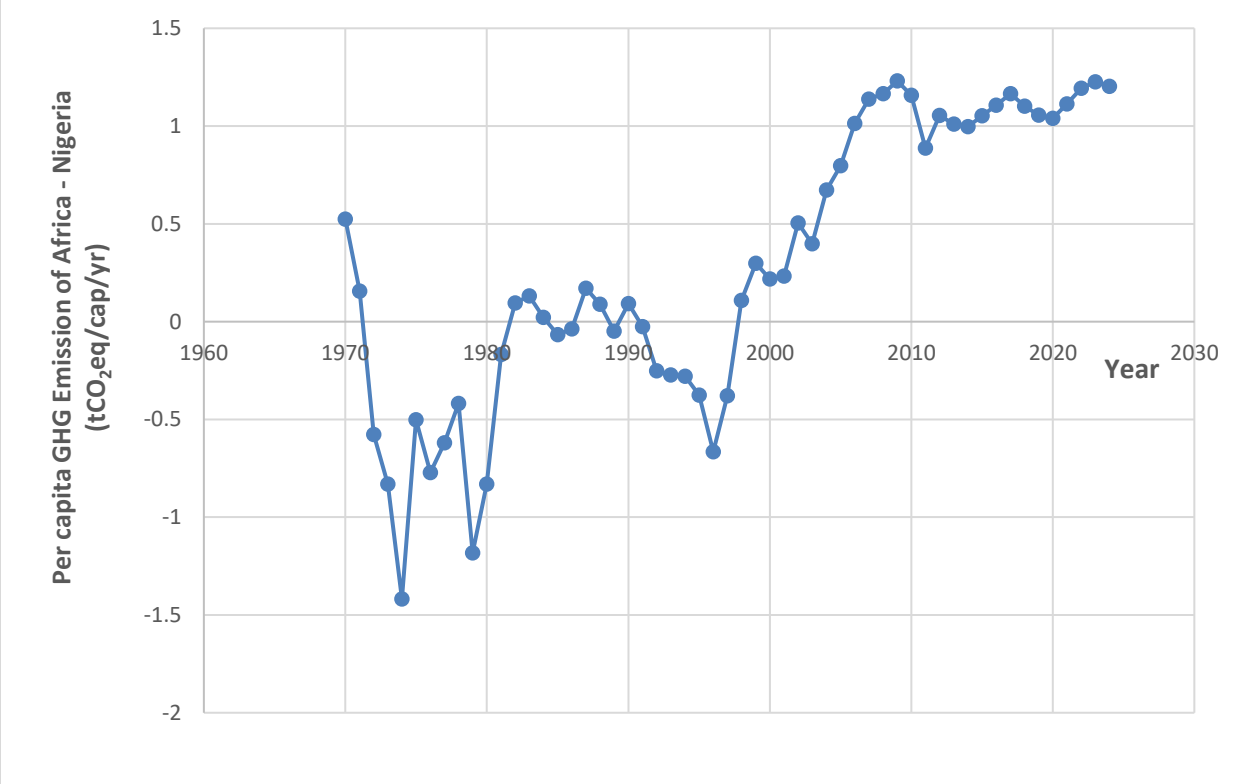


Fig 5 Difference in GHG per capita values between African average and Nigeria

The following statistical tests were further carried out:

Pearson Product–Moment Correlation Coefficient: The Pearson correlation coefficient was used to determine the strength and direction of the linear relationship between Nigeria's and Africa's average per-capita GHG emissions over 1970–2024. The test is appropriate for determining whether the two series exhibit similar year-to-year movements. A positive correlation indicates that increases or decreases in Nigeria's emissions tend to occur in the same direction as changes in the African average. The analysis therefore helps establish the degree of association between Nigeria's emission trajectory and the broader continental pattern, although correlation does not imply causation or equality in emission levels.

Kendall's Tau: The test was used to measure the direction and strength of the monotonic relationship between time and per-capita GHG emissions. As a non-parametric, rank-based statistic, Kendall's tau is appropriate for environmental time-series data that may not satisfy the assumptions of normality or linearity. It provides an indication of whether emissions generally increase or decrease over the study period. A negative value indicates a declining tendency, whereas a positive value indicates an increasing tendency. The statistic therefore complements the Mann–Kendall test by describing the direction and strength of the observed temporal trend.

Sen's Slope Estimator: Sen's slope estimator was employed to quantify the magnitude and direction of the temporal trend in per-capita GHG emissions. While the Mann–Kendall test determines whether a monotonic trend exists, Sen's slope estimates the rate of change per year. Its non-parametric nature makes it suitable for environmental data because it is relatively resistant to extreme observations and does not require normally distributed data. In this study, it enables comparison of the rates at which Nigeria's and Africa's average per-capita GHG emissions have changed, thereby providing an indication of the practical magnitude of the observed trends.

Lag-1 Autocorrelation: Lag-1 autocorrelation was calculated to determine whether successive annual observations in each per-capita GHG emission series are statistically dependent. This diagnostic is important for time-series environmental data because observations in consecutive years are often strongly related. A high positive autocorrelation indicates that an observation tends to resemble the preceding year's observation, violating the independence assumption of conventional trend tests. Determining the degree of autocorrelation is therefore necessary to establish whether the conventional Mann-Kendall test may overstate the significance of an apparent trend and whether an autocorrelation-adjusted trend procedure is required.

Autocorrelation-Adjusted Mann-Kendall Test: The autocorrelation-adjusted Mann-Kendall test was employed to determine whether the observed monotonic trends remain statistically significant after accounting for serial correlation in the annual observations. This adjustment is necessary because the strong positive autocorrelation identified in the three series can inflate the apparent significance of trends when the conventional Mann-Kendall test is applied. The adjusted procedure therefore provides a more reliable assessment of trend significance for the 1970–2024 time series. Its application enables the study to distinguish genuine statistical evidence of a long-term trend from apparent trends that may partly result from temporal dependence among successive observations.

