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The Long-Run Effects of Trade Openness on Carbon Emissions in Sub-Saharan African Countries

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Abstract: Using a panel cointegration model developed based on the data extracted from the World Bank indicators, this study quantified the relationship between carbon emissions, energy consumption, economic growth, and trade openness in sub-Saharan African countries. It discovered from our analysis that there exists a long-run causality association amongst CO₂ emissions, energy consumption, economic growth, and trade openness. The study noted the existence of the Environmental Kuznets Curve (EKC) in the panel using the square term for trade openness; it was found to have a negative impact, thus trade in the long run will somewhat decrease the environmental pollution in this region. The study results imply that there should be stringent policies and rigorous enforcement in sub-Saharan African to ensure sustainable growth without associative environmental issues.

Keywords: trade openness; carbon emission; sub-Saharan Africa; environmental Kuznets curve

1. Introduction

Carbon emissions are topical issues with ever-increasing awareness and policies drawn around the world to curb its production. This stems from the fact that carbon emission is a significant cause of global warming. Since the inception of the industrial revolution, carbon dioxide (CO₂) emissions have risen dramatically. There is still an increasing rate of these emissions through economic developments.

The economies of the sub-Saharan African (SSA) countries have experienced substantial growth over the last years, with growth rates rising from an average of around 4% in the 1980s to around 9% in the 2010s. The economies are depending on the production and export of natural and agricultural resources. A few countries, including Ghana and Nigeria, have rich oil reserves that have opened them up for foreign investments and businesses that contribute grossly to the growth of their economy [1]. Trade amongst countries has risen substantially, increasing free trade with the advent of the General Agreement on Tariffs and Trade (GATT). African nations have recently formed a Continental Free Trade Area (ACFTA) to facilitate trade between member countries, aiming to develop a common continental market for goods and services. It is hoped that enhanced trade integration between African countries could yield large economic gains for the nations.

Economic growth is one of the most popular variables used in this research study area. International trade, estimated at \$6 trillion a year, maybe a tool to ensure environmental protection and conservation, or not, even though the findings on these topics are conflicting. For example, the work of [2–4] asserts that trade liberalization is good for the environment. Discussions have been conducted on the possible adverse environmental consequences of free trade, with concerns that a fully interconnected world economy (for example, the European Union, NAFTA, and the WTO) would intensify resource scarcity, raise global pollution, and encourage dumping in low-income countries.

When countries are signing up a trade agreement with sub-Saharan economies to enhance cooperation and trade through industrialization, higher CO₂ emissions are bound to happen without proper regulation. Conversely, concerns surrounding the possible adverse environmental consequences of free trade have been extensively debated. Hence, the amount of real GDP of every nation is a crucial element in the interpretation of the environment's legislations. In the light of World Bank 2030 plan for Sustainable Climate Change and the background, this paper explores the imminent and long-run effects of trade openness on carbon emissions across selected Sub-Saharan economies based on socio-economic and environmental policies.

Kamara [5] reports that between 2006 and 2010, Foreign direct investment (FDI) grew from an annual average of US\$14.9 billion to US\$30.3 billion between 2001 and 2005. Sadly, many countries in sub-Saharan Africa (SSA) have not adequately taken environmental considerations in policy formulation to increase trade, FDI, and, consequently, economic growth. Many researchers, including [6–8] have shown immense interest in the relationship between economic growth and energy consumption. There have been calls to limit fossil fuels' use and increase the usage of alternative energy sources such as renewable energy to supplement the energy deficit. Limiting fossil fuels aims to reduce CO₂ emissions, but fossil fuels dominate the energy mix of many SSA countries [9]. There is no doubt that industrialized countries seem to contribute more to CO₂ emissions. This is one of the many reasons why most research of this nature concentrates on developed economies. Lindmark [10] also mentioned a high increase in carbon emissions during a country's developing stages.

Reduction of CO₂ emissions through technological means or economic means such as increasing fuel prices, the introduction of taxes to limit fossil fuel consumption are the two main ways previous studies provided on how to reduce emissions. However, these policies and innovations may have growth consequences even though they may reduce carbon emissions [11]. A possible potential solution is to be able to regulate the possible factors affecting CO₂ emissions. Nevertheless, this can only be done if there is an established relationship among these factors.

Several researchers [12–14] have tried to establish similar relationships in other parts of the world. This research differs from previous studies because it includes additional variables; trade openness to investigate whether or not they contribute to CO₂ emissions besides the primarily studied variable energy consumption on selected Sub-Saharan economies. Findings from this study provide a better understanding of policymakers and researchers on how to formulate proper economic and environmental policies with regards to key drivers of CO₂ emissions to effectively address the threat of global warming to our environment.

The rest of the manuscript takes the following structures—Section 2 reviews related literature to the study. Section 3 presents the research methodology, and Section 4 addresses findings, results, and discussions. Section 5 concludes the paper and sets out several policy implications for our research work.

2. Literature Review

2.1. Trade and the Pollution Haven

The discussion of whether inter-country differences in environmental regulations are turning developing nations into “pollution haven” has recently drawn much attention. The pollution haven hypothesis (PHH) by Copeland and Taylor [15] explains trade’s influence on the environment. It stipulates that the political and regulatory conditions favor the relocation of companies to benefit from environmental conditions that are less demanding than in their territory, contributing to the degradation of the environment [16].

