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RESEARCH ARTICLE

Does economic growth, international trade, and urbanization uphold environmental sustainability in sub-Saharan Africa? Insights from quantile and causality procedures

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Abstract

International trade and urbanization are increasing at an unprecedented rate in sub-Saharan Africa (SSA). The region has also witnessed a fair share of economic growth, with minimal investment and consumption of renewables. Therefore, this study investigates the influence of economic growth, international trade, and urbanization on CO_2 emissions in SSA. The current study enriches the existing literature by employing the panel quantile regression analysis to account for existing levels of CO_2 emissions in the region. Empirical findings reveal that GDP increases CO_2 emissions across quantiles, especially in countries where the existing level of CO_2 emissions is low. International trade improves environmental sustainability in countries where the existing levels of CO_2 emissions are at their lowest and highest levels but exacts a reversed impact on CO_2 emissions at the median. Further findings suggest that urbanization increases CO_2 emissions across the observed quantiles with a more pronounced effect in countries where the existing levels of CO_2 emissions are at its lowest level. The study also reveals a bi-directional causality between economic growth, international trade, urbanization, and the emissions of CO_2. The limitations of the study and possible direction for future research have been highlighted. Policy directions are discussed.

Keywords Economic growth · International trade · Urbanization · CO_2 emission · sub-Saharan Africa · Quantile regression

Introduction

In recent times, protecting the environment has become an increasing concern and has dominated political, economic, social, and health discussions. This is due to the dire consequences of climate change and global warming on the environment (Ahmed et al. 2021). As noted by Nathaniel and Adeleye (2020), climate change alters the natural environment, slows down the economic development process, and then threatens the well-being of the society. As opined by Nathaniel and Iheonu (2019), even though the contribution of SSA countries to global CO_2 emissions is low compared to industrially advanced countries, the region is worse hit by the impact of climate change and global warming. This is because about two-third of the African population depend majorly on natural resources and agriculture for their livelihood (Serdeczny et al. 2016). Therefore, extreme conditions like flooding and drought automatically transmit to the loss of livelihood for a vast number of Africans. It has also been observed by Shobande (2020) that the emissions of CO_2 have great consequence on infant and under-five mortality rates in Africa—a region with the highest level of child mortality (Iheonu et al. 2019). CO_2 emissions not only are culpable for climate change threat but also add to global warming and makes up approximately 60% of the greenhouse gases

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(GHGs) (Aye and Edoja 2017). In SSA, the level of CO_2 emissions has consistently increased as revealed in Fig. 1 based on data from the World Development Indicators (WDI), with its attendant effect on society.

On the average, SSA emitted more than 444,000 kiloton (kt) of CO_2 between 1960 and 2014. In 1960, the level of CO_2 emissions in SSA stood at about 126,000 kt. However, it increased substantially to more than 822,000 kt in 2014.

Various factors have been observed to spur the level of CO_2 emissions. Environmental theories have linked economic growth, international trade, and urbanization to emissions (Nathaniel et al. 2020a, 2020b, 2020c). We take into consideration these three fundamentals in this study. Nathaniel et al. (2020f) observe that economic growth leads to rising CO_2 emission level. According to Ssali et al. (2019), as nations strive to grow and develop, the demand for energy rises which leads to the increase in emissions. Put succinctly, the economic growth process of countries compels massive use of natural resources and energy; because of this, more waste is being produced leading to increased CO_2 emissions and environmental degradation (Nathaniel and Khan 2020; Adedoyin et al. 2020; Omojolaibi and Nathaniel 2020; Kasperowicz 2015). Also, economic growth emanating from structural transformation increases CO_2 emissions. This notion is embedded in the environmental Daly (1973) curve hypothesis which asserts that green development is not enough to offset the usage of scarce natural resources and the overall damage to the environment. This hypothesis posits that economic growth and production activities cause environmental pollution to persist.

