Examining the Role of Trade on the Relationship between Environmental Quality and Energy Consumption: Insights from Sub-Saharan Africa

Abstract

In spite of the overwhelming evidence linking the energy use and environmental quality, the part played by international trade in the relationship has not been thoroughly studied, particularly in Sub-Saharan Africa. This study, which includes 35 selected economies in Sub-Saharan Africa divided into 20 low-income countries (LICs) and 15 middle-income countries (MICs), examines the moderating influence of trade on the nexus between energy use and environmental quality between 1996 and 2020. In this regard, the cross-sectional augmented autoregressive distributed lag (CS-ARDL) was employed. The results showed that, especially in MICs, energy use has an unfavorableconsequence on the quality of the environment. It also demonstrated that trade's effectiveness considerably reduces the damaging effects of energy use on the environment. We suggest that the newlysigned and ratified African Continental Free Trade Agreement (AfCFTA) outline a number of ways that State Parties are required to deepen the links between the AfCFTA and the environment, with an emphasis on practical strategies and tactics.

JEL Classifications:Q43, F13, C23, Q58

Keywords: Energy Use, Environmental Quality, Trade, CS_ARDL, AfCFTA

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1.0 Introduction

One of the most significant issues facing both developing and industrialized nations worldwide is the climate change. As the state of the earth continues to deteriorate, governments, international organizations, corporate groups, and academia appear to have all begun to pay attention to this growing crisis. **Akadiri et al. (2019**) claim that emissions of CO_2 are to blame for this damage. Similarly, economic activities are typically to blame for high levels of carbon emissions, according to **Eregha&Mesagan (2017).** The type and quantity of products and services an economy creates and consumes determine its rate of growth. To make a living, there is always a tendency to produce and market. The standard of living is heavily influenced by the commodities and services that are made available to the populace in society at large. Growth also has a development component that makes equal distribution feasible. In order to do this, products must be transported around the globe. To improve the quality of living, production, particularly in the manufacturing sector, is exported from one nation to another**(Mesagan et al., 2022).** The majority of the commodities and services imported by developing countries come from the industrialized countries. As a result, Sub-Saharan Africa (SSA) has witnessed an unprecedented increase in the tendency of importing both new and second-hand goods from these countries since the late 1980s, partly for consumption and industrial uptake.

Asserting a link between economic activity and environmental quality are **Faruq (2023**), **Ahmad & Du (2017**), **Padhan et al. (2019), Kahia et al. (2019), and Ahmad & Du (2019).**This implies that attempts to promote economic growth, particularly through industrial and manufacturing activities, are linked to an increase in energy consumption, which fuels carbon emissions, which in turn degrades environmental quality. The reason for this is that SSA economies are largely dependent on technologies that use energy sources like coal, gas, and fossil fuels, which are perceived to be less expensive to consume yet with high negative environmental effects, in their efforts to promote economic expansion. This reasoning is in line with the first-order condition of the Kuznet Curve (EKC) of environment, which holds that as the economy expands, carbon emissions increase and have a detrimental effect on the environment. Unfortunately, the majority of the world's economies, especially the SSA, are not affluent enough to use less carbon-emitting (energy-efficient) technologies to drive their growth expansion-drive.

More specifically, it's crucial to understand how environmental quality and economic development are related. According to **Abdouli and Hammami (2017**), there is evidence for both a one-way causal link between environmental quality and growth, on one hand, and a causative flow in the other direction, on the other hand, with growth driving environmental change. According to the research, increased economic activity—including production, distribution, and trade—degrades the quality of the environment because it causes biodiversity loss, deforestation for the creation of industries and manufacturing facilities, and carbon emissions from the use of heavy energy. Likewise, the findings of **Danish and Wang (2018), Saud et al. (2019), and Akadiri et al. (2019)**—which found a reciprocal connection between the quality of the environment and economic performance. This shows that while economic success is constrained by environmental quality, environmental vulnerability is increased by economic performance. This illustrates how tighter environmental controls designed to enhance environmental quality can restrict industrial/manufacturing activities, which consequently slows economic growth**(Olaniyi et al., 2023)**.

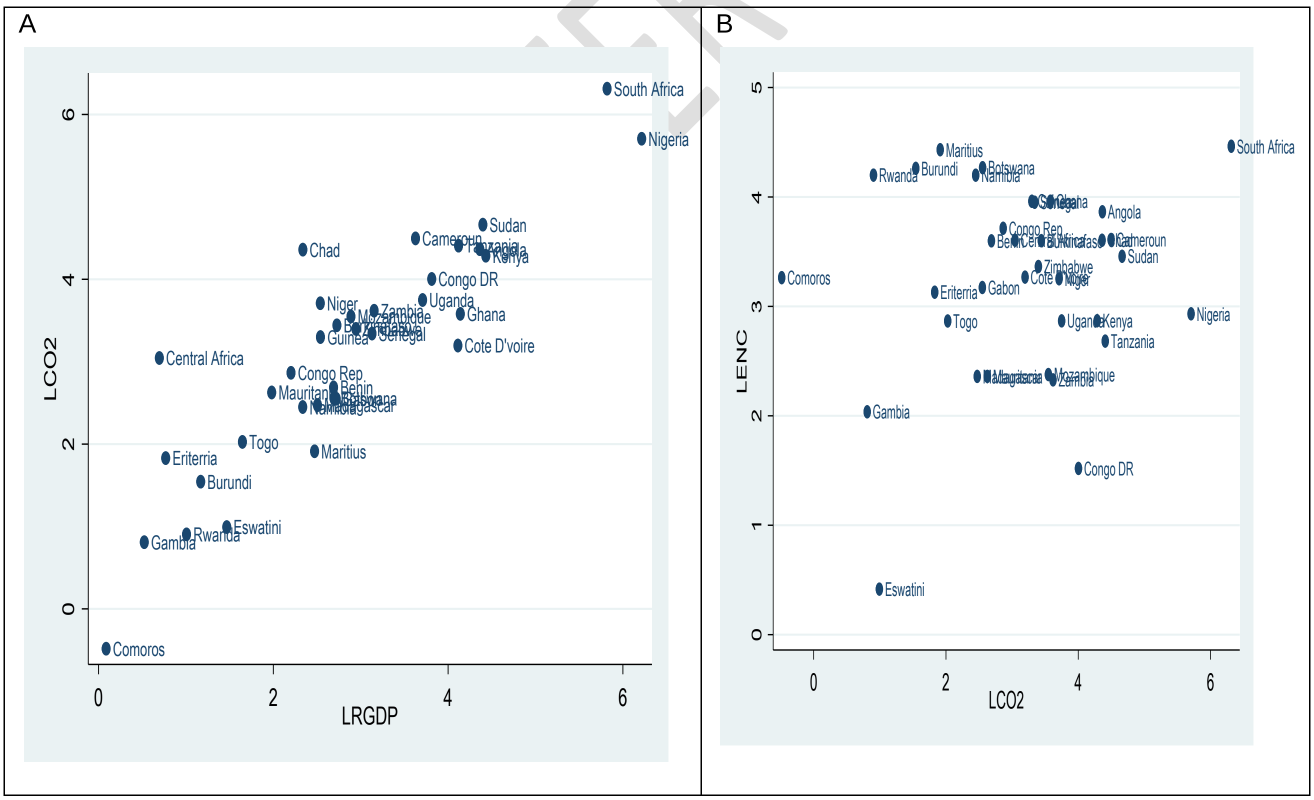
Meanwhile, SSA countries, which are solely grouped into middle-income and low-income economies, are currently experiencing influx of all sorts of imports due to globalization. For instance, products like auto tailpipes, used electrical and electronics equipment (UEEE) and used clothing, which cost tens of billions of dollars, which release harmful pollutants and heat-trapping gases, are prevalent across the SSA countries **(Abubakar*et al.,* 2018; Agbo, 2018**). As latent demand for industrial technologies and consumer products like cars are stimulated across the developing economies, a significant amount of outdated, used, and on the verge of being discarded goods are making their way to low- and middle-income country marketplaces, especially in the SSA. As a result, there is a significant buildup of carbon emitting (energy-inefficient) technologies as well as secondhand goods in these countries without enough funds to deal with concerns like air pollution, climate change, or other environmental **problems(Olaoye&Dauda, 2022)**. The empirical results show that it may be difficult to predict how international trade has induced energy consumption with its attendant effects on the climate in SSA.Additionally, given that trade in manufactured goods is a part of ecosystems and some anti-globalization activists contend that increased global trade is fundamentally detrimental to the environment, it is possible to conclude that this practice is even more harmful **(Krugman et al., 2013).**It is clear that trade in manufactured goods has a considerable influence on the quality of the environment, especially in the developing nations. Consequently, this is the reason why the interaction between environmental quality and trade seem to attract our attention in this study. While considerable damage has been brought about by climate change, the harms that can be expected if we continue on our current course of "business as usual," are on the edge of being truly catastrophic **(Maslin 2009; Urry 2011)**. However, as **Giddens (2009)**emphasizes, the creation of excessive climate change is not solely the result of ignorance; in reality, there is widespread awareness that enormous carbon emissions are being generated.

