

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 unfavorable consequence 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 newly signed 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

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 CO₂ 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, our paper'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 (CO₂) 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, In Iraq Akadiri et al. (2019) revealed a unit-directional relationship between energy use and CO₂ 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 also interconnects 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):

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

Where EQ, RGDP, REQ and GCI denote total environmental quality (proxied by CO₂), 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;

$$\ln E Q = \beta_0 + \beta_1 ENC_{i,t} + \beta_2 \ln R GDP_{i,t} + \beta_3 REQ_{i,t} + \beta_4 \ln G CI_{i,t} + \varepsilon_{i,t} \quad - \quad - \quad 2$$

where i represents a cross-section of countries; t stands for the years 1996 to 2020; β_0 is the intercept; $\beta_1 - \beta_4$ 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.

$$\ln E Q = \beta_0 + \beta_1 ENC_{i,t} + \beta_2 \ln TOP_{i,t} + \beta_3 \ln ENC_{i,t} \cdot TOP_{i,t} + \beta_4 \ln R GDP_{i,t} + \beta_5 REQ_{i,t} + \beta_6 \ln G CI_{i,t} + \varepsilon_{i,t} \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad 3$$

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 on the quality of environment is arrived at by taking partial derivatives of equation (3):

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

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 consumption enhance 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 diminishing environmental quality. Considering the magnitude, if $\frac{\partial E Q_{i,t}}{\partial ENC_{i,t}} > 0$, energy consumption together with trade openness enhance environmental quality (EQ) but if $\frac{\partial E Q_{i,t}}{\partial ENC_{i,t}} < 0$, 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;

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

where y_{it} is environmental quality for economy i at time t ; α_{ij} represents a matrix of the regressors (factors); θ'_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 denotes in 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:

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

Where \bar{y}_t and \bar{x}_t are the cross-sectional averages of the cause-and-effect factors, 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:

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

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 dissimilarities in 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:

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

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

Where $\tilde{\Delta}_{SH}$ and $\tilde{\Delta}_{ASH}$ 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:

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

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

Where λ_i , $CA_{i,t-1}$, $\Delta CA_{i,t}$, $\overline{CA_{t-1}}$ and $\overline{\Delta CA_{t-1}}$ 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:

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

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

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

Variable	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 kt and 24,773 kt respectively. 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 economies are 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 absence of 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

Variables	Full Sample					
	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 homogeneous features of 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	Middle-Income	
		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
InENC	-2.309*	-3.018*	-2.738*	-4.766*
InRGDP	-1.756	-1.994***	-2.021	-3.984*
InGCI	-2.017***	-2.757*	-2.332*	-4.752*
InCO2	-1.757	-2.466*	-2.623*	-4.939*
InTOP	-1.159	-2.918*	-1.73	-4.668*
REQ	-1.732	-2.734*	-2.434*	-5.027*
Low-Income Countries				
InENC	-2.885*	-3.152*	-2.909*	-4.796*
InRGDP	-1.865	-2.066***	-1.913	-4.127*
InGCI	-2.158**	-2.791*	-2.657**	-4.893*
InCO2	-1.875	-2.552*	-2.582*	-4.919*
InTOP	-1.43	-2.997*	-1.804	-4.908*
REQ	-2.066***	-2.499*	-2.401*	-4.718*
Middle-Income Countries				
InENC	-2.17***	-2.613*	-2.144***	-4.816*
InRGDP	-1.768	-1.844*	-2.323**	-3.616*
InGCI	-1.734	-2.51*	-1.772	-4.975*
InCO2	-1.808	-2.308*	-2.297**	-4.798*
InTOP	-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 7 cointegration 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		
	Low-Income			Low-Income		
	Full Sample	Middle Income		Full Sample	Middle Income	
D.lnCO ₂	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.		
lnCO ₂ (-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 trade openness 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 CO₂ 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 finding follows 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 long terms. 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 noticeable influence 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	37.05	5.87E	28.03	70892	99.76	13.68	Mean	16.99	5.40E	19.02	51925	48.89	38.40
Std	161	+10	005	.53	84	423	Std	163	+10	934	.73	126	462
dev	9.926	2.32E	5.224	10164	30.15	4.945	dev	1.459	1.68E	2.618	15458	9.697	12.14
	249	+10	198	.92	368	91		453	+10	716	.57	3	446
Min	22.12	2.54E	17.71		51.88	7.065	Min	12.99	3.43E	15.00		27.23	7.065
	487	+10	226	54670	745	217		901	+10	382	33030	39	217
Max	48.30	8.72E	42.82		152.5	22.59	Max	19.41	8.43E	24.95		64.47	48.80
	559	+10	085	87360	471	615		169	+10	072	81010	887	383
Benin							Madagascar						
Mean	32.47	9.00E	17.97	9883.	51.67	31.94	Mean	10.59	9.59E	18.85	27468	53.78	28.94
	975	+09	916	733	812	609		264	+09	782	.93	865	896