The results of these tests are tabulated below (Table 3):

Table 3: Results of statistical tests on the GHG per capita for African average, Nigeria and the difference

Analysis	Nigeria	African average	Africa − Nigeria
Number of observations	55	55	55
Mean ($tCO_2e\ capita^{-1}$)	2.720	3.005	0.285
1970 ($tCO_2e\ capita^{-1}$)	3.079	3.603	0.524

2024 (tCO_2e $capita^{-1}$)	1.538	2.741	1.203
Pearson r	0.465	—	—
Pearson p-value	<0.001	—	—
Kendall's τ	−0.679	−0.224	+0.651
Sen's slope	−0.0426	−0.0063	+0.0384
Lag-1 autocorrelation	0.929	0.908	0.923
Adjusted MK Z	−1.808	−1.421	+1.731
Adjusted MK p-value	0.071	0.155	0.083
Significant at α = 0.05?	No	No	No

Nigeria's per-capita GHG emissions are substantially lower than the African average by 2024 and have declined considerably faster over the study period. However, after accounting for strong serial autocorrelation, neither Nigeria's declining trajectory nor the African average's decline is statistically significant at the 5% level, and the apparent widening of the Nigeria–Africa per-capita emissions gap is likewise not significant at that level. At the same time, the two series exhibit a statistically significant moderate positive association ($r = 0.465$, $p < 0.001$), indicating that Nigeria's year-to-year emission dynamics are partly synchronized with the broader African trajectory despite its lower and more rapidly declining per-capita emissions.

3.4 Comparison of GHG per GDP for Nigeria and the Average for the rest of Africa

The total GHG per GDP values of Nigeria and the average for the rest of Africa for the period 1990 – 2024 is given in Figure 6.

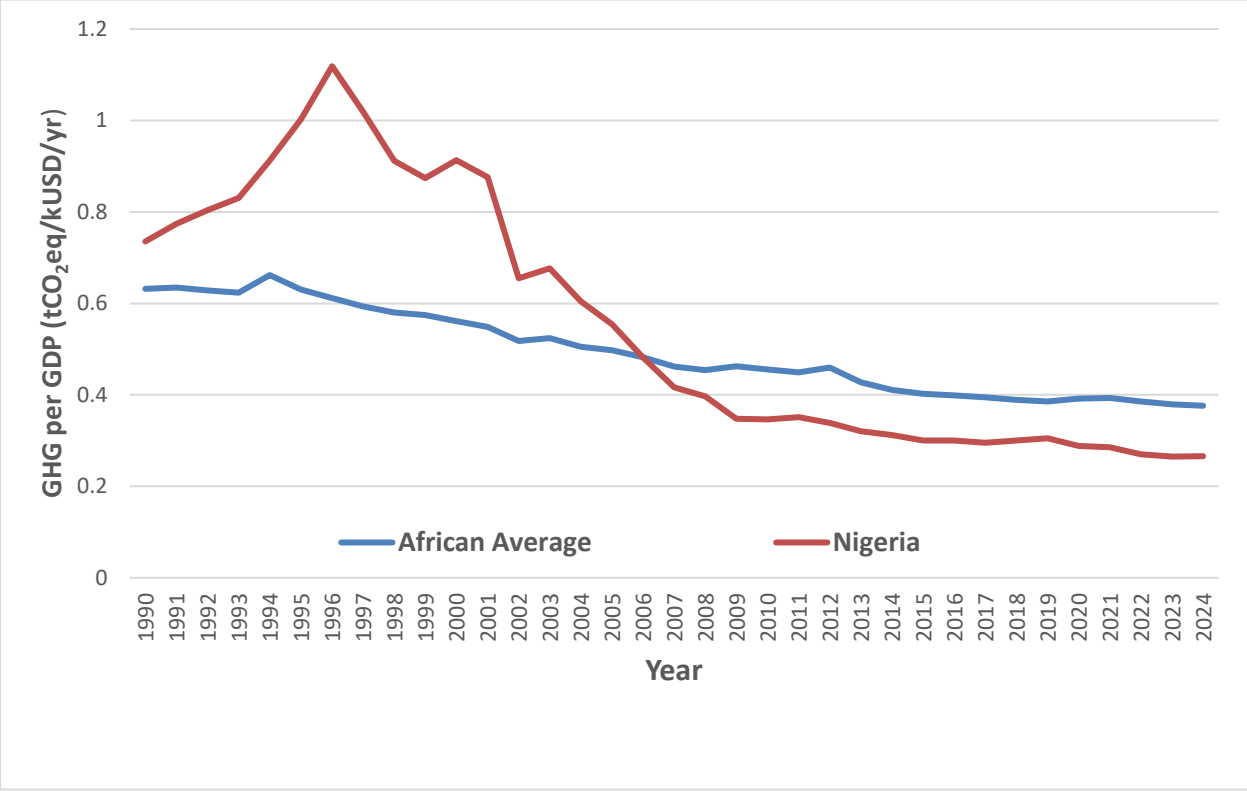


Fig 6 Comparison of Nigeria Emission per GDP to Average Africa Emission per GDP

The graph identifies the year 2006 as the time when Nigeria's carbon efficiency equates that of the rest of Africa and from then onwards, Nigeria's carbon efficiency (till year 2024) is higher than the rest of Africa.

Given the uniform trend in the graph from 2009 to 2024, the Mann-Kendall trend test was conducted to examine if the trend in the time series is consistently increasing or decreasing. The result of the test is as given below:

Mann-Kendall Test Statistics

Test	Nigeria	Rest of Africa
S-statistic	−96	−98
Variance (Var(S))	149.33	149.33
Z-score	−7.78	−7.94
p-value	< 0.0001 (effectively 0)	< 0.0001 (effectively 0)
Kendall's τ	−0.800	= −0.817

From the result above, the following deductions can be made:

- Both p-values are < 0.0001, meaning there is overwhelming evidence that GHG per GDP has declined significantly from 2009–2024 for both Nigeria and the African average.
- The negative Z-scores confirm a monotonic downward trend.
- Nigeria's slope (−0.00674 per year) is *slightly steeper* than the African average (−0.00634 per year).
- Over 16 years, African Average declined by roughly 18.7% relative to its starting value while Nigeria declined by roughly 23.5% relative to its starting value.

Nigeria is decarbonizing its economy (GHG per unit of GDP) at a *faster rate* than the African continental average. The widening of the gap, means Nigeria is pulling ahead of the continent in terms of GHG efficiency.

3.5 Comparison of Nigeria with African Top 10 Emitters (1970 – 2024)

The top 10 leading countries in total GHGs emission in Africa in year 2024 are; South Africa, Egypt, Nigeria, Algeria, Ethiopia, Sudan and South Sudan, Morocco, Kenya, Tanzania and Chad. The variation of their various GHGs levels from 1970 to 2024 is as shown in the graph below (Figure 7).