Thus, it is crucial to explicitly look into how energy consumption and international trade interact to affect how well are African countries doing in terms of environmental quality (**Quadri et al., 2023**). This is due to the fact that African economies have resolved to increase energy consumption that enhances environmental quality despite an abundance of cheap sources of energy to speed up economic activities in these countries(**Adigwe et al., 2023**). In light of this, ourpaper's subsequent sections are as follows: the review of the literature is covered in part 2, and research methodology is covered in section 3. The themes of sections 4 and 5 are respectively, empirical analysis and discussion of results, conclusion, and policy recommendations.

1.2 Stylized facts on Sub-Saharan African Economies

The SSA countries are divided into two of the middle-income countries are the economies with per capita gross national income of more than US$995, in the years 2015–17 while the low-income economies are those with equal to or less than US$995, in the same period. The average values of real gross domestic product (RGDP) and carbon emission (CO_2) for SSA countries from 1996 to 2020 are depicted in panel A of Fig. 1. It is evident that countries with higher level of RGDP such as Nigeria and South Africa are associated with higher level of carbon emissions while in countries such as Rwanda, Eswatini and the Gambia with low level of RGDP are associated with lower level of carbon emission. However, in panel B, the average values of energy usage and carbon emissions are depicted. The pattern of the relation between these two variables appears not too discernible.

Figure 1. Average RGDP, Energy Use and Carbon Emissions in Sub-Saharan Africa (1996–2020).



Source: Author's Computation from World Development Indicators (2021)

2.0 Review of Literature

According **to Baz et al. (2020**), in Pakistan, found that energy use is causally linked with environmental quality with indications of an unequal impact.**Mesagan&Olunkwa (2020)** showed that capital has a substantial direct impact on carbon emission and that capital also drives energy usage to enhance environmental quality. While **Adejumo (2019**) found that in Nigeria energy consumption produces carbon with its attendant effects on environmental quality, and the study supports the EKC preposition. **Salahuddin&Gow (2019)** focused on Qatar, found that environmental damage is caused by both energy use and GDP per person. Between 1972 and 2012, I, n Iraq**Akadiri et al. (2019**) revealed a unit-directional relationship between energy use and CO_2 emissions as well as between economic performance and energy use.**Kahia et al. (2019)** in his study of 12 MENA countries found that as the economy expands, environmental quality deteriorates. Also, it was found that FDI, renewable energy, and global trade all enhance environmental quality by reducing CO2 emissions.According to**Bekun et al. (2019)**gave support for the EKC U-shaped hypothesis regarding the relationship between growth and ecological footprint.

According to **Charfeddine et al. (2018**), found that energy use has a positive and considerable impact on economic production, respectively. Similar circumstances for BRI economies between 1980 and 2016 were explored by **Saud et al. (2018**). They used the DSUR technique of estimate, and the results showed that trade, FDI, and financial development promote environmental quality while energy use and economic performance decrease it. **Rahman and Kashem (2017)**discovered that energy use, export, and population density have an adverse influence on the environment. **Eregha&Mesagan (2017**) investigated the position of various energy-dependent economies in Africa. They demonstrated that economic output is positively and dramatically impacted by energy usage and oil prices**(Adebiyi et al., 2023**).

The studies conducted by **Ahmad & Du (2017), Abdouli&Hammami (2017), Padhan et al. (2019), Akadiri et al. (2019), and Akadiri et al. (2019)** all appear to be remarkably comparable to this one. These earlier studies focused on the direction of influence between environmental quality, energy consumption, and economic growth, but the current study extended the frontiers of knowledge through the use of the recent CS-ARDL estimator, introduced by **Chudik et al. (2016)**, and alsointerconnects energy consumption and trade in order to ascertain if emission reduction through energy consumption assisted by international trade has a significant impact on the corresponding quality of the environment in SSA countries. This is the primary original contribution of the study.

3.0 Theoretical Framework and Methodology

3.1 Theoretical Framework and Model Specification

The theory of the treadmill of production, which highlights the manner in which the relentless pursuit of growth in the economy causes economies all over the world to become "entrapped on a treadmill," in which their well-being cannot be enhanced by economic expansion but the consequences of this pursuit of growth creates vast, detrimental environmental damage, provides the framework to examine the relationship between energy use and environmental quality in this study. The theory focuses on how businesses, which control the production process, are the main agents driving the treadmill through energy consumption, and explores the precise driving force that maintains the system of the treadmill so tenaciously, while somehow underscoring the manner in which the state (via environmental regulations) and labor force in general keep supporting the treadmill's continual propagation**(Omogoroye et al., 2023)**. According to the theory, environmental damage results from human pursuit of economic prosperity. The theory's central tenet is that the increased contribution of the manufacturing activities to aggregate production that results from intensive energy utilization leads to economic growth. As more strain is being placed on the environment and carbon emissions are produced as a result of energy utilization, environmental degradation intensifies (**Mesagan&Olunkwa**, **2020**; **Padhan et al., 2019**; **Kahia et al., 2019**)**.**The claim that increasing energy use and economic development have negative consequences on environmental quality is thus theoretically accurate. When the economy of a country is more accessible to international trade, it will have access to more energy-efficient technology, which will help to improve the unfavorable environmental situation. The model summarizing the consequences of the use of energy and regulatory factors on the environment in SSA countries following the above theoretical expositions, and Wu et al. (2021) as cited in Afolabi, (2023):

$$EQ = f(ENC, RGDP, REQ, GCI) \qquad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad 1$$

Where EQ, RGDP, REQ and GCI denote total environmental quality (proxiedby CO_2), real GDP (a proxy for economic growth), regulatory quality and gross capital investment, in that order. The determinants are all expressed in logarithms (rep by the prefix "ln") except the REQ which is in percentile. Thus, elasticity is used to express how the independent variables affect the quality of the environment.