Std dev	7.859	2.81E	3.953	2962.	8.105	10.74	Std dev	0.013	1.99E	7.491	1643.	11.46	11.65
	682	+09	15	208	848	164		223	+09	732	617	104	001
Min	13.33	5.07E	12.08	39.09	7.065	217	Min	10.55	6.52E	9.526	23040	34.03	7.065
	205	+09	604	5830	593	217		672	+09	116	23040	06	217
Max	41.55	1.47E	26.38	65.26	48.36	956	Max	10.62	1.32E	38.74	29580	74.35	48.03
	419	+10	651	15090	827	956		766	+10	61	29580	735	922
Botswana							Mauritius						
Mean	66.65	1.14E	29.01	13827	96.16	64.30	Mean	78.47	9.36E	22.83	5291.	114.5	64.73
	946	+10	868	.87	458	351		927	+09	584	333	829	59
Std dev	3.702	2.78E	5.079	3734.	11.98	21.43	Std dev	6.272	2.60E	3.490	1193.	12.18	23.44
	099	+09	967	074	678	775		691	+09	136	792	016	397
Min	60.17	6.98E	21.69	77.82	7.065	217	Min	63.78	5.41E	17.27	85.88	7.065	217
	227	+09	278	8790	069	217		766	+09	291	2960	374	217
Max	74.68	1.62E	39.11	125.7	77.17	391	Max	84.54	1.39E	29.38	132.1	86.05	769
	798	+10	812	25810	83	391		236	+10	878	6850	991	769
Burkina Faso							Mauritania						
Mean	36.59	8.76E	19.95	45.60	38.16	142	Mean	10.59	4.90E	30.14	10792	79.19	27.88
	092	+09	875	22578	651	142		156	+09	703	.4	198	764
Std dev	0.003	3.51E	3.789	5974.	12.29	12.34	Std dev	0.000	1.33E	14.28	1964.	17.29	13.16
	897	+09	381	004	53	331		103	+09	799	209	093	726
Min	36.58	4.09E	13.45	30.36	7.065	217	Min	10.59	3.33E	9.543	49.01	7.065	217
	346	+09	168	13840	824	217		143	+09	8	7610	694	217
Max	36.60	1.53E	27.39	64.03	50.27	027	Max	10.59	7.32E	49.16	110.7	60	60
	339	+10	178	32210	585	027		19	+09	682	14290	881	60
Burundi							Mozambique						
Mean	70.90	2.55E	11.44	2861.	31.46	13.34	Mean	8.027	1.06E	34.42	26984	75.90	28.51
	534	+09	916	333	396	998		336	+10	761	.67	096	752
Std dev	0.034	5.05E	4.890	1044.	9.072	5.871	Std dev	2.096	4.87E	13.02	5039.	25.59	9.926
	857	+08	496	094	461	138		362	+09	6	496	221	838
Min	70.80	1.90E	2.781	20.96	4.891	304	Min	5.321	3.77E	18.32	37.74	7.065	217
	327	+09	138	1800	405	304		251	+09	691	19160	057	217
Max	70.99	3.23E	18.97	26.44	47.2	231	Max	12.61	1.82E	60.05	127.2	47.82	609
	019	+09	487	4870	47.2	231		995	+10	831	36120	042	609
Cameroun							Namibia						
Mean	26.20	2.49E	18.54	84401	45.59	18.62	Mean	65.03	8.24E	21.91	11693	94.31	52.00
	853	+10	679	.87	944	713		695	+09	757	.33	69	154
Std dev	9.618	7.36E	0.771	3182.	5.476	4.896	Std dev	1.930	2.33E	5.121	2331.	11.85	17.26
	091	+09	232	404	809	571		238	+09	193	085	499	008
Min	14.65	1.45E	17.19	33.73	7.065	217	Min	61.75	4.87E	13.69	75.13	7.065	217
	179	+10	233	79220	898	217		233	+09	207	9200	927	217
Max	38.31	3.76E	19.81	56.92	25.35	885	Max	67.11	1.13E	34.77	123.7	68.64	865
	786	+10	805	90120	442	885		417	+10	655	19190	628	865
Central African Republic							Niger						
Mean	36.76	1.88E	14.43	21747	42.66	10.44	Mean	27.86	7.25E	22.53	27741	39.06	25.17
	89	+09	865	.87	578	018		699	+09	806	.87	491	82
Std dev	0.018	2.69E	6.722	1501.	8.304	4.523	Std dev	18.05	2.68E	7.764	8331.	6.056	8.259
	716	+08	864	435	923	707		342	+09	145	529	909	258
Min	36.71	1.50E	6.404	31.49	5.288	462	Min	13.71	4.11E	11.19	30.83	7.065	217
	083	+09	793	18690	425	462		825	+09	953	16300	439	217
Max	36.81	2.55E	57.14	21.19	355	565	Max	66.63	1.26E	32.64	51.94	40.19	608
	032	+09	26	24760	355	565		141	+10	046	42720	599	608
Chad							Nigeria						
Mean	36.76	7.12E	27.27	50691	74.30	12.39	Mean	18.93	3.37E	24.76	25830	37.28	17.84
	795	+09	253	.6	544	743		216	+11	299	4.8	27	192
Std dev	0.000	2.97E	10.61	17152	18.14	3.075	Std dev	1.273	1.29E	8.338	26024	9.785	6.145
	163	+09	599	.99	185	01		984	+11	632	.09	754	608
Min	36.76	2.82E	13.69	46.61	7.065	217	Min	15.85	1.61E	14.90	22273	16.35	7.065
	775	+09	15	28700	003	217		414	+11	391	0	219	217
Max	36.76	1.10E	60.15	126.3	20.39	801	Max	21.65	5.09E	40.61	30818	53.27	27.01
	851	+10	617	81650	508	801		634	+11	495	0	796	422
Comoros							Rwanda						
Mean	26.11	8.07E	16.54	414.6	37.34	9.427	Mean	66.63	5.74E	18.65	3719.	38.73	33.81
	684	+08	146	667	154	354		572	+09	191	333	505	765