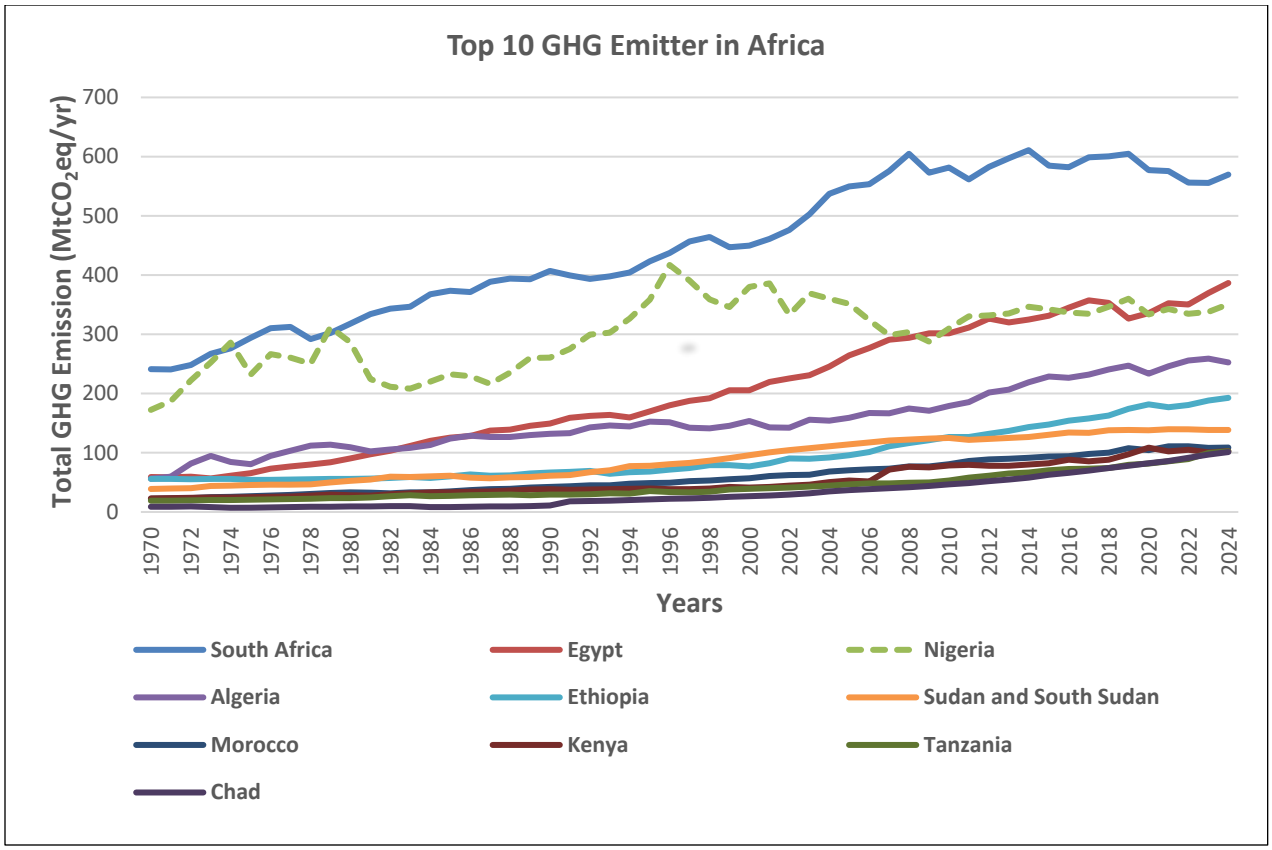


Fig 7 Trajectory of Africa's Top 10 Total GHG Emitters from 1970 to 2024

From Year 2008 to 2024, Nigeria is the only country amongst the first 5 that has commendably maintained a fairly constant GHG emission regime. South Africa, Egypt, Algeria and Ethiopia have ascending trajectories of total GHG emission.

The Compound Annual Growth Rate (CAGR) for the ten countries is computed and ranked in order of magnitude. CAGR is computed using the formula below:

$$CAGR = (End_{value}/Begin_{value})^{1/n} - 1 \quad (1)$$

The result of CAGR computation for the 10 countries is reproduced in Table 4.

Table 4: CAGR Results for Top 10 African Countries (1970–2024)

Country	Emissions 1970 (Mt CO_2e)	Emissions 2024 (Mt CO_2e)	CAGR	Rank by Growth Rate
Chad	8.75	101.17	+4.66%	1st
Tanzania	19.03	102.53	+3.18%	2nd
Ethiopia	55.66	192.70	+2.32%	3rd
Kenya	22.93	102.84	+2.82%	4th
Morocco	22.25	108.74	+2.99%	5th
Sudan & South Sudan	38.82	138.70	+2.40%	6th
Algeria	56.30	252.70	+2.83%	7th
Egypt	59.16	386.60	+3.52%	8th
Nigeria	172.37	350.56	+1.34%	9th
South Africa	241.15	569.81	+1.78%	10th

From the table above, Chad's emissions have skyrocketed from just 8.75 Mt in 1970 to 101.17 Mt in 2024. This is a nearly 12-fold increase, which is remarkable for a country that started from a very low base. This rapid growth is likely driven by population growth, agricultural expansion, and land-use changes. Tanzania (+3.18%) and Egypt (+3.52%) have sustained consistently high growth rates. Egypt's growth is particularly significant because it also started from a relatively high base (59.16 Mt), meaning its absolute increase is massive (from 59 Mt to 386 Mt). Nigeria has the Second-Slowest Growth Rate (+1.34%) despite being one of the continent's top emitters, Nigeria's CAGR is remarkably low. This is because its emissions were already very high in 1970 (172.37 Mt), and after peaking in 1996 (417 Mt), they have fluctuated and only grown modestly over the full 54-year period. This reflects a volatile emissions trajectory tied to economic instability and changes in the oil and gas sector, rather than steady growth. South Africa, the continent's largest emitter, has the lowest CAGR. This indicates a mature, heavily industrialized economy where emissions have plateaued. Its emissions grew from 241 Mt to 570 Mt over 54 years, but this represents only a 2.36-fold increase which is much slower than the 11.5-fold increase seen in Chad. Countries that started with very low emissions (Chad, Tanzania) show the highest CAGRs, while countries that started with very high emissions (South Africa, Nigeria) show the lowest CAGRs. This is a classic example of the "base effect," where a small absolute increase from a tiny base results in a huge percentage growth rate. While Chad has the highest CAGR, its 2024 total (101 Mt) is still far smaller than Nigeria's (350 Mt) or South Africa's (570 Mt). This highlights that CAGR is a measure of *growth rate*, not *scale*. Nigeria may have a low growth rate, but its sheer volume of emissions means its impact on the continent's total is far greater than Chad's.