The relationship between international trade and CO_2 emissions has generated mixed reactions from researchers, and as such, there is no consensus on the impact of international trade on CO_2 emissions. Trade pattern, industry location, gains from trade, international relation, and production costs are affected by environmental issues (Islam et al. 2012). One theory that has examined the linkage between international trade and CO_2 emission is the pollution haven hypothesis. This theory emphasizes that trade liberalization creates the avenue for the movement of enterprise from countries which have strict environmental regulations to countries that do not have strict environmental regulations such as those in SSA. Trade liberalization also influences the increase in environmental degradation because of the increase in energy demand. Furthermore, with international trade, the increase in the demand for traded goods which uses CO_2 emitting technologies would increase CO_2 emissions.

Africa is the fastest urbanizing region of the world. SSA, in particular, has continued to be urbanized more rapidly compared to other regions of the world as shown in Fig. 2. Urbanization heralds rapid increase in energy demand (fossil fuels) with consequential environmental problems (Nathaniel et al. 2020d, 2020e).

The environmental transition theory explains the link between urbanization and environmental pollution. The theory hypothesizes that cities undergo a series of environmental challenges as they develop. The development of cities breeds industrialization accompanied by more energy demand leading to the increase in GHGs. The evolvement of societies from low to middle-stage development promotes an increase in urban population, and thus, the growth of economies takes precedence over the sustainability of the environment.

This study is justified based on the following reasons: (1) the vulnerable nature of SSA to climate change and the attendant effect on human health, livelihood, and the environment, and (2) the rising rate of urbanization and the increase in international trade as the region integrates with the rest of the world. The study adds value to the existing literature by employing the quantile regression procedure which considers existing levels of CO_2 emissions across SSA and thus gives estimates across quantile points. That is, it ascertains whether existing levels of CO_2 emissions matter for the behaviour of economic growth, international trade, and urbanization on CO_2 emissions in the region. The study also adopts the Dumitrescu and Hurlin (2012) panel causality test to examine the directions of causality among the fundamentals to be observed. This is because the direction of causality is germane for robust policy implementation. Both techniques are utilized after ascertaining their feasibility using first-generation panel econometric methodologies.

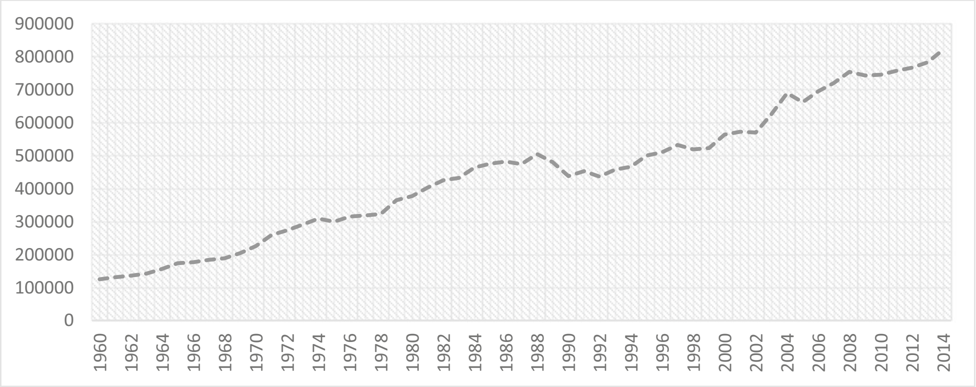

Fig. 1 SSA CO_2 emissions (Kt), 1960–2014. Source: World Bank (2020)

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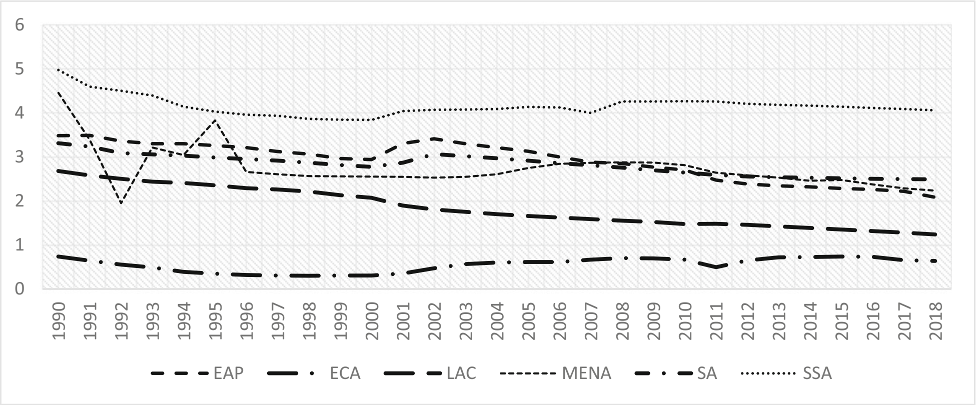