Equation (1) is represented explicitly as;

$$ln\,EQ = \beta_0 + \beta_1 ENC_{i,t} + \beta_2\, ln\,RGDP_{i,t} + \beta_3 REQ_{i,t} + \beta_4\, ln\,GCI_{i,t} + \varepsilon_{i,t} \qquad - \quad - \qquad 2$$

wherei represents a cross-section of countries; t stands for the years 1996 to 2020; β_0 is the intercept;β_1-β_4 are each variable's elasticities; and ε is the noise(error).

In this paper, we investigate whether the degree of trade openness among African economies affects how much energy use from industrial and domestic activities and how clean the environment becomes. Equation (3), which provides a rich method of modeling the moderating impact that internationalization has on the link between energy use and the quality of the environment in SSA, thereby captures the conditional impacts. The conditional effect is represented by include product of the trade openness and energy use as one of the explanatory factors in the equation.

$$ln\,EQ = \beta_0 + \beta_1 ENC_{i,t} + \beta_2\, ln\,TOP_{i,t} + \beta_3\, ln\,ENC_{i,t}\_TOP_{i,t} + \beta_4\, ln\,RGDP_{i,t} + \beta_5 REQ_{i,t} + \beta_6\, ln\,GCI_{i,t} + +\varepsilon_{i,t} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad 3$$

where TOP denotes trade openness; ENC_TOP is the interactive term of energy consumption and trade openness; and all other factors stay the same as they were before. The total impact of energy consumption which includes the marginal influence of trade onthe quality of environment is arrived at by taking partial derivatives of equation (3):

$$\frac{\partial EQ_{i,t}}{\partial ENC_{i,t}} = \beta_1 + \beta_3 TOP_{i,t} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad 4$$

The sign and magnitude of this equation should be considered while interpreting it. Considering the sign, if $\beta_1 > 0$ and $\beta_3 < 0$, energy consumption deteriorates environmental quality (ECF) only when foreign trade offers energy-inefficient technologies. However, if $\beta_1 < 0$ and $\beta_3 > 0$, it implies that using energy-efficient technologies via foreign trade would make energy consumptionenhance environmental quality (EQ). Meanwhile, if$\beta_1 > 0$ and $\beta_3 > 0$, then energy consumption and foreign trade complementarily promote environmental quality (EQ). Lastly, if $\beta_1 < 0$ and $\beta_3 < 0$, the nexus of energy consumption-environmental quality (EQ) has amplifying influence in diminishingenvironmental quality. Considering the magnitude, if $\frac{\partial EQ_{i,t}}{\partial ENC_{i,t}} > 0$, energy consumption together with trade opennessenhance environmental quality (EQ) but if $\frac{\partial EQ_{i,t}}{\partial ENC_{i,t}} < 0$, both energy use and trade openness reduce the quality of environment in the sampled SSA countries.

3.2 Estimation Technique

The unique CS-ARDL estimating technique created by Chudik et al. (2016) is the primary analytical method employed by this paper. Aspects of the Mean Group (MG) and Pool Mean Group (PMG) estimators can be incorporated into the CS-ARDL thanks to Chudik and Pesaran's (2015) dynamic common correlated effects (DCCE) approach while accounting for cross-sectional dependence. It takes into consideration heterogeneous slopes, allows for small numbers of samples, concurrently analyzes both long- and short-run models, handles the problem of cross-sectional dependence, and assumes that parameters are expressed by similar characteristics. Additionally, it can be applied if the panel data is uneven and the series contains structural breaks. These are the five explanations for why we selected this estimator over others. Using the panel ARDL/PMG estimator, the validity of the CS-ARDL estimates is evaluated.Equations (2) in the panel ARDL version are expressed as;

$$\Delta y_{it} = w_i + \delta_i(y_{i,t-1} - \theta_i^{'} x_{i,t-1}) + \sum_{j-1}^{p-1} \phi_{ij}\Delta y_{i,t-j} + \sum_{j-0}^{q-1} \alpha_{ij}\Delta x_{i,t-j} + \varepsilon_{it} \qquad - \qquad - \qquad 5$$

wherey$_{it}$ is environmental quality for economyi at time t; α_{ij} represents a matrix of the regressors(factors); $\theta_i^{'}$ is a connection between y_{it} and x_{it}; in the long-run equilibrium, δ_i is the error correction term; ϕ_{ij} and α_{ij} show the connection between y_{it} and x_{it}in the short-run; and the items in the parentheses denotesin the long-run link.

Chudik et al. (2016)created the CS-ARDL model by adding cross-sectional averages to the dependent and explanatory variables, which accounts for gradient asymmetry and cross-sectional relationships. Equation (5) can be changed to be stated as its CS-ARDL equivalent, which is:

$$\Delta y_{it} = \mu_i + \delta_i(y_{i,t-1} - \theta_i^{'} x_{i,t-1} + \delta_i^{-1} n_i \overline{y_t} + \delta_i^{-1} \varphi_i^{'} \overline{x_t}) + \sum_{j-1}^{p-1} \phi_{ij}\Delta y_{i,t-j} + \sum_{j-0}^{q-1} \alpha_{ij}\Delta x_{i,t-j} + \sum_{j-0}^{p-1} \tau_{ik}\Delta \bar{y}_{t-j} + \sum_{j-0}^{q-1} \Delta_{ik}\varphi \bar{x}_{t-j} + \varepsilon_{it} \qquad - \qquad - \qquad 6$$

Where $\overline{y_t}$ and $\overline{x_t}$are the cross-sectional averages of the cause-and-effectfactors, respectively.

We first carried out some basic testing before applying the CS-ARDL and PMG estimators. These include the panel unit root test, slope homogeneity test, cross-sectional dependence (CD) test, and panel cointegration test. In an attempt to avoid unclear and biased estimates in panel data analysis due to differences in spatio-temporal features, and spatial effects, a CD test must be performed (**Afolabi, 2023; Majeed et al., 2022**). The CD test, which **Pesaran (2004)**first introduced, is described as:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho ij\right) \qquad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad 7$$

where, T, N and ρ_{ij} stand respectively for time, panel data size, and correlation coefficient. The alternative hypothesis contradicts the null hypothesis of the CD test, which claims that there is CD in the sampled nations.

For the dissimilaritiesin the demographic and economic profile of these SSA countries, it is crucial to perform the test for slope homogeneity across the cross-sectional units after the CD test. The estimations can be incoherent if slope heterogeneity is not taken into consideration (**Afolabi, 2023**; **Zuo et al., 2022**). As a result, this study makes use of the slope homogeneity test that **Pesaran and Yamagata (2008**) presented. This is how its test statistic is expressed:

$$\tilde{\Delta}_{SH} = (N)^{\frac{1}{2}}(2K)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - k\right) \qquad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad 8$$

$$\tilde{\Delta}_{ASH} = (N)^{\frac{1}{2}}\left(\frac{2k(T-k-1)}{T+1}\right)^{-\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - k\right) \qquad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad 9$$

Where Δ˜SH and Δ˜ASH are delta tilde and adjusted delta tilde, respectively. The alternative hypothesis of the slope homogeneity test indicates that the gradients are not homogeneous in the cross-sections, contrary to the null hypothesis.