Therefore, the study identifies the pollution haven hypothesis (PHH) as low environmental protections that have competitive benefits for countries and affect foreign trading trends. The effects of trade openness on the world can be explained by composition, scale, and technical effects [2,17,18]. The theory was initially being developed to examine better and understand how trade openness affects industrial air pollution. This theory has been used by many authors [2,17,18] to examine and analyze the effects of trade openness on environmental quality and also the effectiveness of pollution regulations.

The scale effect posits that economic growth has a negative effect on the environment due to increased trading activities, which increases production. This increase in production and consumption causes an increase in environmental damages. The composition effect suggests that the composition of production changes when the demand for traded goods manufactured by polluting methods rises and vice versa. It measures the change in environmental pollution due to changes in goods produced. Environmental effects can be positive or negative depending on trade specialization and techniques used. The technique effect suggests that technological development leads to changes in the effects of production on the environment. It illustrates the environmental effect of transferred expertise and creative manufacturing practices as profits and trade increase. With free trade, the transition of new and more environmentally sustainable technologies with more energy-efficient processing methods will lead to lower environmental harm. The technique effect could also represent technological advances that lead to more serious environmental damages.

2.2. CO₂ Emissions and Trade Openness

Using the cointegration, error correction model, and the granger causality test, ref. [19] investigated the relationship between CO₂ emissions and economic growth in the United Kingdom. A short and long-run causality running between the variables was observed. It also found a unidirectional causality from the real gross domestic product (RGDP) to foreign trade ratio, foreign trade ratio to CO₂ emissions, and foreign trade ratio to final energy consumption. The results further revealed an inverted U-shape relationship between CO₂ and GDP. Hence the EKC hypothesis confirmed in the UK and trade openness can increase CO₂ emissions.

Akin [20] examined the impact of foreign trade, energy consumption, and income on CO₂ emissions using panel data cointegration analysis. The results revealed a significant positive relationship. Findings suggest that the unidirectional causality of CO₂ emissions to trade openness persists in the short term.

In Turkey, Ozturk and Acaravci [21] found a positive and significant relationship between CO₂ and trade openness, while Boutabba [22] indicated that trade openness negatively influences CO₂ levels in India. Additionally, many studies have found a link between CO₂ emissions and trade openness Jalil [23] with contradictory results. A unidirectional causality running from trade openness to CO₂ emissions was also identified by Omri et al. [24]. Using instrumental variables, modus operandi Managi et al. [25] measured trade’s aggregate effect on environmental quality [25]. The findings revealed that foreign trade reduces pollution in non-advanced economies, with opposing responses in advanced economies: this change was attributed to the scale and composition of trade impacts.

On the other side, trade openness will minimize CO₂ emissions in the long run. Al Mamun et al. [26] examined the role of real income, trade openness, population growth, and energy consumption on CO₂ emissions using data from 82 developing countries from 1980 to 2012 using various mean group (MG) methods. The findings revealed that the proportional change in trade, the holding of all other explanatory variable constants, decreases CO₂ emissions by 0.3%. Interestingly, the findings for low-income, middle-income, and full survey countries were inconclusive.

2.3. CO₂ Emissions, Energy Consumption and Economic Growth

Fossil energy has become the symbol of modern industrial civilization. This has resulted in a tremendous increase in greenhouse gas emissions. The relationship between energy consumption and economic growth is still unclear, but the energy consumption is undoubtedly associated with a vital factor; the environment. Till now, a substantial amount of literature has diverged on the link between economic growth, energy consumption, and environmental pollution.

Adeyemi and Awodun [27] examined the relation amid biomass energy use, economic growth, and carbon emissions in West Africa from 1980 to 2010 by incorporating the role of pollution production and energy demand into an increased endogenous growth model. They also employed a simultaneous equation model estimated with three stages least squares (3SLS). They analyzed individual West African countries and a panel of countries in their work. The results showed an entirely significant relationship with feedback effects between GDP, biomass consumption, and carbon emissions in five West African countries (Nigeria, Burkina Faso, Gambia, Mali, and Togo). Partial significant ties have been identified between the variables in the remaining West African countries.

Long et al. [28] investigated the relationship between energy consumption, carbon emission levels, and economic growth in China from 1952 to 2012. They used unit root and cointegration analysis to evaluate the stationarity. They examined the mutual effects of energy consumption, carbon emissions, and economic growth through the Granger's causality test. They also performed a static and dynamic regression study of the determinants of carbon emissions and economic development. The findings showed that coal has a significant effect on economic growth and carbon emissions. Gross domestic product has a bi-directional relationship with CO₂ emissions, coal, gas, and energy consumption.

The long-term causal relationship between economic development, energy use, and pollutant emissions with labor and capital has been investigated as additional variables in South Africa [29] using the bounds testing approach to cointegration and the Granger causality test in a multivariate framework. Their results showed a unidirectional causality from pollutants' emissions to economic growth, from energy consumption to economic growth, and from energy consumption to environmental pollution, with no causal feedback. These results suggest that South Africa, a developing country, cannot increase economic growth or energy consumption without increasing emissions; hence, it has to reduce growth and energy consumption to reduce carbon emissions.

Conversely, Zhang, and Cheng [30] used the Toda and Yamamoto approach to research the relationship between energy use, economic development, and carbon emissions in China. They observe unidirectional long-term causality from economic development to energy consumption and from energy consumption to carbon dioxide emissions. Their findings indicate that both carbon emissions and energy consumption does not lead to economic growth.