Fig. 2 Urban population growth (annual %). Source: World Bank (2020). EAP is East Asia and Pacific, ECA is Europe and Central Asia, LAC is Latin America and the Caribbean, MENA is Middle East and North America, SA is South Asia, and SSA is Sub Saharan Africa

The rest of the paper includes the literature review, the methodology and model specification, the presentation and discussion of results, and the conclusions with relevant policy recommendations.

Literature review

Environmental crisis facing SSA and Africa, in general, is an actual menace to the very being of the continent ranging from famine, and epidemic diseases to unmanageable peaks of industrial and household wastes, among others. Undoubtedly, protecting the quality of the environment in SSA through the effective implementation of policies is an issue that needs to be scrutinized more prudently and assimilated into an overall strategy of sustainable economic development of the region.

Dogan and Turkekul (2016) assessed the link between CO_2 emissions, real output, energy consumption, international trade, urbanization, and financial development in the United States applying the autoregressive distributed lag (ARDL) model. The finding reveals that urbanization increases environmental degradation while international trade leads to environmental improvements. They further discovered a two-way causation between CO_2 emissions, gross domestic product (GDP), and urbanization. Their findings were in line with the studies of Shahbaz et al. 2013, Boutabba 2014, Omri et al. 2015, Zhang et al. 2017, Marques et al. 2018, and Liu and Bae 2018, but contradicts that of Ghosh (2010) who discovered no causality between CO_2 emissions and economic growth.

Khan et al. (2020) discovered that economic growth increases CO_2 emissions in Pakistan. Similarly, Mikayilov et al. (2018) employed the ARDL bootstrap (BT), dynamic ordinary least square (OLS), fully modified OLS, and the canonical cointegrating regression (CCR) methods with consistent results. It was revealed that economic growth had an affirmative and substantial long-term influence on the carbon emissions in Azerbaijan. In 17 transitional economies, Mitić et al. (2017) employed DOLS and FMOLS techniques and revealed that a 1% change in economic growth results in around a 0.35% variation in CO_2 emissions on average, for the considered group of nations.

In Ghana, Appiah et al. (2017) scrutinized the tie between CO_2 emissions and economic growth applying the OLS technique from 1970 to 2016. The result revealed that CO_2 emissions and GDP per capita increase at a different pace and differ overtime. Correspondingly, Feng et al. (2015) examined the drivers of the United States (US) CO_2 emissions from 1997 to 2013 employing structural decomposition analysis. The result depicted that before 2007, the rise in CO_2 emission was primarily driven by economic growth but after 2007, declining emissions were the consequence of economic recession with variations in gasoline mix.

Karasoy and Akçay (2019) also made known that an increase in international trade and conventional energy increases CO_2 emissions in Turkey using the ARDL model and the vector error correction model (VECM). This, however, contradicts the finding of Jayanthakumaran et al. (2012) and Shahbaz et al. (2013) that identified carbon emission increase because of economic growth, but international trade reduces it. Moreover, a one-way link among real GDP and carbon emission was observed in Tunisia adopting the ARDL and error correction model (ECM) (Farhani and Ozturk 2015). According to Ren et al. (2014), China's global embodied CO_2 emission equilibrium has been in a state of constant rise for the period 2001–2011. Using the input-output approach, they observed that the tie between per capita GDP and carbon dioxide emission is inverse N-typed and the country's industries are in the growing phase of the curve. Thus, FDI and international trade comparative advantage are two main elements boosting China's carbon emissions. Andersson (2018) employed country-specific fixed-effect panel model and revealed that trade liberalization, weak ecological institutes, exchange rate policy, and legal and property rights affect emissions in China. This is also true using Pedroni (1999) and Westerlund (2007) panel cointegration, as trade openness hampers ecological quality for the international, and high-, middle-, and low-income panels, but the influence differs in these different groups of nations (Shahbaz et al. 2017).