Std dev	0.012	1.75E	2.169	109.5	2.544	3.549	Std dev	0.000	2.91E	4.892	1103.	9.521	19.80
	841	+08	261	952	609	874		535	+09	123	92	416	418
Min	26.07	5.42E	11.80		33.15	4.368	Min	66.63	1.95E	11.98		27.35	7.065
	828	+08	176	290	618	932		412	+09	212	1960	119	217
Max	26.15	1.09E	19.24		42.99	17.83	Max	66.63	1.12E	26.13		57.93	60.09
	213	+09	888	640	615	784		694	+10	304	5340	633	615
Congo DR							Senegal						
Mean	3.494	2.69E	15.64	46180	59.33	5.794	Mean	50.80	1.44E	24.25	21233	55.10	40.34
	345	+10	844	.8	81	3		452	+10	032	.2	199	576
Std dev	1.186	9.83E	7.875	7064.	18.56	2.283	Std dev	3.160	4.24E	4.614	4525.	5.287	12.65
	73	+09	462	297	655	356		653	+09	496	731	239	898
Min	1.639	1.62E			25.04	1.630	Min	44.52	8.67E	15.84		46.27	7.065
	733	+10	2.1	34010	194	435		372	+09	806	15030	243	217
Max	5.815	4.53E	28.78		90.74	9.803	Max	55.16	2.29E	35.14		64.24	51.18
	208	+10	135	55500	761	922		466	+10	423	29230	975	483
Congo Rep							South Africa						
Mean	33.57	8.73E	37.04	13834	125.6	9.540	Mean	86.41	2.89E	17.05	48431	51.58	57.94
	808	+09	647	.67	656	579		569	+11	086	4.3	037	666
Std dev	8.618	2.06E	16.85	2681.	15.50	2.971	Std dev	1.111	5.55E	1.897	69018	6.112	19.71
	692	+09	924	849	051	117		266	+10	364	.96	856	648
Min	15.82	5.93E	15.59		93.00	4.807	Min	84.24	2.01E	12.40	36461	42.19	7.065
	491	+09	811	9190	286	693		343	+11	005	0	925	217
Max	42.04	1.23E	79.40		156.8	16.91	Max	88.14	3.60E	21.28	56086	65.97	72.54
	299	+10	108	19200	618	542		867	+11	725	0	452	902
Cote D'Ivoire							Sudan						
Mean	28.00	3.69E	17.69	22803	56.24	26.08	Mean	25.98	7.85E	27.20	90074	21.81	7.217
	792	+10	268	.73	961	625		762	+10	592	.8	321	962
Std dev	5.275	1.09E	3.684	2087.	7.264	11.16	Std dev	7.122	1.43E	6.981	13401	14.58	2.022
	617	+10	289	699	271	777		911	+10	29	.11	275	818
Min	20.86	2.64E	12.02		42.20	7.065	Min	12.97	4.57E	12.47		0.756	3.846
	776	+10	348	18880	452	217		351	+10	306	63870	876	154
Max	40.89	6.10E	23.48		70.30	44.23	Max	32.82	9.73E	39.54	10625	44.34	10.86
	198	+10	476	26040	109	077		946	+10	908	0	437	957
Eriteria							Tanzania						
Mean	25.43	2.08E	18.85	5605.	57.14	4.381	Mean	10.73	3.39E	29.06	64036	38.57	30.50
	639	+09	808	333	438	538		134	+10	263	.53	584	38
Std dev	4.008	1.09E	9.755	384.3	25.94	4.605	Std dev	3.411	1.48E	8.482	14021	9.798	9.250
	241	+08	747	61	699	558		028	+10	632	.28	519	304
Min	19.10	1.79E	9.263		27.97	0.473	Min	5.541	1.57E	14.89		23.98	7.065
	594	+09	796	4840	214	934		691	+10	974	43540	087	217
Max	35.21	2.25E	45.51		116.6	14.67	Max	14.90	6.15E	41.01		56.16	39.81
	807	+09	418	6330	175	391		684	+10	825	84000	612	042
Eswatini							Togo						
Mean	8.188	3.32E	15.98	2401.	116.5	36.29	Mean	16.43	3.30E	20.16	5787.	79.79	20.58
	844	+09	258	2	54	536		069	+09	297	867	031	925
Std dev	10.30	7.26E	3.520	165.4	31.69	11.90	Std dev	2.928	9.30E	5.011	1349.	16.10	6.416
	958	+08	765	368	747	161		339	+08	852	281	392	777
Min		2.24E	11.82		79.66	7.065	Min	12.01	2.19E	13.33		54.37	7.065
	0	+09	455	2080	687	217		933	+09	986	3460	207	217
Max	22.86	4.40E	23.69		175.7	47.56	Max	24.10	5.19E	32.22		112.7	36.95
	097	+09	217	2790	98	757		152	+09	33	7890	61	652
Gabon							Uganda						
Mean	25.39	1.18E	25.79	13489	85.04	33.63	Mean	17.59	2.30E	22.83	29605	38.56	41.46
	377	+10	133	.47	596	249		937	+10	14	.47	514	59
Std dev	6.142	2.06E	4.741	821.7	9.248	16.50	Std dev	0.035	9.94E	3.288	9369.	5.656	13.37
	287	+09	246	522	608	586		599	+09	231	727	674	673
Min	16.46	9.69E	19.25			7.065	Min	17.54	9.95E	16.44		30.04	7.065
	213	+09	823	11990	70.06	217		744	+09	715	16910	392	217
Max	36.77	1.55E	39.55		101.7	63.58	Max	17.76	4.08E	30.81		56.25	55.97
	855	+10	766	15350	019	696		213	+10	946	43290	827	826
Gambia							Zambia						
Mean	21.12	1.20E	14.26	2173.	50.56	29.49	Mean	9.579	1.48E	24.23	31121	67.63	28.27
	148	+09	366	467	259	379		782	+10	123	.07	584	843