2.4. The Environmental Kuznets Curve

In extending educational and academic objectives, the environmental Kuznets curve (EKC) has become an instrument or standard for explaining the link amid assessed natural environmental and economic growth. The critical theoretical development explaining the likelihood of an EKC interaction was discussed by Grossman and Krueger [31], indicating three potential effects of a rise in economic-global trade treaties' growth. Researchers have considered this hypothesis globally, considering both developing and developed economies with different approaches, turning points,

and outcomes. Since the commencement of the EKC hypothesis proposal, not all research works fit this hypothesis.

Series of previous research, which includes [32–36], among many others, have examined the association linking CO₂ emissions and income and confirmed the EKC concept throughout the range of nations and regions. To mention few, multiple studies support the EKC hypothesis through the panel data or time-series. Skaza and Blais [37] examined 190 developed and developing nations; Al-Mulali and Sheau-Ting [38] also investigated 189 economies from Asia Pacific, Eastern Europe, the Americas, Middle East and North Africa (MENA), Sub-Saharan Africa and Western Europe; ref. [24] also analyzed MENA nations.

Another study [39] and Al-Mulali et al. [40] presented contradictory findings that do not endorse the EKC's legitimacy in Tunisia and Vietnam. Dogan and Turkekul [41] also analyzed the connection amid CO₂ emission, real output, energy usage, trade openness, financial growth, and urbanization in the United States for the timeframe 1960 to 2010 by utilizing the bound test for cointegration. Their analysis concluded that the United States of America does not accept the logic behind the EKC model; hence, EKC was not verified. On the other hand, Amissah and Clotthey [36] employed the common correlated effects mean group (CCEMG) approach for 25 emerging economies in Africa spanning from 1990 to 2015 by examining environmental effects on economic growth. Their conclusion verified the EKC framework across all the panels (25 nations, oil-exporting and non-oil exporting) with turning points of \$3197.65, \$1433.67, and \$5909.16 amid the three panels in their study.

In another study by Shahbaz et al. [42] also examined EKC's presence among 19 African nations from 1971–2012, utilizing the ARDL bound test method. The researchers concluded the existence of EKC amid African nations; moreover, concerning Tanzania and Sudan, the association amid CO₂ emission and economic growth depicted U shaped. Shahbaz et al. [43] investigated the impact of financial progress, economic development, trade openness, and coal usage on environmental sustainability through the utilization of data from 1965 to 2008 in South Africa by applying ARDL bound test approach. Their evidential observation depicted the existence of the EKC hypothesis, while trade openness increases the environment's efficiency by reducing the production of CO₂ emissions. Ref. [44] explored the effect regarding CO₂ emissions and economic production in 22 OECD nations for the period 1975–1998. The authors ascertained the EKC presence across the nations by utilizing the pooled mean group (PMG) methodology.

Farhani and Shahbaz [45] examined the causal association amid CO₂ emission, economic development, and renewable and nonrenewable energy usage from 1980–2009 for ten nations within the Middle East and North Africa (MENA). They utilized the FMOLS and the dynamic ordinary least squares (DOLS) to approximate the long-term projections. Their findings provided proof of the EKC phenomenon in the economies concerned. Also, a study by Rehman et al. [46] considering the relevance of the EKC hypothesis in India, Sri Lanka, Bangladesh, and Pakistan. Data are spanning from 1984–2018 by applying the fixed effects model (FEM) considering corruption and trade openness relationships. The outcome depicted a verification of the EKC hypothesis among the economies under study. To conclude, this study examines the long-run effect of trade openness on carbon emissions in selected Sub-Saharan economies while testing the validity of the EKC hypothesis.

3. Model and Empirical Analysis

3.1. Methodology and Data Collection

In this study, the data on CO₂ emissions, GDP, trade openness, and energy consumption compiled from the World Development Indicators for selected Sub-Saharan African economies, namely: Benin, Botswana, Cameroon, Cote d'Ivoire, Gabon, Kenya, Mauritius, Mozambique, Namibia, Nigeria, Senegal, South Africa, Sudan, Togo, Tanzania, Zimbabwe, Zambia, and Ghana. The data gathered were yearly, ranging from 1990 to 2014. Some elements used in measuring pollution in other literature

includes SO₂, nitrogen oxide (NO), and CO₂. In our study, however, CO₂ was used considering its global effects. The variables used in the study are defined as follows:

- (1) Carbon emissions (CO₂)—Carbon emissions measured in metric tons per capita.
- (2) Energy consumption (EN)—consumption of energy measured in kg of oil equivalent per capita.
- (3) Gross Domestic Product (GDP)—real gross domestic product per capita measured in current USD.
- (4) Trade Openness (TO)—Trade openness is the sum of imports and export measured in current USD.

In specifying the models applied for the analysis, trade openness and energy consumption are considered critical forces of economic growth. Environmental pollution is therefore characterized as the result of energy consumption in association to trade openness and economic growth. This study, therefore, came up with:

$$CO_{2it} = f(EN_{it}, GDP_{it}, TO_{it}) \quad (1)$$

The chosen variables were transformed into natural logarithms to evaluate the progression level of the parameters. This is achieved by taking their log differences to estimate Equation (2). This also helps to reduce the problem of heteroscedasticity. The transformed selected variables are used to explore the association between the dependent and independent variable to obtain:

$$\ln CO_{2it} = \alpha_0 + \alpha_1 \ln EN_{it} + \alpha_2 \ln GDP_{it} + \alpha_3 \ln TO_{it} + \varepsilon_{it} \quad (2)$$

where $\ln CO_{2it}$ signifies the natural log of CO₂ emissions, $\ln EN_{it}$ depicts the natural log of energy usage, while $\ln GDP_{it}$ represents the natural log of real GDP, and $\ln TO_{it}$ also depicts the natural log of trade openness. The ε_{it} represent the unobserved term. The elasticity of environmental pollution concerning energy consumption, real income, and trade openness is indicated with the coefficients α_1 , α_2 and α_3 respectively. The constant parameter is shown with α_0 .