After the slope homogeneity and CD testing, we conducted the panel unit root test. Im, **Pesaran and Shin**(IPS) and Levin-Lin Chu are two examples of first-generation unit root approaches, but they are unable to resolve CD issues (**Wu et al., 2021**). We thus made use of the second-generation cross-sectional augmented CADF and IPS (CIPS), by **Pesaran (2007)**, to establish the order of integration of each variable and account for the observed cross-sectional dependence among the sampled nations. The CIPS test statistic's formula is:

$$CIPS = \frac{1}{N}\sum_{i=1}^{n} \Delta CA_{i,t} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad 10$$

$$\Delta CA_{i,t} = \lambda_i + \lambda_i CA_{i,t-1} + \lambda_i \overline{CA_{t-1}} + \sum_{l=0}^{p} \lambda_{il} \Delta \overline{CA_{t-1}} + \sum_{l=0}^{p} \lambda_{il} \Delta CA_{i,t-1} + \mu_{it} \quad - \qquad 11$$

Where λ_i, $CA_{i,t-1}$, $\Delta CA_{i,t}$, $\overline{CA_{t-1}}$ and $\Delta\overline{CA_{t-1}}$ denotes the intercept, the cross-sectional units, its, first difference, its mean values, and the cross-sectional units' first difference, in that order.

The panel cointegration test is run following the panel unit root test to assess the status of the long-term linkages between the variables. In contrast to more well-known cointegration methods like **Kao and Pedroni**, the **Westerlund**test, developed by **Westerlund in 2007**, delivers objective results and takes CD and heterogeneity into account. The following is a list of expected test results for the **Westerlund** test:

$$\alpha_i(L)\Delta y_{it} = \delta_{1i} + \delta_{2i} t + \alpha_i(y_{it-} - \beta_i^{`} x_{it-1} + \lambda_i(L)^{v_{it}}) + e_{it} \quad - \quad - \quad - \quad - \qquad 12$$

Where $\delta_{1i} = \alpha_i(1)\varphi_{2i} - \alpha_i\varphi_{1i} + \alpha_i\varphi_{2i}$ and $\delta_{2i} = -\alpha_i\varphi_{2i}$ β_i is the EC coefficient and α_i isthe path in which the regressor and regressandcointegrate.

3.3 Data Descriptions and Sources

The study cut-across 35 of 46 SSA countries due to data limitation. The selected 35 countries (see the appendix) are divided into two strata of low-income and middle-income economies. Low-income economies are those with per capita gross national incomes of $995 or less in the years 2015–17, while middle-income economies have per capita gross national incomes of over $995 (World Economic Outlook, 2019).We employed annual secondary data for the period of 1996-2020. Table 1 shows the description and the sources of variables.

Table 1: Data Descriptions and Sources

Variables	Definition	Description	Data Source
EQ	Environmental Quality	captured with carbon emissions (CO_2) measured in kilo tonnes: EQ decreases as CO_2 increases.	World development Indicator, 2022
RGDP	Real Gross Domestic Product	Captured with GDP (US$ Billion 2015 constant)	World development Indicator, 2022
ENC	Energy use	Captured with fossil fuel energy consumed per capita (EN)	World development Indicator, 2022
GCI	Gross Capital Investment	Proxied with gross capital formation	World development Indicator, 2022
TOP	Trade Openness	Captured with trade in % of GDP	World development Indicator, 2022
REQ	Regulatory Quality	Captured with quality of regulations (in Percentile Rank)	World Governance Indicator (2022)
ENC*TOP	Energy use interaction and trade openness interaction	Captured with multiplication energy consumption and trade openness	Derived

Source: Author's Compilation

4.0 Empirical Analysis and Discussion of Results

4.1 Preliminary Analysis

The full sample (the total of the two groups), middle-income countries (MICs), and low-income countries (LICs) are all represented by descriptive statistics in Table 2, as well as the important variables of interest. Although it averaged about 33.17% across the entire sample, it demonstrates that energy use is higher in MICs than in LICs, as expected. This directly correlates with economic activity as represented by RGDP, where the average, minimum, and maximum values of real GDP are higher in MICs than LICs despite having fewer observations. The relatively higher real GDP in MICs in conjunction with higher energy consumption leads to higher carbon emissions in the MICs than in LICs with 73,983 ktand 24,773 ktrespectively. This is a pointer that LICs are likely to be faced with less environmental challenges associated with energy use than the MICs, all things being equal.Similarly, the Sub-Saharan African economiesare somewhat trade opened economies with about 63% but MICs seem to be more opened to international trade with 78% than LICs with 52%. In general, regulatory quality seems to be low in SSA but with higher average in the MICs than in LICs with 36.35% and 21.03% respectively.

Table 2: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
ENC	875	33.1743	22.4628	0	88.1487
RGDP	875	3.37E+10	7.53E+10	5.42E+08	5.09E+11
GCI	875	21.761	9.276	1.525	79.401
CO2	875	45863.185	88678.343	290	560859.98
TOP	875	63.755	29.393	0.757	175.798
REQ	875	27.599	19.702	0.474	86.058
Low-Income Countries					
ENC	500	28.388	19.205	0	70.9902
RGDP	500	1.31E+10	1.84E+10	5.42E+08	9.73E+10
GCI	500	20.688	9.729	1.525	60.156
CO2	500	24773.113	23681.859	290	106250
TOP	500	52.871	22.226	0.757	132.383
REQ	500	21.033	14.707	0.474	60.096
Middle-Income Countries					
ENC	375	39.556	24.811	0	88.149
RGDP	375	6.12E+10	1.07E+11	2.24E+09	5.09E+11
GCI	375	23.192	8.436	11.825	79.401
CO2	375	73983.28	127441.15	2080	560859.98
TOP	375	78.266	31.47	16.352	175.798
REQ	375	36.354	22.001	4.808	86.058

4.2 Correlation Analysis

The magnitude and direction of the correlations between the regressand and the relevant regressors are checked using the correlation test. The intensity of the association raises the question of whether multicollinearity exists or not. Table 3 correlation test results show that there are relatively minor correlations between the factors taken into account, with real GDP having the strongest link with carbon emissions in LICs, MICs, and the total sample. The outcome reveals an absenceof multicollinearity in the model and that there is no particularly strong correlation between the variables. As a result, multicollinearity is not a concern when incorporating all the independent variables into the empirical model.

Table 3: Correlation Matrix

Full Sample						
Variables	ENC	RGDP	GCI	CO2	TOP	REQ
ENC	1					

RGDP	-0.018	1				
GCI	-0.003	0	1			
CO2	0.021	0.881	0.003	1		
TOP	0.015	-0.201	0.381	-0.186	1	
REQ	-0.05	0.107	0.102	0.15	0.203	1
Low-Income Countries						
ENC	1					
RGDP	-0.012	1				
GCI	0.005	0.293	1			
CO2	0.176	0.865	0.356	1		
TOP	0.064	-0.244	0.39	-0.123	1	
REQ	-0.053	-0.087	0.249	-0.11	0.025	1
Middle-Income Countries						
ENC	1					
RGDP	0.133	1				
GCI	0.048	-0.154	1			
CO2	0.313	0.871	-0.163	1		
TOP	0.13	-0.477	0.353	-0.439	1	
REQ	0.584	-0.008	-0.141	0.083	0.058	1

4.3 Cross-sectional Dependence

Following the variance in the homogeneousfeaturesof the sampled countries, cross-sectional dependence (CD) testing is essential in panel analyses. The **Pesaran** CD test result is displayed in Table 4, and it shows that the null hypothesis of no CD could not be accepted at the 1% level of significance. As a result, the dynamics of variables (including carbon emissions, energy usage, real GDP, trade openness, and capital creation) could affect other nations in the sample. This suggests that LICs and MICs in SSA are cross-sectionally reliant. Overall, the outcome supports the Sub-Saharan African region's interconnectedness.