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Baek et al. (2009) employed a cointegration analysis to evaluate the ecological consequences of globalization on both advanced and emerging nations. The result specified that international trade and income growth tend to raise ecological quality in advanced nations, although they have damaging effects on ecological quality in most emerging nations. Causality test displayed that a deviation in trade and income advancement caused a resultant deviation in ecological quality in advanced nations while the opposite holds for emerging nations. However, in Bangladesh, Islam et al. (2012) employed both partial and general equilibrium analysis and discovered a strong positive relationship between global trade and CO_2 emissions from gas fuels. From the Johansen-Fisher panel cointegration test, CO_2 emissions, energy consumption, economic growth, trade openness, and urbanization in newly industrialized nations are cointegrated (Hossain 2011). Furthermore, the causality test revealed no evidence of long-term causation, but unidirectional short-term causation exists from economic growth and trade openness to CO_2 emissions. However, regarding GDP, trade openness, and urbanization, ecological quality is established to be standard in the long term.

A study among developed countries applying generalized least-squares panel model disclosed that the influence of growth/decline in urban populations on CO_2 emissions is asymmetrical and that the issue of decline in urbanization is linked with interferences to the creation and distribution of products in addition to electricity access and other energy sources (McGee and York 2018). Wang et al. (2013) analysed factors of energy-related carbon emissions applying STIRPAT procedure in Guangdong Province, China. The results specified that factors such as population, urbanization level, per capita GDP, industrialization level, and service level can cause an upsurge in CO_2 emissions. Nevertheless, a drop in CO_2 emissions can result from technology level, energy consumption structure, and degree of international trade. Liu and Bae (2018) also explore the connection amid urbanization, industrialization, and CO_2 emissions in China applying ARDL and VECM. The result indicates that 1% increases of actual GDP, urbanization, and industrialization raise CO_2 emissions by 0.6, 0.3, and 1.0%, respectively.

Ali et al. (2019) assessed the impact of urbanization on CO_2 emissions in Pakistan employing both ARDL and VECM techniques. With a data set from 1972–2014, the findings revealed that urbanization enhances CO_2 emissions in every time dimension and one-way causation from urbanization to CO_2 emission existed in the short run. However, Khoshnevis Yazdi and Dariani (2019) found bidirectional causality between economic growth, urbanization, and CO_2 emissions, which is supported by Salahuddin et al. (2019). Sarwar and Alsaggaf (2019) adopted the difference-GMM, system-GMM, and dynamic mean group (DMG) estimations procedure with outcomes revealing that urbanization has a substantial and affirmative coefficient but can be controlled by increasing the per capita income of the urban population. Furthermore, economic growth is also accountable for CO_2 emissions.

In summary, there is a consensus that economic growth and urbanization raise the level of CO_2 emissions. The influence of international trade remains mixed. It is also observed that the studies did not take into consideration existing levels of CO_2 emissions into their analysis. This study is therefore a significant addition to the literature. Further, the reviewed studies may offer blanket policy options with reference to the panel studies due to their inability to account for the existing level of CO_2 emissions.

Materials and methods

Theoretical framework and data

Demographic and economic factors are capable of influencing environmental quality as posited by Ehrlich and Holdren (1971) in their famous ecological model (*IPAT*). The authors noted that environmental impact (*I*) could be affected by population(*P*), affluence(*A*), and technology(*T*). However, the (*IPAT*) framework was not fully embraced because of the difficulty in estimating the non-proportional impact of each of the variables on (*I*). As a result of the deficiencies of the(*IPAT*), York et al. (2003) introduced the STIRPAT (stochastic impacts by regression on population, affluence, and technology) framework which formed the basis of our study. The STIRPAT model suggests that environmental deterioration is both a function of demographic and economic factors. The STIRPAT equation is given as:

$$I_t = \psi_o P_t^{\xi 1} A_t^{\xi 2} T_t^{\xi 3} \mu_{it} \tag{1}$$

The logarithmic structure of the model, following Nathaniel (2019), is given as:

$$lnI_{it} = \psi_i + \xi_1 lnP_{it} + \xi_2 lnA_{it} + \xi_3 lnT_{it} + \mu_{it} \tag{2}$$