In the study, we expected α_1 to have a positive outcome. This was because higher energy consumption (fossil fuels) is expected to increase environmental pollution. We also expected to obtain a positive α_2 , since an increase in economic growth will increase environmental pollution if the economies rely on fossil fuels. We expected α_3 to be either positive or negative, as seen in other economic literature such as [20,47], who suggests that the sign of trade openness varies depending on the degree of economic development.

Employing the theory behind the EKC analysis, we lastly examined the reality of an inverted U-shape relationship between trade openness and CO₂ emissions. Shahbaz and Sinha [48] argued that EKC's outcome might differ based on explanatory variables, empirical approaches, period, and economies in question. To obtain Equation (3), the square of trade was incorporated into Equation (2). The equation applied is to verify the validity of the EKC hypothesis in the model. The study, therefore, defined the EKC model as below:

$$\ln CO_{2it} = \alpha_0 + \alpha_1 \ln EN_{it} + \alpha_2 \ln GDP_{it} + \alpha_3 \ln TO_{it} + \alpha_4 \ln(TO_{it}^2) + \varepsilon_{it} \quad (3)$$

where α_0 in the model is the interception parameter, which differs between country i and year t .

3.2. Data Tests and Analysis

3.2.1. Slope Homogeneity Test

As the first preliminary test, the Pesaran and Yamagata's slope homogeneity test was conducted. The results of the slope homogeneity test, shown in Table 1, the p -values are smaller than 5%, proving the fact that the slope coefficients are not homogeneous.

Table 1. Results of Pesaran and Yamagata [49] slope homogeneity test.

	Stat.	p-Value
$\tilde{\Delta}$ test	1.837 **	0.042
$\tilde{\Delta}_{adj}$ test	2.193 **	0.023

The symbol ** indicates 5% level of significance. Source: Authors' calculation.

3.2.2. Cross-Sectional Dependence Test

Trade openness primarily involves various economies; thus, it has become vital when considering the effect of cross-sectional reliance on the dataset specified. This study, therefore, commenced by analyzing the cross-sectional dependency test. Cross-sectional dependency among panels, if not checked, can lead to biased estimations. Using the parametric test proposed by Breusch and Pagan [50], Pesaran [51], and Pesaran et al. [52], This research investigated the presence of cross-sectional dependency across the chosen variables. Ref. [50] suggested a Lagrange Multiplier for null cross-section error correlation testing. It is determined by applying the squares and including the correlation coefficients amid cross-section residues after the ordinary least square (OLS) approximation. The null hypothesis H0 for this test is that there is no cross-section dependence and the alternative hypothesis H1 for this test is that there is cross-section dependence.

The Lagrange Multiplier (LM) test is more pertinent and does not necessitate a unique cross-section unit sequence. However, it is only relevant if N is significantly smaller and T is higher:

$$CD_{LM} = T \sum_{i=1}^{N-1} \sum_{j=i-1}^N \hat{\rho}_{ij}^2 \quad (4)$$

where $\hat{\rho}_{ij}$ denotes the result of the pairwise residual correlation sample, which can be defined as:

$$\hat{\rho}_{ij} = \hat{\rho}_{ji} = \frac{\sum_{t=1}^T \varepsilon_{it} \varepsilon_{jt}}{\left(\sum_{t=1}^T \varepsilon_{it}^2\right)^{1/2} \left(\sum_{t=1}^T \varepsilon_{jt}^2\right)^{1/2}} \quad (5)$$

The null and alternative hypotheses to be verified are specified as:

$$\mathbf{H0.} \hat{\rho}_{ij} = \hat{\rho}_{ji} = \text{cor}(\varepsilon_{it} \varepsilon_{jt}) = \text{for } i \neq j,$$

$$\mathbf{H1.} \hat{\rho}_{ij} = \hat{\rho}_{ji} = \text{cor}(\varepsilon_{it} \varepsilon_{jt}) \neq \text{for } i \neq j$$

Pesaran [51] proposed an alternative to the Lagrange multiplier (LM) test by Breusch and Pagan [50] due to the latter's limitations when N is large. The alternative test by Pesaran et al. is based on the pairwise correlation coefficient rather than the squares used in the LM test. The test is computed as below:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i}^N \hat{\rho}_{ij} \right) \quad (6)$$

This method is utilized when $T > N$ or $N > T$, and is asymptotically standard and normally distributed. The null and alternative hypotheses were coherent with the CD_{LM1} the test utilized by Breusch et al. [50]. The study presents the outcome of the test in Table 2.

Table 2. Results of Cross-Sectional Dependency Test.

Variables	Breusch Pagan	Pesaran LM	Pesaran CD
LnCO ₂	661.16 (0.00) *	29.04 (0.00) *	10.79 (0.00) *
LnEN	1710.18 (0.00) *	89.01 (0.00) *	31.62 (0.00) *
LnGDP	1345.11 (0.00) *	68.14 (0.00) *	32.93 (0.00) *
LnTO	572.86 (0.00) *	24.00 (0.00) *	6.14 (0.00) *

The symbol * indicates 1% level of significance. Source: authors' calculation.