Table 4: Cross-Sectional Dependence

Variable	Full Sample	Low-Income	Middle-Income
lnENC	6.18 (0.0000)	5.23 (0.0000)	4.64 (0.0000)
lnRGDP	102.09 (0.0000)	53.62 (0.0000)	46.89 (0.0000)
lnGCI	12.02 (0.0000)	14.37 (0.0000)	1.2 (0.229)
lnCO2	64.09 (0.0000)	41.92 (0.0000)	20.37 (0.0000)
lnTOP	8.81 (0.0000)	8.71 (0.0000)	9.32 (0.0000)
REQ	42.22 (0.0000)	16.78 (0.0000)	25.85 (0.0000)

4.4 Analysis of The Unit Root

Following the CD test, stationarity tests utilizing appropriate techniques must be carried out. The CIPS and CADF unit root techniques, that is capable of successfully manage CD concerns, were introduced by **Pesaran (2007)**. Table 5 presents the results of these two methods and shows that the variables have heterogeneous order of integration throughout the three models. Some of the series become stable at (I(0)), whereas others do not until they have first been differenced (I(1)). This satisfies a prerequisite for using the CS-ARDL framework. This finding raises the prospect that the variables could cointegrate, necessitating the execution of a cointegration test to explore this potential.

Table 5: The Unit Root Tests

Full Sample				
Variable	**CADF**		**CIPS**	
	Level	First Diff	Level	First Diff
lnENC	-2.309*	-3.018*	-2.738*	-4.766*
lnRGDP	-1.756	-1.994***	-2.021	-3.984*
lnGCI	-2.017***	-2.757*	-2.332*	-4.752*
lnCO2	-1.757	-2.466*	-2.623*	-4.939*
lnTOP	-1.159	-2.918*	-1.73	-4.668*
REQ	-1.732	-2.734*	-2.434*	-5.027*
Low-Income Countries				
lnENC	-2.885*	-3.152*	-2.909*	-4.796*
lnRGDP	-1.865	-2.066***	-1.913	-4.127*
lnGCI	-2.158**	-2.791*	-2.657**	-4.893*
lnCO2	-1.875	-2.552*	-2.582*	-4.919*
lnTOP	-1.43	-2.997*	-1.804	-4.908*
REQ	-2.066***	-2.499*	-2.401*	-4.718*
Middle-Income Countries				
lnENC	-2.17***	-2.613*	-2.144***	-4.816*
lnRGDP	-1.768	-1.844*	-2.323**	-3.616*
lnGCI	-1.734	-2.51*	-1.772	-4.975*
lnCO2	-1.808	-2.308*	-2.297**	-4.798*
lnTOP	-1.602	-2.876*	-1.948	-4.517*
REQ	-1.589	-2.966*	-2.637*	-5.42*

Note: *, **, & * are 1%, 5% & 10% level of sig. respectively**

4.5 Analysis of homogeneity slope

To prevent inconsistent panel estimators, slope parameter status must be determined prior to panel data estimation. Both the model with an interactive term of energy usage and trade openness (Model B) and the model without an interactive element (Model A) are subjected to the slope homogeneity test. According to Table 6, which presents the results of the slope homogeneity test established by **Pesaran and Yamagata (2008)**, the null hypothesis that the slope parameters are uniform throughout the three panels is rejected. The variability in slopes across the sampled nations is amply demonstrated by this result. Therefore, among other factors, Sub-Saharan African nations differ in their levels of energy use and environmental degradation (CO2).

Table 6: Testing for slope heterogeneity

Full Sample

	MODEL A		MODEL B	
	SH	ASH	SH	ASH
VALUE	27.598	31.657	20.029	24.288
PROB	0.000	0.000	0.000	0.000
	Low-Income Countries			
VALUE	19.118	21.93	14.253	17.284
PROB	0.000	0.000	0.000	0.000
	Middle-Income Countries			
VALUE	16.84	19.317	11.883	14.411
PROB	0.000	0.000	0.000	0.000

4.6 Analysis of Cointegration

Due to the shortcomings of conventional cointegration test methodologies, the **Westerlund (2007)** 2nd-generation test was employed.in an attempt to remedy the longitudinal dependency observed across SSA countries. Table 7cointegration result shows cointegration in all three panels for both Models A and B. This merely suggests that since these variables co-move over time, there is cointegration between environmental degradation, energy use, real GDP, trade openness, and gross capital investments.

Table 7: Cointegration Test

	MODEL A			MODEL B		
	FULL SAMPLE					
Statistic	Value	Z-value	P-value	Value	Z-value	P-value
Gt	-2.237	-1.486	0.069	-2.305	0.701	0.758
Ga	-6.75	2.603	0.995	-6.136	5.476	1
Pt	-13.706	-3.269	0.001	-14.788	-1.854	0.032
Pa	-7.537	-1.151	0.125	-7.123	1.948	0.974
	LOW-INCOME COUNTRIES					
Gt	-2.46	-2.094	0.018	-2.462	-0.158	0.437
Ga	-6.87	1.892	0.971	-6.101	4.158	1
Pt	-7.576	-0.273	0.392	-8.791	0.599	0.726
Pa	-6.257	-0.087	0.465	-5.617	2.242	0.988
	MIDDLE INCOME COUNTRIES					
Gt	-1.94	0.148	0.559	-2.462	-0.158	0.437
Ga	-6.591	1.791	0.963	-6.101	4.158	1
Pt	-11.159	-3.866	0	-8.791	0.599	0.726
Pa	-8.405	-1.214	0.112	-5.617	2.242	0.988

4.7 Presentation and discussion of empirical results

In light of the findings from the preliminary tests, the CS-ARDL model is expected to shed more light on the connection between energy use and the quality of the environment in Sub-Saharan Africa (Model A) and assess the mitigating impact of trade openness in lessening the influence (Model B). The results of the analysis, which was conducted on three panels (the complete sample, low-income countries (LICs), and medium-income countries (MICs), are shown in Table 8. The long-run outcomes are provided following the short-run estimations, which are displayed in the top half of the Table.

According to Model A's findings, energy use, regardless of the temporal dimension, has a favorable influence on emissions of carbon in both LICS and MICs. The positive effect demonstrates that as energy consumption rises, environmental degradation occurs in both LICs and MICs, but it is only substantial in the case of MICs. This suggests that increased energy use for industrial purposes causes a rise in carbon emissions, which enables both short- and long-term damage of the environment. Additionally, both in the short- and long-term, Model A shows positive elasticities between carbon emission (CO2) and RGDP as well as GCI in the chosen African countries, which is empirical proof of growing industrial activity in these countries.Empirically, this result is consistent with those made by **Baz et al. (2020)**, **Faruq (2019)**, **Adejumo (2019)**, and **Salahuddin&Gow (2019)**, who found that energy usage promotes environmental degradation in Pakistan, Africa, Nigeria, and Qatar, respectively. The outcome emphasizes the trade-off between energy use and environmental quality in Sub-Saharan Africa's middle-income and low-income nations.