3.6 Comparison of Nigeria GHGs Emission Density with African Top 10 Emitter (1970 – 2024)

Country surface area data were obtained from the World Bank's World Development Indicators (Indicator AG.SRF.TOTL.K2), which compiles official statistics from the Food and Agriculture Organization of the United Nations (FAO). Table 5 gives the land areas of the top 10 GHG emitters in Africa with the land areas of South Sudan and Sudan combined.

Table 5: Land Areas of Top 10 African Countries GHG Emitters

Country	Land Area (Km^2)	Country	Land Area (Km^2)
Chad	1,284,000	Sudan & South Sudan	2,524,883
Tanzania	947,300	Algeria	2,381,740
Ethiopia	1,136,240	Egypt	1,001,450
Kenya	591,969	Nigeria	923,770
Morocco	446,550	South Africa	1,219,090

Source: World Bank (2026)

From Figure 8, all the top 10 GHG emitters in Africa have ascending order of emission densities except Nigeria and South Africa which has descending trajectories when compared to their peaks which occurred in 1996 and 2019 respectively. This implies an increasing land-use efficiency by these 2 countries in recent years. Nigeria has however faired better than South Africa given that from the graph, the two countries have equal emission densities in 1971 (202.6612154 $tCO_2eq/yr\text{-}km^2$), 1981 (243.0666616 $tCO_2eq/yr\text{-}km^2$), 1993 (328.0049066 $tCO_2eq/yr\text{-}km^2$), 1999 (374.5868079 $tCO_2eq/yr\text{-}km^2$), and 2002 (360.293262 $tCO_2eq/yr\text{-}km^2$).

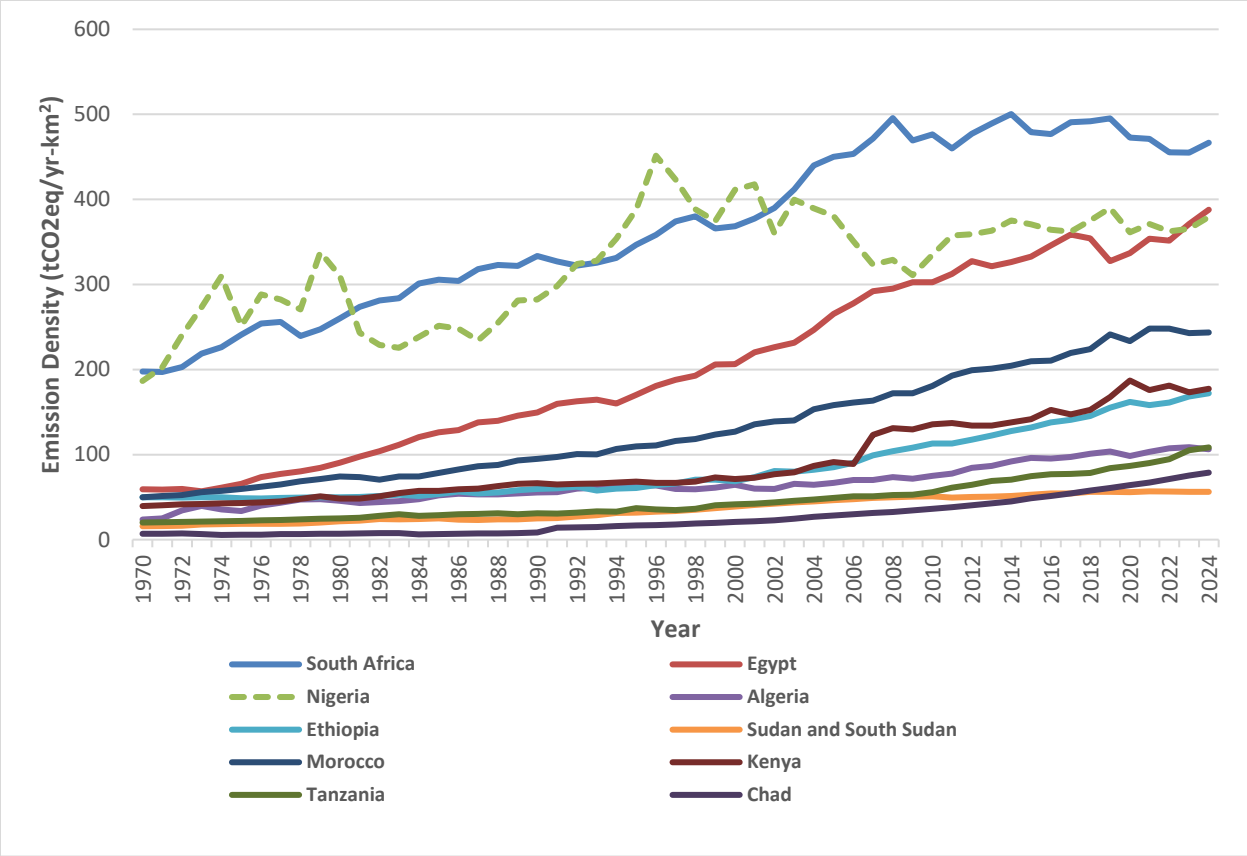


Fig 8 Nigeria GHGs Emission Density with African Top 10 Emitter (1970 – 2024)

In terms of land area, Nigeria is the 3rd smallest of the top 10 GHG emitters in Africa after Morocco and Kenya which explains why it's GHG emission density is higher than all the other countries except South Africa. Given the similarity in Nigeria's emission density in the last 3 years (2022 – 2024) with Egypt (a country that is slightly larger), Nigeria's landuse efficiency is positively increasing.