3.2.3. Panel Unit Root Test

To conduct panel data analysis, the premiere procedure estimates the degree of integration of each variable, thus testing for the existence of unit root in our variables. In the study, we reduced the problem of inconsistency and invalid test statistics in our estimation by employing two alternative unit root test approaches. The Levin–Lin–Chu (LLC) approach by Levin et al. [53] and the Im-Pesaran-Shin (IPS) test by Im et al. [54]. They were used to examine stationarity's availability in our panel data and presented in (Table 3). Therefore, the null hypothesis of non-stationarity within the sequence is assessed against the alternative hypothesis that the proportion of the variables is entirely fixed. Equation (7) specifies the test based on Levin–Lin–Chu (LLC) approach:

$$\Delta Y_{it} = \pi_i Y_{i,t-1} + \gamma_i Z_{it} + U_{it} \quad (7)$$

where U_{it} is white noise and $U_{it} \sim N(0; \sigma^2)$. The Im-Pesaran-Shin (IPS) test by Im et al. [54] proposed a new concept that rectifies the OLS methodology's shortfalls by using the autoregressive methods across panels.

Table 3. Results of the Panel Unit Root Test.

Variables	LLC Test		IPS Test	
	Intercept	Intercept and Trend	Intercept	Intercept and Trend
Level				
Ln CO ₂	0.77 (0.78)	−15.69 (0.00) *	1.44 (0.92)	−5.87 (0.00) *
LnEN	0.44 (0.67)	−0.113 (0.45)	2.39 (0.99)	−0.78 (0.21)
LnGDP	2.77(0.99)	−2.57 (0.00) *	5.85 (1.00)	−1.42 (0.07) ***
LnTO	−2.83(0.00) *	−2.36 (0.00) *	−3.15 (0.00)	−2.45 (0.00) *
First difference				
ΔLn CO ₂	−7.13(0.00) *	4.54 (0.00) *	−9.72 (0.00) *	−17.59 (0.00) *
ΔLnEN	−0.63 (0.00) *	−8.37 (0.00) *	−3.00 (0.00) *	−12.83 (0.00) *
ΔLnGDP	−0.54 (0.00) *	−8.38 (0.00) *	−4.08 (0.00) *	−12.41 (0.00) *
ΔLnTO	−9.21 (0.00) *	−7.58 (0.00) *	−5.29 (0.00) *	−13.83 (0.00) *

The symbol * and *** indicate 1% and 10% level of significance. Source: authors' calculation.

All the series are tested for non-stationarity after their logarithmic transformation. The non-stationarity for each variable is tested under two conditions: using intercepts, and intercept and trend in the models. All variables are stationary at a significant level of 1% as shown in Table 3. After the unit root test, the study proceeded to check for the presence of long-term cointegrating associations among the variables.

In addition, the Pesaran [55] cross-sectionally augmented Dickey-Fuller (CADF) as a second generation unit root test that considers cross-sectional dependence. As shown in Table 4, the null hypothesis can be strongly rejected and therefore all series are integrated of order 1.

Table 4. Results of second generation panel unit root test.

Variable	Level	First Difference
LnCO ₂	−2.482	−7.902 *
LnEN	−1.382	−9.332 *
LnGDP	−0.482	−5.810 *
LnTO	0.291	−6.301 *

The symbol * indicates 1% level of significance. Source: authors' compilation.

3.2.4. Panel Cointegration Test

In this section, we applied the Westerlund panel cointegration test [56] to find out the existence of cointegrating relationship. The test provides four statistics of G_T , G_α , P_T , and P_α . The first two statistics can detect cointegration in cross-sectional units, while the last two statistics determine cointegration in the whole panel. Table 5 reports the findings of the Westerlund panel cointegration test. According to the results, we can reject the H0 (no cointegration) and confirm the long-run cointegrating relationship among variables.

Table 5. Results of Westerlund cointegration test.

Stat.	Value	z-Value	p-Value
G_T	−2.63 *	−2.51	0.00
G_α	−8.55 *	3.28	0.00
P_T	−17.39 *	−7.11	0.00
P_α	−12.49 *	−3.55	0.00

Note: * shows p -value is smaller than 0.01 level. Source: authors' calculation.

Besides, to check the cointegration with the structural break, we conducted the Westerlund and Edgerton's test [57], including two LM statistics as follows:

$$LM_\varphi(i) = T\hat{\varphi}_i\left(\frac{\hat{\omega}_i}{\hat{\sigma}_i}\right) \quad (8)$$

$$LM_\varphi(i) = T\hat{\varphi}_i\left(\frac{\hat{\omega}_i}{\hat{\sigma}_i}\right) \quad (9)$$

where, $\hat{\varphi}_i$ and $\hat{\omega}_i$ denotes the least square estimate of φ_i . Table 6 presents the results of this test, expressing that the H0 of no cointegration can be rejected.

Table 6. Results of the Westerlund and Edgerton tests.

Model	$Z_\varphi(N)$	$Z_\tau(N)$
No Break	−5.93 (0.00) *	−5.71 (0.00) *
Level shift	−1.59 (0.04) **	−1.68 (0.02) **
Regime shift	−4.66 (0.00) *	−4.37 (0.00) *

Note: The symbol * and ** indicate 1% and 5% level of significance. Source: authors' compilation.

3.2.5. Cointegration Estimation

Many studies proposed that the presence of long-run effects between the dependent and independent variables should be estimated using the two main methods of ordinary least square (OLS) based estimators. That is the fully modified OLS (FMOLS) and dynamics OLS (DOLS). The key difference between the two methods lies in how autocorrelation is resolved in regression [58] Whereas with FMOLS, the Newey-West can be used for correction, DOLS embraces to add more lagged and lead variables. Pedroni [59] proposed the approach to estimating the coefficients used to measure the long-run effects.