Table 8: Empirical Analysis

	MODEL A			**MODEL B**		
	Full Sample	**Low-Income**	**Middle Income**	**Full Sample**	**Low-Income**	**Middle Income**
D.lnCO2	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**	**Coefficient**
ECT	-1.35(0.039)*	-1.345(0.06)*	-1.27(0.069)*	-1.418(0.047)*	-1.422(0.092)*	-1.355(0.069)*
	Short Run Est.			Short Run Est.		
lnCO2(-1)	-0.35(0.039)*	-0.345(0.06)*	-1.27(0.069)*	-0.418(0.047)*	-0.422(0.092)*	-0.355(0.069)*
LnRGDP	0.168'(0.104)	0.168(0.124)	0.204(0.132)	0.413(0.139)	-0.006(0.108)	0.296(0.101)*
LnENC	41.313(49.937)	37.524(59.68)	0.68(0.34) **	96.70(84.40)	302.1(220.3)	-5.809(2.262)**
LnGCI	0.007 (0.037)	0.03(0.028)	-0.05(0.046)	-0.045(0.053)	0.004(0.035)	-0.126(0.058)**
REQ	-0.003(0.002)	0.001(0.001)	0.004(0.003)	-0.003(0.001)	0.001(0.001)	-0.006(0.004)*
LnTOP				92.81(63.99)	194.7(145.8)	-5.539(1.953)*
lnENC_TOP				-29.07(20.84)	-53.66(44.35)	1.499(0.564)*
	Long Run Est.			**Long Run Est.**		
REQ	-0.002(0.001) ***	0.001(0.001)	-0.003(0.002)	-0.002(0.001)	0.001(0.001)	-0.004(0.003)
LnENC	31.504(38.116)	21.42(40.36)	0.52(0.252) **	67.01(62.09)	189.8(135.6)	-5.113(2.082)**
LnGCI	0.006(0.028)	0.018(0.02)	-0.031(0.038)	-0.039(0.039)	0.010(0.035)	-0.095(0.049)***
LnRGDP	0.127(0.081)	0.129(0.108)	0.131(0.103)	0.107(0.101)	-0.218(0.279)	0.221(0.070)*
LnTOP				65.38(46.84)	132.7(92.39)	-4.682(1.653)*
lnENC_TOP				-20.81(15.65)	-37.28(28.58)	1.307(0.514)**
	Diagnostics			**Diagnostics**		

Obs	805	460	345	805	460	345
Groups	35	20	15	35	20	15
RMSE	0.07	0.05	0.08	0.08	0.05	0.09
CD Statistic	2.8	0.42	-0.38	1.23	-0.412	0.79
P-value	0.0051	0.6759	0.7013	0.2196	0.6792	0.4309

Note: *p < 0.01, **p < 0.05, ***p < 0.10

The importation of more energy-efficient technology, however, has the ability to partially offset the harm that energy usage does to the environment, according to empirical studies (**Kahia et al. 2019, Kashem, 2017)**. Consequently, energy consumption variable and the trade openness variable interacted, and the outcome (given in Model B) is addressed here. Precisely, in the LICS, the result shows that tradeopenness increases the rate of carbon emission which indirectly deteriorates the environment while in MICs, trade is found to reduce the rate of carbon emissions which thus promotes the quality of the environment.Examining its moderating role on the nexus between energy consumption and environmental quality, in MICs, trade is found to significantly dampen the influence of energy use on the degree of carbon emission which therefore facilitates environmental quality both in the short and long runs whereas, in the case of LICs, the reverse is the case. Trade openness worsens environmental degradation. This shows that utilizing global trade to import energy-efficient technologies, particularly in MICs, may be a viable method of raising environmental standards in Sub-Saharan African nations. The result corroborates the findings of **Thuy, & Nguyen, (2022), and Ike et. al, (2020)** in developing economies and G-7 countries, respectively that trade openness dampens the consequence of CO_2 emissions on the damage of the environment. This implies that in promoting environmental sustainability firms in industrial/manufacturing sector must be compelled to import largely environmental-friendly technologies in their production activities.

Furthermore, the results show that real GDP, a measure of economic expansion, has a considerable short- and long-term impact on degradation of the environment in SSA's LICs and MICs. This outcome is conceivable given that rising economic activity increases energy demand and greenhouse gas emissions, which reduces environmental quality. The persistent economic expansion that SSA nations experienced, especially in the first ten years of the twenty-first century, could be blamed for the pollution- and emission-producing effects of economic growth (World Bank, 2018). Additionally, it might be linked to the countries' expanding efforts to industrialize and diversify their economies, which have significantly boosted the magnitude of economic activities in all markets (**Afolabi and Ogunjimi, 2020**).Due to the growing number of economic activities that have a negative impact on the environment and the natural environment, the environment is frequently the victim of these economic activities. If not immediately handled, it might make Sub-Saharan Africa's environmental issues even worse. According to **Afolabi (2023), and Zuo et al. (2022),**this findingfollows theoretical predictions and the views of these researchers.

Likewise, there is a link between big capital expenditures and energy use that is both positive and significant, although it only applies to MICs in the short- and-longterms. This demonstrates how Sub-Saharan Africa's growing investment money promotes environmental deterioration. This study contradicts the findings of **Wu et al. (2021)** and **Awosusi et al. (2022)**, who discovered that, in Uruguay and the MENA region, respectively, trade openness exacerbated damage to the environment. However, the finding shows that degradation of the environment in SSA, and especially in the MICs on the continent, is a trade-off for the pursuit of economic expansion that drives increasing capital investment. Regardless of the time dimension, it was discovered that environmental regulation quality was inversely connected to carbon emission primarily in whole sample and MICs.This shows that passing and putting into practice suitable environmental laws has a noticeableinfluence on reducing carbon emissions and enhancing environmental quality. It is obvious that everyone in sub-Saharan Africa needs to adopt and adhere by laws and regulations that are more environmentally friendly, including greening (**Hassan et al., 2020)**. Not to mention, the error correction terms imply that the pace of recovery from a shock to a long-run equilibrium across economies is somewhat slow.

5.0 Conclusion and Policy Implications

This study addresses the growing concern about the relationship between environmental quality and human activities, particularly in Sub-Saharan Africa, where the pursuit of economic growth comes with significant energy consumption and environmental challenges. Despite an expanding body of knowledge on this topic, the role of international trade in influencing this relationship, especially in Sub-Saharan Africa, has not been thoroughly explored. In light of the escalating trade volumes between Sub-Saharan African countries and developed economies, this research aims to elucidate the moderating effect of trade on the environmental impact of energy usage.

The study classifies Sub-Saharan African countries into Middle-Income Countries (MICs) and Low-Income Countries (LICs) based on per capita income levels. Utilizing reliable databases, annual data for relevant variables spanning 1996–2020 were collected. The analysis employs the CS-ARDL estimator, with robustness tests conducted using the PMG estimator.

The findings reveal that, irrespective of the timeframe considered, energy utilization has an adverse impact on carbon emissions in both LICs and MICs within Sub-Saharan Africa. This indicates that energy consumption negatively affects the ecosystem across the region, with MICs experiencing more significant repercussions. When exploring the moderating role of trade in the relationship between environmental quality and energy usage, it is observed that, in MICs, trade significantly mitigates the adverse effects of energy consumption on carbon emissions, thereby fostering environmental quality in both short and long-term perspectives. Conversely, in LICs, the opposite trend is observed, indicating that trade exacerbates the environmental consequences of energy usage in these countries.