3.7 Comparison of Nigeria GHGs Emission per Capita with African Top 10 Emitter

Nigeria is the most populous country in Africa with a population density of 257.13 persons per km^2 as at year 2025 (World Bank, 2026). The most positive GHG emission parameter of Nigeria is her emission per capita as indicated in the graph below (Figure 9).

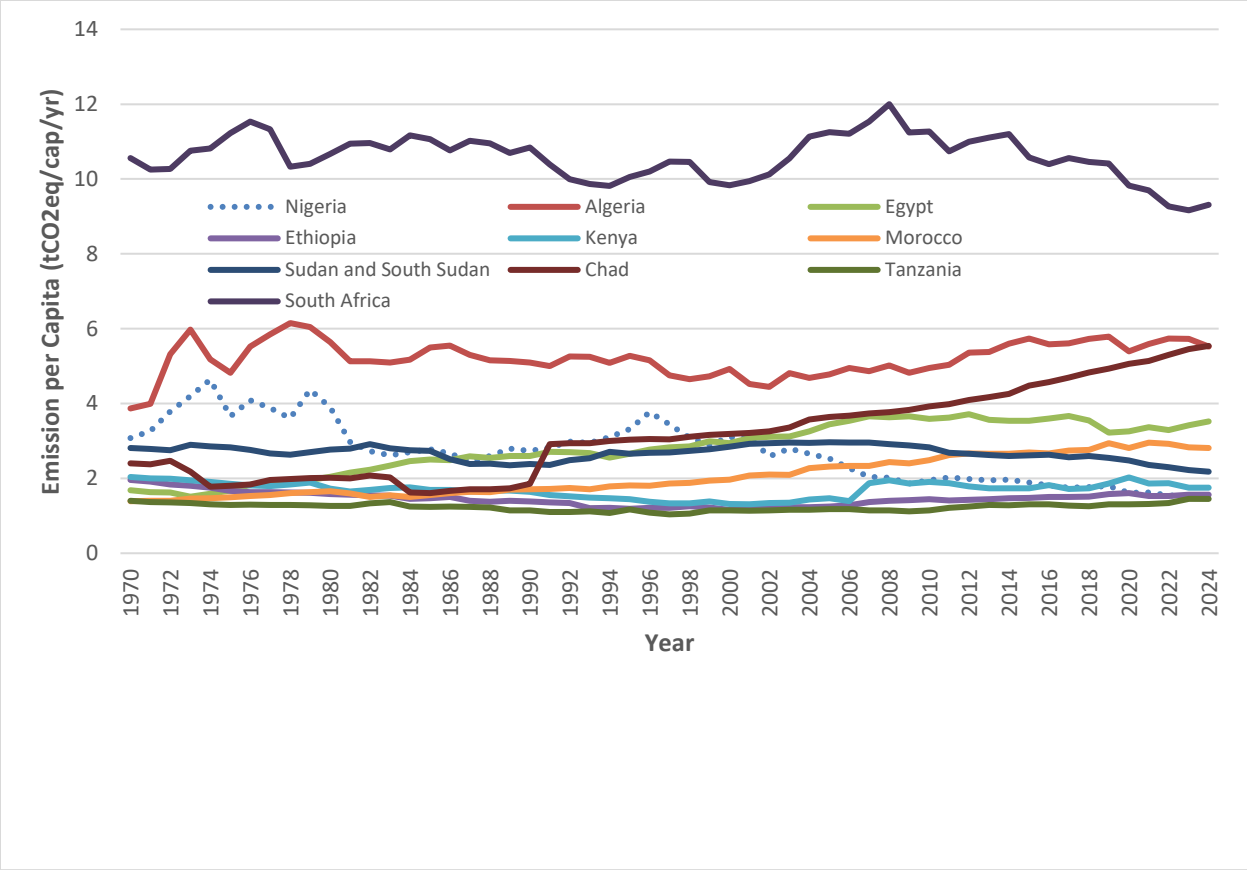


Fig 9 GHG Emission per Capita of African Top 10 Emitters

To determine if each country's per capita GHG emission has changed significantly over the period (1970 – 2024) and how fast it has changed, the Mann-Kendall trend test and Sen's Slope Estimator (Hipel and McLeod, 1994) was conducted. The result of the tests is summarized below:

Mann–Kendall and Sen's Slope Results

Country	*n*	*MK S*	*Kendall's τ*	*Z*	*p-value*	*Trend*	*Sen's slope*
Nigeria	55	−1,009	−0.672	−7.318	<0.001	Decreasing	−0.0426
Algeria	55	113	0.075	0.813	0.416	No significant trend	+0.0047
Egypt	55	1,175	0.784	8.523	<0.001	Increasing	+0.0433
Ethiopia	55	−261	−0.173	−1.887	0.059	No significant trend	−0.0043
Kenya	55	−199	−0.132	−1.437	0.151	No significant trend	−0.0030
Morocco	55	1,377	0.918	9.989	<0.001	Increasing	+0.0304
Sudan and South Sudan	55	−325	−0.217	−2.352	0.019	Decreasing	−0.0044
Chad	55	1,195	0.797	8.668	<0.001	Increasing	+0.0692
Tanzania	55	−101	−0.067	−0.726	0.468	No significant trend	−0.0006
South Africa	55	−229	−0.152	−1.655	0.098	No significant trend	−0.0104

Significance criterion: $\alpha = 0.05$. Sen's slope is expressed in tCO_2-eq/capita/year per year.

From the result above, Nigeria shows a strong and statistically significant decreasing trend in per-capita GHG emissions:

$\tau = -0.672$, $Z = -7.318$, $p < 0.001$

with a Sen's slope of approximately:

-0.0426 tCO_2-eq/capita/year

This means that, over 1970–2024, Nigeria's per-capita GHG emissions exhibited a strong downward monotonic trend.

This contrasts markedly with Egypt, Morocco and Chad, all of which show highly significant increasing trends. Sudan and South Sudan also show a statistically significant decline.