This article employed three error estimators, the above mentioned and the Pool Mean Group (PMG), to examine the validity of openness of trade on carbon emissions in Sub-Saharan economies:

$$\hat{\beta}_{FMOLS} = \left(\sum_{i=1}^N \hat{L}_{22i}^{-1} \sum_{t=1}^T (X_{it} - \bar{X}_i)^2 \right)^{-1} \sum_{i=1}^N \hat{L}_{11i}^{-1} \hat{L}_{22i}^{-1} \left(\sum_{t=1}^T (X_{it} - \bar{X}_i) z_{it}^* - T \delta_i \right) \tag{10}$$

in which:

$$z_{it}^* = (z_{it} - \bar{z}_i) - \left(\frac{\hat{L}_{21i}}{\hat{L}_{22i}} \right) \Delta X_{it} + \left(\frac{\hat{L}_{21i} - \hat{L}_{22i}}{\hat{L}_{22i}} \right) \beta (X_{it} - \bar{X}_i)$$

and δ_i is denoted as:

$$\delta_i \equiv \hat{\Gamma}_{2li} + \hat{\Omega}_{2li}^0 - \left(\frac{\hat{L}_{21i}}{\hat{L}_{22i}} \right) (\hat{\Gamma}_{22i} + \hat{\Omega}_{22i}^0)$$

Considering Ω as asymptotic covariance matrix for the long-term variance and a dynamic covariance, and L is a lower triangular matrix with partition calculation, then, DOLS estimator is utilized to take the below form:

$$z_{it} = \beta_i' X_{it} + \sum_{j=-q}^q \zeta_{ij} \Delta X_{i,t+j} + \gamma_{li}, D_{li} + \varepsilon_{it} \tag{11}$$

in which q is defined as the numbers of lags specified for the models. Subsequently, the DOLS estimation method is linked to Kao and Chiang [60] for the use of finite sample properties. The study presents the results of cointegration estimates in Tables 7 and 8.

Table 7. Results of Panel FMOLS cointegration estimate results.

Variables	Dependent Variable in CO ₂	
	Coefficient	p-Value
LnEN	0.21	0.00 *
LnGDP	0.22	0.00 *
LnTO	0.33	0.00 *

The symbol * indicates 1% level of significance. Source: authors' compilation.

Table 8. Results of panel DOLS cointegration estimate results.

Variables	Dependent Variable In CO ₂	
	Coefficient	p-Value
LnEN	0.34	0.00 *
LnGDP	0.23	0.00 *
LnTO	0.40	0.00 *

The symbol * indicates 1% level of significance. Source: authors' compilation.

3.2.6. Panel FMOLS Estimate for EKC Results

To examine the long-run impact of trade on the environment, we include the square of trade openness. We relate trade openness to the EKC framework since many studies uphold the theory that trade openness correlates to growth. Thus, an increase in trade has the effect of increasing economic growth. Tables 9 and 10 display FMOLS and DOLS estimation.

Table 9. Result of environmental Kuznets curve, FMOLS estimation.

Variables	Coefficient	p-Value
LnEN	0.22	0.00 *
LnGDP	0.22	0.00 *
LnTO	0.89	0.00 *
LNTOSQ	−0.08	0.00 *

The symbol * indicates 1% level of significance. Source: authors' calculation.

Table 10. Environmental Kuznets curve, DOLS estimation.

Variables	Coefficient	p-Value
LnEN	0.34	0.02 **
LnGDP	0.20	0.00 *
LnTO	0.99	0.04 **
LNTOSQ	−0.07	0.27

The symbols * and ** indicate the 1% and 5% level of significance, respectively. Source: authors' calculation.

3.2.7. Robustness Test

The mean group estimator, according to Pesaran and Smith [61], offers coherent assessments of the average values. This requires the parameters to be independently variable within groups and may not recognize the capacity for homogeneity among the groups. The follow-up step is the usual pooled method. Considering on merit of PMG over the DOLS and FMOLS methods shows that it permits the long-term coefficients are bound to be the same. In contrast, the short-term dynamic specification varies from nation to nation. The PMG is which is considered as the intermediary estimation method since it includes averaging and pooling. This is estimated as below:

$$\gamma_{it} = \sum_{j=i}^p \beta_{ij} Y_{i,t-j} + \sum_{j=0}^q \delta_{ij} X_{i,t-j} + \mu + \varepsilon_{it} \quad (12)$$

The cross-section divisions (nations) are depicted by $i = 1, 2, \dots, N$, $t = 1, 2, \dots, T$ stands for the timelines, $X_{it}(k,1)$ is a vector response variable for the nation i , μ depicts the static effect, β_{ij} the coefficient of the dependent lagged variable, while δ_{ij} are $k \times 1$ coefficient vectors. The study presents the outcome of the test in Table 11.

Table 11. Pooled Mean Group (PMG) cointegration estimate results.

Variables	Dependent Variable in CO ₂	
	Coefficient	p-Value
LnEN	0.62	0.00 *
LnGDP	0.26	0.00 *
LnTO	0.37	0.00 *

The symbol * indicates 1% level of significance. Source: authors' compilation.