The findings of the study have notable policy implications, leading to key recommendations for Sub-Saharan African (SSA) countries to address the environmental challenges associated with energy usage and economic growth:

i. Implement legislative measures aimed at reducing environmental degradation in SSA, particularly in economies classified as Middle-Income Countries (MICs) and Low-Income Countries (LICs) aggressively pursuing economic growth.
ii. Enforce strict adherence to environmentally friendly policies, especially by manufacturing and agricultural firms involved in importing capital and technologies for industrial purposes.
iii. Place restrictions on the age of secondhand goods that can be imported (e.g., limiting the import of used vehicles to no more than 10 years old).
iv. Promote the use of renewable energy sources in both industrial and domestic settings by deploying modern environmental conservation technologies for environmental audit and management.
v. Sub-Saharan African governments should ensure that foreign-owned businesses and multinational corporations adhere strictly to national environmental legislation and international best practices. Hold these entities accountable for any negative environmental impacts resulting from their operations.

Given the ratification of the African Continental Free Trade Area (AfCFTA), environmental considerations must be prioritized. Define steps that State Parties must take to strengthen the relationship between AfCFTA and the environment. Focus on doable strategies within AfCFTA protocols, including Technical Trade Barriers, Phytosanitary and Sanitary Measures, and Trade Efficiency Annexes.

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Appendix

country	ENC	RGDP	GCI	CO2	TOP	REQ	country	ENC	RGDP	GCI	CO2	TOP	REQ
Angola							Kenya						

Mean	37.05161	5.87E+10	28.03005	70892.53	99.7684	13.68423
Stddev	9.926249	2.32E+10	5.224198	10164.92	30.15368	4.94591
Min	22.12487	2.54E+10	17.71226	54670	51.88745	7.065217
Max	48.30559	8.72E+10	42.82085	87360	152.5471	22.59615
			Benin			
Mean	32.47975	9.00E+09	17.97916	9883.733	51.67812	31.94609
Stddev	7.859682	2.81E+09	3.95315	2962.208	8.105848	10.74164
Min	13.33205	5.07E+09	12.08604	5830	39.09593	7.065217
Max	41.55419	1.47E+10	26.38651	15090	65.26827	48.36956
			Botswana			
Mean	66.65946	1.14E+10	29.01868	13827.87	96.16458	64.30351
Stddev	3.702099	2.78E+09	5.079967	3734.074	11.98678	21.43775
Min	60.17227	6.98E+09	21.69278	8790	77.82069	7.065217
Max	74.68798	1.62E+10	39.11812	25810	125.783	77.17391
			Burkina Faso			
Mean	36.59092	8.76E+09	19.95875	22578	45.60651	38.16142
Stddev	0.003897	3.51E+09	3.789381	5974.004	12.2953	12.34331
Min	36.58346	4.09E+09	13.45168	13840	30.36824	7.065217
Max	36.60339	1.53E+10	27.39178	32210	64.03585	50.27027
			Burundi			
Mean	70.90534	2.55E+09	11.44916	2861.333	31.46396	13.34998
Stddev	0.034857	5.05E+08	4.890496	1044.094	9.072461	5.871138
Min	70.80327	1.90E+09	2.781138	1800	20.96405	4.891304
Max	70.99019	3.23E+09	18.97487	4870	47.2	26.44231
			Cameroun			
Mean	26.20853	2.49E+10	18.54679	84401.87	45.59944	18.62713
Stddev	9.618091	7.36E+09	0.771232	3182.404	5.476809	4.896571
Min	14.65179	1.45E+10	17.19233	79220	33.73898	7.065217
Max	38.31786	3.76E+10	19.81805	90120	56.92442	25.35885
			Central African Republic			
Mean	36.7689	1.88E+09	14.43865	21747.87	42.66578	10.44018
Stddev	0.018716	2.69E+08	6.722864	1501.435	8.304923	4.523707
Min	36.71083	1.50E+09	6.404793	18690	31.49425	5.288462
Max	36.81032	2.55E+09	26	24760	57.14355	21.19565
			Chad			

Mean	16.99163	5.40E+10	19.02934	51925.73	48.89126	38.40462
Stddev	1.459453	1.68E+10	2.618716	15458.57	9.6973	12.14446
Min	12.99901	3.43E+10	15.00382	33030	27.2339	7.065217
Max	19.41169	8.43E+10	24.95072	81010	64.47887	48.80383
			Madagascar			
Mean	10.59264	9.59E+09	18.85782	27468.93	53.78865	28.94896
Stddev	0.013223	1.99E+09	7.491732	1643.617	11.46104	11.65001
Min	10.55672	6.52E+09	9.526116	23040	34.0306	7.065217
Max	10.62766	1.32E+10	38.7461	29580	74.35735	48.03922
			Mauritius			
Mean	78.47927	9.36E+09	22.83584	5291.333	114.5829	64.7359
Stddev	6.272691	2.60E+09	3.490136	1193.792	12.18016	23.44397
Min	63.78766	5.41E+09	17.27291	2960	85.88374	7.065217
Max	84.54236	1.39E+10	29.38878	6850	132.1991	86.05769
			Mauritania			
Mean	10.59156	4.90E+09	30.14703	10792.4	79.19198	27.88764
Stddev	0.000103	1.33E+09	14.28799	1964.209	17.29093	13.16726
Min	10.59143	3.33E+09	9.5438	7610	49.01694	7.065217
Max	10.5919	7.32E+09	49.16682	14290	110.7881	60
			Mozambique			
Mean	8.027336	1.06E+10	34.42761	26984.67	75.90096	28.51752
Stddev	2.096362	4.87E+09	13.026	5039.496	25.59221	9.926838
Min	5.321251	3.77E+09	18.32691	19160	37.74057	7.065217
Max	12.61995	1.82E+10	60.05831	36120	127.2042	47.82609
			Namibia			
Mean	65.03695	8.24E+09	21.91757	11693.33	94.3169	52.00154
Stddev	1.930238	2.33E+09	5.121193	2331.085	11.85499	17.26008
Min	61.75233	4.87E+09	13.69207	9200	75.13927	7.065217
Max	67.11417	1.13E+10	34.77655	19190	123.7628	68.64865
			Niger			
Mean	27.86699	7.25E+09	22.53806	27741.87	39.06491	25.1782
Stddev	18.05342	2.68E+09	7.764145	8331.529	6.056909	8.259258
Min	13.71825	4.11E+09	11.19953	16300	30.83439	7.065217
Max	66.63141	1.26E+10	32.64046	42720	51.94599	40.19608
			Nigeria			