3.8 Discussion of Results

The comparative analysis demonstrates that Nigeria occupies a complex and multidimensional position within Africa's greenhouse gas (GHG) emissions landscape. The country's position changes considerably depending on whether emissions are assessed in terms of absolute magnitude, population, economic output or land area. In absolute terms, Nigeria is one of Africa's largest GHG emitters, ranking third among the ten highest-emitting countries in 2024, with emissions of 350.56 $MtCO_2e$, behind South Africa (569.81 $MtCO_2e$) and Egypt (386.60 $MtCO_2e$). However, its relatively low compound annual growth rate (CAGR) of 1.34% over 1970–2024 indicates that its large present-day emissions are not primarily the result of exceptionally rapid growth during the entire study period. Rather, Nigeria entered the period with a comparatively high emissions base of 172.37 $MtCO_2e$ and experienced considerable fluctuations, including a peak of approximately 417 $MtCO_2e$ in 1996. This distinction between emission scale and emission growth is important because a country's contribution to the continental emissions burden depends not only on its rate of increase but also on its initial level and accumulated emissions. Consequently, Nigeria's relatively modest CAGR cannot be interpreted as evidence of a low-emitting economy; its large absolute emissions continue to make it an important contributor to Africa's mitigation challenge.

The comparison with the other major African emitters reinforces this interpretation. Chad recorded the highest CAGR (4.66%), followed by Tanzania (3.18%), Egypt (3.52%), Morocco (2.99%), Algeria (2.83%) and Kenya (2.82%), whereas Nigeria recorded the second-lowest growth rate among the ten countries, at 1.34%, with only South Africa lower at 1.78%. The high growth rates of countries such as Chad and Tanzania need to be interpreted cautiously because they began from substantially smaller emissions bases. Chad, for example, increased from 8.75 $MtCO_2e$ in 1970 to 101.17 $MtCO_2e$ in 2024, representing an approximately twelve-fold increase, yet its 2024 emissions remained far below Nigeria's 350.56 $MtCO_2e$. This illustrates the importance of distinguishing *relative growth* from *absolute emissions burden*. A high CAGR can indicate a rapidly changing emissions trajectory without necessarily making a country one of the dominant contributors to continental emissions. Conversely, Nigeria's lower CAGR reflects the fact that its emissions were already substantial at the beginning of the study period and subsequently fluctuated rather than following a continuously increasing trajectory.

The temporal comparison further indicates that Nigeria's emissions trajectory differs from that of several other major emitters. From approximately 2008 to 2024, Nigeria maintained a relatively stable total-emission trajectory, whereas South Africa, Egypt, Algeria and Ethiopia displayed generally increasing trajectories. This relative stability is noteworthy given Nigeria's demographic and economic expansion. Previous research on African oil-producing countries has demonstrated that the relationships among economic growth, energy consumption and GHG emissions are strongly influenced by the characteristics of fossil-fuel-dependent economies. In a study covering African OPEC countries, Yusuf et al., (2020) found important relationships among GHG emissions, energy consumption and economic growth, including Nigeria, Algeria, Angola, Equatorial Guinea, Gabon and Libya. Similarly, decomposition research on oil-producing sub-Saharan African countries has shown that structural effects and changes in the carbon intensity of energy use can play important roles in determining emissions intensity (Ebohon and Ikeme, 2006). Thus, Nigeria's relatively stable recent total emissions should not automatically be interpreted as evidence of a complete transition away from carbon-intensive development; rather, it may reflect the interaction of economic fluctuations, changes in the petroleum sector, energy demand, technological conditions and other structural factors.

An important finding concerns Nigeria's share of total African GHG emissions. The analysis indicates a weak negative trend in Nigeria's contribution between 1970 and 2024, with Kendall's $\tau = -0.126$ and $p = 0.177$. Therefore, although Nigeria's percentage contribution appears to have declined somewhat over the study period, the decline is not

statistically significant at the 5% level. This finding suggests that Nigeria has not experienced a statistically demonstrable structural reduction in its relative contribution to Africa's total GHG emissions. Instead, changes in Nigeria's emissions have broadly occurred within the wider expansion and transformation of African emissions. This is consistent with recent research showing considerable heterogeneity in African countries' GHG trajectories rather than a uniform continental pathway. Apeaning and Labaran (2024), for example, identified multiple convergence patterns among African countries and found substantial heterogeneity across sectors and countries. Earlier research by Solarin (2014) similarly found evidence of convergence in relative per-capita CO_2 emissions for a number of African countries, while also demonstrating differences among national trajectories. Nigeria's statistically insignificant change in continental share therefore suggests that its position as a major emitter has remained relatively persistent despite fluctuations in its absolute emissions.

The per-capita results provide a substantially different perspective from the absolute-emissions ranking. The data show that Nigeria's per-capita GHG emissions declined from 3.079 tCO_2e/capita in 1970 to 1.538 tCO_2e/capita in 2024, whereas the African average declined from 3.603 to 2.741 tCO_2e/capita over the same period. Consequently, Nigeria's per-capita emissions in 2024 were approximately 1.203 tCO_2e/capita below the African average. This finding is particularly important because it demonstrates why absolute emissions alone can give an incomplete picture of a country's emissions responsibility. Nigeria's large population means that its aggregate emissions are substantial, but when those emissions are normalized by population, its position is considerably less pronounced. The contrast illustrates the importance of employing multiple indicators when evaluating national climate performance.

The statistical comparison between Nigeria and the African average further strengthens this interpretation. The Pearson correlation coefficient of $r = 0.465$ ($p < 0.001$) indicates a moderate and statistically significant positive association between Nigeria's annual per-capita GHG emissions and the African average. This suggests that Nigeria's year-to-year emission movements are partly synchronized with broader African patterns, even though the level of emissions and the long-term rates of change differ. The result is consistent with the wider African literature, which indicates that countries can share broad emissions dynamics while belonging to different convergence or emissions trajectories. Apeaning and Labaran (2024) found multiple local convergence patterns across African countries and emphasized the heterogeneous nature of emissions development across sectors and national economies. Therefore, the moderate correlation observed in this study should be interpreted as evidence of similar temporal movement, rather than evidence that Nigeria has an emission profile identical to the African average.

The trend analysis also calls for a more cautious interpretation. The conventional Mann-Kendall results indicate a strong negative tendency in Nigeria's per-capita emissions, with Kendall's τ of approximately -0.679 and a Sen's slope of -0.0426 tCO_2e $capita^{-1}$ $year^{-1}$. The African average has a much weaker negative Sen's slope of -0.0063, while the Africa-Nigeria difference has a positive slope of 0.0384. At first sight, these results suggest that Nigeria's per-capita emissions have declined considerably faster than the African average and that the gap between Nigeria and the continent has widened. However, the lag-1 autocorrelation coefficients are extremely high; 0.929 for Nigeria, 0.908 for Africa and 0.923 for the difference series. This strong serial dependence means that the observations cannot be treated as statistically independent. Once autocorrelation is accounted for, the adjusted Mann-Kendall p-values are 0.071 for Nigeria, 0.155 for the African average and 0.083 for the difference series. Thus, none of the three trends is statistically significant at the 5% level.