3.2.8. Panel Causality Test

Once cointegration and long-run relationship have been established, the study proceeds to estimate the error correction model (ECM). The augmented Granger type causality test model with a one-period lagged error correction term (ECTt-1). Engle and Granger [62] indicate that the Granger causality test, which is conducted in the first-differenced variables using a VAR, will be ambiguous in the presence of cointegration. The VECM allows us to capture both the long-run and short-run causality. The short-run causal effects can be obtained by the F-test of the lagged independent variables,

but the t-statistics on the coefficient of the lagged error correction term shows the significance of the long-run causal effect. A general ECM is derived as follows:

$$\Delta \ln \text{CO}_{2it} = \alpha_0 + \sum_{k=1}^n \alpha_{1ik} \Delta \ln \text{CO}_{2i,t-k} + \sum_{k=1}^n \alpha_{2ik} \Delta \ln \text{EN}_{i,t-k} + \sum_{k=1}^n \alpha_{3ik} \Delta \ln \text{GDP}_{i,t-k} + \sum_{k=1}^n \alpha_{4ik} \Delta \ln \text{TO}_{i,t-k} + \theta \text{ECT}_{t-1} + v_t \quad (13)$$

The purpose of the error correction term (ECT) is to identify the speed and adjustment of the cointegration vector θ and shows how the variable returns to long-run equilibrium in a short-run period. It has a statistically significant value with the negative coefficient. α_{2ik} , α_{3ik} , α_{4ik} indicate the short-term elasticity for the break values of energy consumption, economic growth, and trade openness. The direction of both causalities within our model was analyzed using the multiple regression causal relationships proposed by Granger with an optimal lag length n (Akaike Info Criterion, AIC = 2), results are shown in Table 12:

Table 12. Results of Panel causality test results.

Dependent Variables	Independent Variable				
	LnCO ₂	LnEN	LnGDP	LnTO	ECT-1
	Short Run				Long Run
LnCO ₂	0	0.01 (0.92)	0.03 (0.46)	0.01 (0.81)	−0.03 (0.00) *
LnEN	−0.03 (0.13)	0	0.02 (0.24)	0.00 (0.91)	−0.00 (0.00) *
LnGDP	−0.01 (0.76)	−0.09 (0.50)	0	0.02 (0.63)	0.00 (0.33)
LnTO	0.02 (0.54)	−0.04 (0.70)	0.07 (0.14)	0	−0.02 (0.02) **

The symbols * and ** indicates 1%, 5% level of significance, respectively. Source: authors' calculation.

4. Results and Discussion

In this section, we discuss the empirical outcomes of our analysis. Before testing for stationarity (panel unit root test), we examined the presence of slope homogeneity and also if there existed a cross-sectional dependency in our panel. Using the approaches of Pesaran and Yamagato [49], Pesaran et al. [51] and Breusch et al. [50], we report the slope homogeneity test and cross-sectional dependency test outcomes as utilized both the dependent and independent variables in Tables 1 and 2.

In light of our outcomes, we dismissed the null hypothesis of the cross-sectional dependency test for the underlined variables at a significant level of 1%. Accordingly, a unit root test was performed to check for stationarity. To debunk any doubts, we decided to use two unit root tests to determine a more reliable inference of the data. The LLC test measurements of Levin et al. [53] and the IPS test measurements of Im et al. [54] were utilized. The results indicated that the variables CO₂ emissions, trade openness, economic growth, and energy consumption were stationary at first difference with a 1% significant level. This shows that in the first difference, all variables have a distinctive order of integration.

After confirming the stationarity of our variables, we move on to explore the long-run relationship between the variables utilizing the Pedroni panel cointegration method [63]. The null hypothesis posits that there is no cointegration in all tests, whereas the alternate hypothesis posits that there is cointegration. The panel cointegration test result indicates that, in most circumstances, the alternative hypothesis of the cointegration test could not be rejected. Along these lines, this study concluded that there was plentiful verification for the presence of cointegrating connections amid the variables CO₂ emissions, trade openness, real GDP, and energy consumption. This shows the existence of a long-run relationship among the variables.

The outcome of the panel FMOLS and DOLS tests so shows the long-run effects of the independent variables trade openness, GDP, and energy consumption on the dependent variable CO₂ emissions. The variables showed significance with energy consumption, GDP, and trade openness with the highest level of significance at 1% in both FMOLS and DOLS. The study also finds that trade openness has a positive relationship to environmental quality (CO₂ emissions) in the region (Sub-Saharan Africa). Thus a percentage increase in trade will increase carbon emissions by 0.33% t a 1% level of significance. This outcome is in line with [64–66].

As a robustness check, the PMG estimation outcome depicted that the coefficients estimated are respectively 0.62, 0.26, and 0.37 for all the economies (nations) pooled. This is seen in all cases such as FMOL, DOLS, and PMG; all coefficients are statistically significant. Comparison from the above three tests can be seen that trade openness has relatively higher coefficients across all three estimates representing 0.33 (FMOLS), 0.40 (DOLS), 0.37 (PMG), also supports the result from the FMOL and DOLS but with different coefficients. In terms of energy consumption, we discovered that it had a positive impact on CO₂ emissions in the Sub-Saharan region. The panel results indicated a positive significant impact of economic growth on CO₂ emissions in the Sub-Saharan region (1%). This shows the existence of a significant long-run nexus between GDP and carbon emissions. This outcome supports the findings of [36].

The effect of the square of trade openness using the FMOLS indicates the existence of EKC for carbon emissions in the sub-Saharan region. The square of trade openness had a significant negative relationship with carbon emissions, meaning in the long run, as trade increases, carbon emissions will decrease hence creating the inverted U-curve. Consequently, the result implies that in the initial stages of economic development in SSA economies, economic expansion is mainly concerned and environmental factors are ignored, focusing both on growing trade with other countries. Investment through this will increase as income increases, thereby increasing energy demand and the deterioration of the environment as a result of the rise in carbon emissions. The upsurge in level of economic growth based on income therefore brings social and environmental awareness that helps reduce pollution of the environment.