Mea	36.76	7.12E	27.27	50691	74.30	12.39
n	795	+09	253	.6	544	743
Stdd	0.000	2.97E	10.61	17152	18.14	3.075
ev	163	+09	599	.99	185	01
	36.76	2.82E	13.69		46.61	7.065
Min	775	+09	15	28700	003	217
	36.76	1.10E	60.15		126.3	20.39
Max	851	+10	617	81650	508	801
			Comoros			
Mea	26.11	8.07E	16.54	414.6	37.34	9.427
n	684	+08	146	667	154	354
Stdd	0.012	1.75E	2.169	109.5	2.544	3.549
ev	841	+08	261	952	609	874
	26.07	5.42E	11.80		33.15	4.368
Min	828	+08	176	290	618	932
	26.15	1.09E	19.24		42.99	17.83
Max	213	+09	888	640	615	784
			Congo DR			
Mea	3.494	2.69E	15.64	46180	59.33	5.794
n	345	+10	844	.8	81	3
Stdd	1.186	9.83E	7.875	7064.	18.56	2.283
ev	73	+09	462	297	655	356
	1.639	1.62E			25.04	1.630
Min	733	+10	2.1	34010	194	435
	5.815	4.53E	28.78		90.74	9.803
Max	208	+10	135	55500	761	922
			Congo Rep			
Mea	33.57	8.73E	37.04	13834	125.6	9.540
n	808	+09	647	.67	656	579
Stdd	8.618	2.06E	16.85	2681.	15.50	2.971
ev	692	+09	924	849	051	117
	15.82	5.93E	15.59		93.00	4.807
Min	491	+09	811	9190	286	693
	42.04	1.23E	79.40		156.8	16.91
Max	299	+10	108	19200	618	542
			Cote D'Ivoire			
Mea	28.00	3.69E	17.69	22803	56.24	26.08
n	792	+10	268	.73	961	625
Stdd	5.275	1.09E	3.684	2087.	7.264	11.16
ev	617	+10	289	699	271	777
	20.86	2.64E	12.02		42.20	7.065
Min	776	+10	348	18880	452	217
	40.89	6.10E	23.48		70.30	44.23
Max	198	+10	476	26040	109	077
			Eriteria			
Mea	25.43	2.08E	18.85	5605.	57.14	4.381
n	639	+09	808	333	438	538
Stdd	4.008	1.09E	9.755	384.3	25.94	4.605
ev	241	+08	747	61	699	558
	19.10	1.79E	9.263		27.97	0.473
Min	594	+09	796	4840	214	934
	35.21	2.25E	45.51		116.6	14.67
Max	807	+09	418	6330	175	391
			Eswatini			
Mea	8.188	3.32E	15.98	2401.	116.5	36.29
n	844	+09	258	2	54	536
Stdd	10.30	7.26E	3.520	165.4	31.69	11.90
ev	958	+08	765	368	747	161
		2.24E	11.82		79.66	7.065
Min	0	+09	455	2080	687	217
	22.86	4.40E	23.69		175.7	47.56
Max	097	+09	217	2790	98	757
			Gabon			

Mea	18.93	3.37E	24.76	25830	37.28	17.84
n	216	+11	299	4.8	27	192
Stdd	1.273	1.29E	8.338	26024	9.785	6.145
ev	984	+11	632	.09	754	608
	15.85	1.61E	14.90	22273	16.35	7.065
Min	414	+11	391	0	219	217
	21.65	5.09E	40.61	30818	53.27	27.01
Max	634	+11	495	0	796	422
			Rwanda			
Mea	66.63	5.74E	18.65	3719.	38.73	33.81
n	572	+09	191	333	505	765
Stdd	0.000	2.91E	4.892	1103.	9.521	19.80
ev	535	+09	123	92	416	418
	66.63	1.95E	11.98		27.35	7.065
Min	412	+09	212	1960	119	217
	66.63	1.12E	26.13		57.93	60.09
Max	694	+10	304	5340	633	615
			Senegal			
Mea	50.80	1.44E	24.25	21233	55.10	40.34
n	452	+10	032	.2	199	576
Stdd	3.160	4.24E	4.614	4525.	5.287	12.65
ev	653	+09	496	731	239	898
	44.52	8.67E	15.84		46.27	7.065
Min	372	+09	806	15030	243	217
	55.16	2.29E	35.14		64.24	51.18
Max	466	+10	423	29230	975	483
			South Africa			
Mea	86.41	2.89E	17.05	48431	51.58	57.94
n	569	+11	086	4.3	037	666
Stdd	1.111	5.55E	1.897	69018	6.112	19.71
ev	266	+10	364	.96	856	648
	84.24	2.01E	12.40	36461	42.19	7.065
Min	343	+11	005	0	925	217
	88.14	3.60E	21.28	56086	65.97	72.54
Max	867	+11	725	0	452	902
			Sudan			
Mea	25.98	7.85E	27.20	90074	21.81	7.217
n	762	+10	592	.8	321	962
Stdd	7.122	1.43E	6.981	13401	14.58	2.022
ev	911	+10	29	.11	275	818
	12.97	4.57E	12.47		0.756	3.846
Min	351	+10	306	63870	876	154
	32.82	9.73E	39.54	10625	44.34	10.86
Max	946	+10	908	0	437	957
			Tanzania			
Mea	10.73	3.39E	29.06	64036	38.57	30.50
n	134	+10	263	.53	584	38
Stdd	3.411	1.48E	8.482	14021	9.798	9.250
ev	028	+10	632	.28	519	304
	5.541	1.57E	14.89		23.98	7.065
Min	691	+10	974	43540	087	217
	14.90	6.15E	41.01		56.16	39.81
Max	684	+10	825	84000	612	042
			Togo			
Mea	16.43	3.30E	20.16	5787.	79.79	20.58
n	069	+09	297	867	031	925
Stdd	2.928	9.30E	5.011	1349.	16.10	6.416
ev	339	+08	852	281	392	777
	12.01	2.19E	13.33		54.37	7.065
Min	933	+09	986	3460	207	217
	24.10	5.19E	32.22		112.7	36.95
Max	152	+09	33	7890	61	652
			Uganda			

Mean	25.39377	1.18E+10	25.79133	13489.47	85.04596	33.63249
Stddev	6.142287	2.06E+09	4.741246	821.7522	9.248608	16.50586
Min	16.46213	9.69E+09	19.25823	11990	70.06	7.065217
Max	36.77855	1.55E+10	39.55766	15350	101.7019	63.58696
Gambia						
Mean	21.12148	1.20E+09	14.26366	2173.467	50.56259	29.49379
Stddev	22.31122	2.53E+08	7.081196	460.0216	7.035044	9.616254
Min	0	7.88E+08	4.562497	1530	39.0891	7.065217
Max	52.54034	1.69E+09	31.95424	3460	68.85879	44.54976
Ghana						
Mean	42.01207	3.53E+10	21.69475	24214.13	79.54771	43.58583
Stddev	11.2125	1.53E+10	4.669964	7338.194	17.3153	14.44968
Min	19.32334	1.70E+10	12.80999	14330	38.51686	7.065217
Max	52.616	6.28E+10	29.00214	37650	116.0484	54.9763
Guinea						
Mean	52.4918	7.33E+09	22.38813	17950.13	71.36174	15.85428
Stddev	0.004461	2.39E+09	6.974725	5983.056	21.92024	4.362981
Min	52.47736	4.46E+09	14.53812	9700	42.41507	7.065217
Max	52.50051	1.27E+10	52.66984	28330	132.3825	22.28261

Mean	17.59937	2.30E+10	22.8314	29605.47	38.56514	41.4659
Stddev	0.035599	9.94E+09	3.288231	9369.727	5.656674	13.37673
Min	17.54744	9.95E+09	16.44715	16910	30.04392	7.065217
Max	17.76213	4.08E+10	30.81946	43290	56.25827	55.97826
Zambia						
Mean	9.579782	1.48E+10	24.23123	31121.07	67.63584	28.27843
Stddev	1.263403	6.13E+09	10.9553	4463.019	8.081647	8.569493
Min	6.736325	7.17E+09	14.65223	24720	56.12138	7.065217
Max	12.02352	2.41E+10	42.80487	37570	80.45602	38.58696
Zimbabwe						
Mean	31.12301	1.76E+10	11.07224	29163.47	70.53121	5.292439
Stddev	5.357309	3.43E+09	5.298181	2276.076	14.75109	5.591081
Min	23.67196	1.04E+10	1.525177	24600	50.02971	0.980392
Max	42.0693	2.20E+10	20.75046	33770	109.5216	23.36957