This finding is methodologically important. The negative Sen's slope for Nigeria nevertheless indicates the direction and magnitude of the observed change, but the autocorrelation-adjusted Mann-Kendall test indicates that the evidence is insufficient to characterize that change as a statistically significant monotonic trend at $\alpha = 0.05$. The same applies to the apparent widening of the Nigeria-Africa per-capita emissions gap. The positive Sen's slope of 0.0384 suggests that the difference generally increased in favour of lower Nigerian per-capita emissions, but the adjusted p-value of 0.083 means that this apparent divergence is not statistically significant at the conventional 5% threshold. This distinction strengthens rather than weakens the study because it prevents visual differences from being presented as statistically established trends. It also demonstrates the importance of accounting for serial correlation in long environmental time series.

The comparison of GHG emissions relative to GDP provides another important dimension of Nigeria's emissions performance. The results indicate that Nigeria's GHG/GDP ratio and that of the African average declined substantially from 2009 to 2024. Nigeria's Kendall's τ was approximately -0.800, compared with -0.817 for the African average,

while the estimated slopes were −0.00674 and −0.00634 per year, respectively. Both conventional Mann-Kendall tests produced p-values below 0.0001. The results therefore suggest a substantial decline in GHG emissions per unit of economic output for both Nigeria and the African average, with Nigeria showing a slightly steeper rate of decline. This research estimates that Nigeria's GHG/GDP declined by approximately 23.5% over the period compared with approximately 18.7% for the African average.

The GHG/GDP results are particularly relevant to the concept of *relative decoupling*. A declining emissions-to-GDP ratio means that fewer GHG emissions are being generated per unit of economic output, although it does not necessarily mean that absolute emissions are declining. This distinction is crucial. Research on Nigeria has shown that economic growth, energy consumption and environmental quality can have complex and sometimes opposing relationships. Rafindadi (2016), for example, found that economic growth increased CO_2 emissions in Nigeria, while energy consumption also exerted a significant emissions-increasing effect. Similarly, research on sub-Saharan Africa identifies technological change, energy composition, substitution between production inputs and economic growth as important influences on energy intensity (Lin and Abudu, 2019). The declining GHG/GDP ratio observed in this study should therefore be interpreted as evidence of *improving emissions efficiency of economic activity*, rather than definitive proof of absolute decoupling between economic growth and emissions.

The year 2006 is also noteworthy because the GHG/GDP trajectories of Nigeria and the African average converged at approximately that point, after which Nigeria's indicator remained below that of the African average through 2024. This suggests that Nigeria's economic activity has become progressively less GHG-intensive relative to the continental benchmark. Nevertheless, this result should not obscure the structural characteristics of the Nigerian economy. Nigeria's dependence on petroleum and other fossil-fuel-related activities means that improvements in GHG/GDP can coexist with substantial absolute emissions. Studies of Nigeria and other oil-producing African economies similarly emphasize the importance of energy consumption and economic structure in shaping emissions outcomes (Yusuf et al., 2020.). Therefore, the observed improvement in GHG/GDP represents an encouraging efficiency signal but does not by itself demonstrate a comprehensive transition to a low-carbon economic structure.

The emission-density analysis introduces a spatial dimension that cannot be captured by either per-capita emissions or GHG/GDP. Nigeria has a land area of approximately 923,770 km^2, making it the third-smallest country by area among the ten major emitters considered, after Morocco and Kenya. Because Nigeria combines a relatively large absolute emissions volume with a comparatively limited land area, its GHG emission density is correspondingly high. The results show that Nigeria's emission density is generally higher than that of most of the other major African emitters, with South Africa being the principal exception. This finding illustrates why spatial normalization is valuable: two countries with similar total emissions can have very different implications when their land areas differ substantially.

The temporal behaviour of Nigeria's emission density is nevertheless noteworthy. Unlike most of the other top ten emitters, whose emission densities generally increased, Nigeria experienced a peak around 1996 followed by a decline. South Africa displayed a similar pattern, although its peak occurred much later, around 2019. The decline in Nigeria's emission density after its 1996 peak is consistent with the relative stability and subsequent moderation of total emissions identified elsewhere in the analysis. However, interpreting declining emission density strictly as "improved land-use efficiency" requires some caution. Emission density is influenced simultaneously by total emissions and land area, and changes in emissions may originate from energy, industrial, transport, agricultural or other sectors rather than from changes in land-management efficiency itself.

The similarity between Nigeria's emission density and Egypt's during 2022–2024 is also informative. This paper notes that Nigeria's emission density approached that of Egypt despite Egypt having a slightly larger land area. This indicates that Nigeria's high spatial emissions burden is not simply a consequence of its being one of Africa's largest emitters; its relatively smaller territorial area also contributes significantly to its high emissions-per-unit-area indicator. Consequently, spatial intensity provides another example of how the interpretation of Nigeria's climate performance depends on the denominator selected.

The per-capita comparison with the ten largest emitters provides perhaps the strongest evidence that Nigeria's emissions profile cannot be adequately characterized using total emissions alone. Nigeria's large population substantially dilutes its aggregate emissions when expressed on a per-capita basis. The Mann-Kendall and Sen's slope

results show considerable heterogeneity among the ten countries. Nigeria recorded a strong negative conventional trend ($\tau = -0.672$; Sen's slope = −0.0426), while Egypt, Morocco and Chad recorded strong positive trends. Sudan and South Sudan also showed a negative trend, whereas Algeria, Ethiopia, Kenya, Tanzania and South Africa did not exhibit statistically significant conventional trends at the 5% level. This heterogeneity is consistent with the broader African literature, which has found multiple emissions trajectories rather than a single continental pathway (Apeaning and Labaran, 2024).