Std dev	22.31 122	2.53E +08	7.081 196	460.0 216	7.035 044	9.616 254	Std dev	1.263 403	6.13E +09	10.95 53	4463. 019	8.081 647	8.569 493
Min	0 52.54	+08 1.69E	497 31.95	1530 3460	91 68.85	217 44.54	Min	325 12.02	+09 2.41E	223 42.80	24720	138 80.45	217 38.58
Max	034	+09	424	3460	879	976	Max	352	+10	487	37570	602	696
Ghana							Zimbabwe						
Mean	42.01 207	3.53E +10	21.69 475	24214 .13	79.54 771	43.58 583	Mean	31.12 301	1.76E +10	11.07 224	29163 .47	70.53 121	5.292 439
Std dev	11.21 25	1.53E +10	4.669 964	7338. 194	17.31 53	14.44 968	Std dev	5.357 309	3.43E +09	5.298 181	2276. 076	14.75 109	5.591 081
Min	19.32 334	1.70E +10	12.80 999	14330	38.51 686	7.065 217	Min	23.67 196	1.04E +10	1.525 177	24600	50.02 971	0.980 392
Max	52.61 6	6.28E +10	29.00 214	37650	116.0 484	54.97 63	Max	42.06 93	2.20E +10	20.75 046	33770	109.5 216	23.36 957
Guinea													
Mean	52.49 18	7.33E +09	22.38 813	17950 .13	71.36 174	15.85 428							
Std dev	0.004 461	2.39E +09	6.974 725	5983. 056	21.92 024	4.362 981							
Min	52.47 736	4.46E +09	14.53 812	9700	42.41 507	7.065 217							
Max	52.50 051	1.27E +10	52.66 984	28330	132.3 825	22.28 261							