This could indicate that as the sub-region develops, the need and desire for economic growth and development outweighs that of environmental quality; hence, higher carbon emissions at higher income levels. The rest of the results in the study showed that energy consumption has a positive significant (1%) relationship, like the result of the previous model without the square of trade. Like the impact of energy consumption on carbon emissions, GDP also showed a highly positive significant relationship with carbon emissions. On the other hand, trade openness in this model showed a positive and highly significant impact on carbon emissions.

The output of the panel VECM Granger causality results in Table 12 indicates a long-run relationship between CO₂ emissions and the variables energy consumption, economic growth, and trade openness. Similarly, there is a long-run relationship amongst the variables when energy consumption and trade openness are dependent variables. There was no short-run relationship recorded.

5. Conclusions and Policy Recommendations

This research mainly investigated the long-run relationship between trade and CO₂ emissions, with other critical explanatory variables such as energy consumption and economic growth for 18 selected sub-Saharan African countries. The data for this research spanned from 1990 to 2014 and were derived from the World Development Indicators. A current panel estimation method was used for this study. The variables employed in this study were stationary at the first difference and cross-sectional dependent on the test outcome. Moreover, the cointegration test outcome depicted that in the long-term energy usage, CO₂ emissions, economic growth, and trade openness were integrated. Besides, the panel finding employing the FMOLS, DOLS, and PMG methods depicted that trade openness increases CO₂ emissions in the employed panel. Using the error correction model, the short and long-term causal correlation was established. The panel VECM Granger causality

findings demonstrated no short-run panel causality among the variables. Alternatively, the findings depicted that there were long-run causal associations amid the variables. This lagged error correction term in the carbon emissions and energy is statistically significant. Hence the results showed that there are unidirectional causal relationships among these variables and trade openness Granger-caused environmental pollution in these Sub-Saharan countries in the long run.

The paper also attempted to test the EKC hypothesis for our chosen panel. The findings based on the FMOLS estimation suggest the existence of an inverted u shape of trade and carbon emissions in the panel; hence, the existence of EKC. Our results demonstrated the existence of a statistically significant long-term relationship between CO₂ emission and energy consumption, economic growth, and trade openness. There was no record of any short-run relationship implying that trade, as well as other variables, will preferably be more influential on environmental pollution in the long run.

The study's empirical outcome also leads us to conclude that energy consumption and economic growth cause an increase in carbon emissions in sub-Saharan African countries. This suggests that the substantial and steady increase in economic growth, as witnessed over the last few decades, which is projected to continue, would have adverse consequences on the environment. Therefore, efforts should be made in reducing carbon emissions through means such as a reduction in coal usage. Efforts need to be made for practical support for renewable energy, vigorously advocating industrial electrification and renewable building heating systems, and saving carbon effectively. As a region, Africa must follow the cap and trade scheme to guarantee an atmosphere free of pollution. Policymakers in Africa have to set a limit on the amount of total CO₂ emissions that can be generated each year by an organization or a given business. The cap and trade program uses emissions trading; thus, it allows businesses that have used up their quota to buy from other organizations that have not used up their total emissions quota. This will provide economic incentives and motivate businesses and organizations to use green energy and other efficient production methods to limit carbon emissions.

The study noted the existence of the environmental Kuznets curve (EKC) in our panel as the square term for trade openness was found to have a negative impact, thus trade in the long run will somewhat decrease the environmental pollution. The results show that growth in trade will harm the environment initially, but in the long run, the trade will increase environmental quality; thus, there will be a reduction in carbon emissions. This means there should be stringent policies, and rigorous enforcement is undertaken to ensure sustainable growth without the associative environmental issues. Also, a carbon tax policy will need to be implemented. High taxes should be levied on firms that emit high harmful gases. Upon implementing the taxes, companies in Africa would calculate the cost of lowering their emissions against the tax they would pay if they continued to produce at their present rates.

The scope of this study considered the long-run effects of trade openness on CO₂ emissions in Sub-Saharan Africa. The restructuring of trade reforms across the continent, like establishing the African Continental Free Trade Area (ACFTA) would enhance trade cooperation amid various African economies. Therefore, by far, trade is one of the key drivers that will either enhance CO₂ emissions or help emerging economies minimize it while sustaining the growth of the economy concurrently.

It can also be established from the study that pollution levels in the atmosphere are the outcome of trade openness negatively impacting air quality. Removing tariffs and other trade barriers to environmentally friendly goods are likely to increase green innovations at a reduced cost. As pollution reduction initiatives to be implemented in the energy sector are identified, firms and organizations should be rewarded for the integration of renewable energy sources to increase the adoption of advanced energy-saving technologies.

The study's results show that more trade does not necessarily induce emissions, confirming various past studies. The inverse is also true, particularly as nations are progressively embracing environmentally friendly production technologies. These technologies will reduce the heavy dependence on old and conventional forms of energy production. This has many policy implications that require diverse techniques to enhance economic growth and improve environmental quality.

Overall, the study suggests that African economies should develop and enforce efficient laws and policies to prevent or reduce environmental pollution while favorable for sustainable growth. Besides, a new detailed economic development evaluation framework in the selected African countries should be developed to reduce contaminant emissions to the atmosphere. The region should adopt initiatives to encourage low carbon as well as sustainable and high economic development, reinforce national structures to create a compelling and functional climate change system, and also massively to educate the general public on tackling climate change challenges.

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