The contrast between Nigeria and countries such as Egypt, Morocco and Chad is especially significant. Egypt's per-capita emissions increased at a Sen's slope of 0.0433 tCO_2e $capita^{-1}$ $year^{-1}$, Morocco's at 0.0304 and Chad's at 0.0692, while Nigeria's slope was −0.0426. These divergent trajectories likely reflect differences in demographic growth, economic structure, energy systems, industrialization, agricultural activity and resource endowments. Recent research on Africa's GHG convergence similarly emphasizes that differences in wealth, industrialization, trade intensity, renewable-energy use and sectoral composition help explain heterogeneous emissions pathways across countries (Apeaning and Labaran, 2024). Therefore, Nigeria's declining per-capita emissions should not necessarily be interpreted as evidence that Nigeria has achieved superior climate policy performance across all dimensions; rather, it reflects the interaction of demographic and economic factors with the country's evolving emissions structure.

Taken together, the results demonstrate a pronounced *emissions-scale versus emissions-intensity paradox* in Nigeria. Nigeria is a major contributor to Africa's aggregate GHG emissions, yet its per-capita emissions are comparatively low and its GHG emissions per unit of GDP have declined substantially. At the same time, its emissions density is relatively high because of the combination of large absolute emissions and comparatively limited land area. These apparently contradictory findings are not mutually exclusive. They demonstrate that national emissions performance is inherently multidimensional. A country can be a major emitter in aggregate while having relatively low per-capita emissions and improving economic emissions intensity. This is particularly relevant to climate policy because different indicators answer different policy questions: total emissions are relevant to continental mitigation potential; per-capita emissions inform distributional and climate-justice considerations; GHG/GDP indicates the emissions intensity of economic activity; and emission density provides information on spatial concentration.

The findings also have implications for the application of the principle of Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC). Nigeria's third-place position in absolute African emissions means that it has an important role to play in continental mitigation. However, its comparatively low per-capita emissions indicate that the country's contribution must also be interpreted in relation to population and development needs. The distinction is particularly important in international climate negotiations because aggregate emissions and per-capita responsibility can lead to different assessments of national responsibility. The results therefore support a more differentiated understanding of Nigeria's climate position: Nigeria cannot reasonably be treated as a negligible emitter given its absolute emissions, but neither can it be evaluated solely on the basis of aggregate emissions without considering its population size, relatively low per-capita emissions and declining GHG/GDP.

Overall, the study suggests that Nigeria should be regarded neither simply as an African *GHG-emission leader* nor as a *climate-performance laggard*. Instead, its position is conditional on the metric used. Its high absolute emissions and high emission density identify it as an important target for mitigation interventions, while its relatively low per-capita emissions and declining GHG/GDP indicate areas of comparatively favourable performance. The relatively stable total-emissions trajectory since about 2008 and the lower CAGR compared with most of the other major emitters further suggest that Nigeria's future contribution to Africa's emissions will depend heavily on whether economic and population growth are accompanied by continued improvements in energy efficiency, expansion of low-carbon energy sources, reduction of fossil-fuel-related emissions and structural transformation. Evidence from Nigeria indicates that energy consumption remains closely connected to environmental outcomes, while research across sub-Saharan Africa emphasizes the importance of energy efficiency, technological change and energy composition (Rafindadi, 2016).

Finally, the statistical analysis provides an important qualification to the interpretation of Nigeria's per-capita trajectory. The descriptive evidence strongly indicates that Nigeria's per-capita GHG emissions have fallen relative to both their historical level and the African average, but the autocorrelation-adjusted Mann-Kendall results do not establish a statistically significant monotonic trend at the 5% level. This finding illustrates the value of combining descriptive comparisons with robust statistical inference. In contrast, the GHG/GDP analysis provides strong evidence of declining emissions intensity over 2009–2024, although this is interpreted as improvement in economic emissions

efficiency rather than unequivocal absolute decoupling. Collectively, the evidence demonstrates that Nigeria's GHG trajectory is characterized by **high aggregate emissions, relatively low per-capita emissions, declining emissions intensity and relatively high spatial emissions intensity**. This multidimensional profile is the principal insight emerging from the comparative analysis and provides a more balanced basis for assessing Nigeria's role in Africa's climate-change mitigation and sustainable-development agenda.

4.0 CONCLUSION

This study conducted a comparative analysis of Nigeria's greenhouse gas emissions within the African continent over 1970–2024 using multiple indicators. The findings reveal that Nigeria's emissions position is multidimensional and depends on the metric employed. In absolute terms, Nigeria ranked third among Africa's top ten emitters in 2024 with 350.56 $MtCO_2e$, yet its compound annual growth rate of 1.34% was the second-lowest, reflecting its already substantial 1970 emissions base and subsequent volatility. Nigeria's percentage contribution to Africa's total emissions exhibited a weak, statistically insignificant declining trend ($\tau = -0.126$; $p = 0.177$), indicating relative stability in its continental share.

The per-capita analysis revealed a contrasting picture: Nigeria's per-capita emissions declined from 3.079 to 1.538 tCO_2e/capita over the study period, remaining below the African average since 1984. However, after accounting for strong serial autocorrelation, the adjusted Mann–Kendall test indicated that neither Nigeria's declining trajectory nor the apparent widening of the Nigeria-Africa gap was statistically significant at the 5% level (adjusted $p = 0.071$ and 0.083, respectively). In contrast, GHG emissions per GDP declined significantly for both Nigeria and the African average from 2009 to 2024, with Nigeria exhibiting a slightly steeper decline, indicating improving carbon efficiency of economic activity. Emission density analysis revealed that Nigeria's combination of large absolute emissions and relatively small land area results in high spatial emissions intensity, although a post-1996 decline suggests improving land-use efficiency.

The study concludes that Nigeria's emissions profile is characterised by a pronounced scale-versus-intensity paradox: high aggregate emissions coexist with low and declining per-capita emissions, improving emission intensity, and high spatial density. This multidimensional profile supports Nigeria's position under the CBDR-RC principle in international climate negotiations, while also identifying the country as an important target for mitigation interventions. Future progress will depend on accelerated improvements in energy efficiency, expansion of low-carbon energy, structural transformation, and absolute emission reductions alongside continued per-capita and intensity gains.

Data Availability Statement
Data supporting the findings of this study are openly available by the Emissions Database for Global Atmospheric Research (EDGAR) of the European Commission at https://edgar.jrc.ec.europa.eu/report_2025.

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