where $\xi 1$, $\xi 2$, and $\xi 3$ are the parameters of P, A, and T respectively. To remove the proportional effect on the *IPA T* model, ψ_i, μ_{it}, t, and i represent the constant, disturbance term, time dimension, and countries, respectively. In the current study, and in line with existing literature, CO_2 emissions is our environmental impact indicator (*I*).Urbanization, GDP, and trade are captured by *P*, *A*, and *T* respectively. We expand the STIRPAT model to accommodate renewable energy in line with empirical literature (Nathaniel and Iheonu 2019; Asongu et al. 2019). Bello et al. (2018) argued that *T* can be decomposed into various variables. We adopted trade in place of technology since trade transfers technological innovation (diffusion) from developed economies to either emerging

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economies or less developed (LDCs) economies. Technological innovation aids in reducing energy pollutants and accelerates economic activities. Also, trade openness may have a negative impact because of dumping activities from the developed economies who sees LDCs as pollution haven. Therefore, by incorporating the variables into Eq. (3), we derive the model for the study as:

$$lnCO_{2i,t} = \xi_0 + \xi_1 URB_{i,t} + \xi_2 lnGDP_{i,t} + \xi_3 Trade_{i,t} + \xi_4 RE_{i,t} + \mu_{i,t} \quad (3)$$

where $lnCO_2$, URB, $lnGDP$, $Trade$,and RE are the natural logarithm of carbon emissions, urbanization, the natural logarithm of GDP, trade, and renewable energy respectively.

The dataset for this study is sourced from the World Bank, World Development Indicators, WDI (2020). The time span for the study is for the period 1990 to 2016 for 34 SSA countries (see Appendices annex 2). The description and measurements of the variables are presented in Table 1. The description and measurements of the variables are presented in Table 1. In this study, CO_2 emissions and GDP are converted to their natural logarithm.

Methodology

Cross-sectional dependency tests

The study employs three tests for cross-sectional dependence in line with the nature of the dataset which has a larger number of cross-sections in comparison to the time period. They include the Pesaran (2004) cross-sectional dependence (CD) test, the Friedman (1937) test statistic, and the Frees (1995) test statistic. The application of these tests is due to robustness purposes. According to Nathaniel and Iheonu et al. (2019) and Baltagi et al. (2016), cross-sectional dependence entails an unidentified mutual shock, and interactions among social networks. Furthermore, it entails a situation where the error terms of different entities are seen not to be mutually exclusive. According to Iheonu et al. (2019), Iheonu et al. (2019), and Iheonu and Nwachukwu (2020), ignoring the presence of cross-sectional dependence can result to invalid test statistics and estimator inefficiency. Generally, the cross-sectional dependence test has a null hypothesis where:

$$\rho_{ij} = corr\left(e_{it}, e_{jt}\right) = 0 \forall i \neq j \quad (4)$$

Panel unit root tests

In ascertaining the stationarity properties of variables, two generations of panel unit root tests exist. The first-generation panel unit root procedure assumes cross-sectional independence while the second-generation panel unit root procedure accounts for cross-sectional dependence. In line with the results of the test for cross-sectional dependence, we apply the first-generation panel unit root procedure which includes the Im, Pesaran, and Shin (IPS 2003), the ADF-Fisher panel unit root procedure, and the PP-Fisher panel unit root procedure proposed by Maddala and Wu (1999) and Choi (2001). Basically, these tests assume a variation of the autoregressive parameter for all cross-sections (Agbugba et al. 2018), and they are employed for robustness purposes.

Panel cointegration tests

The study employs three panel cointegration tests. They include the panel Pedroni (1999); Pesaran (2004), the Johansen-Fisher panel cointegration test proposed by Maddala and Wu (1999), and the Kao (1999) panel cointegration test. These tests are jointly employed to verify the existence of long-run association among the variables to be examined in the econometric model. All three cointegration tests assume cross-sectional independence. It is noted also that both the Pedroni test and the Kao test are derived through residuals which emanate from a long-run static regression estimation (Adusah-Poku 2016).

Quantile regression

To observe the relationship between economic growth, international trade, and urbanization on CO_2 emissions in SSA, the study utilizes the QR to estimate the parameters all through the conditional distribution of CO_2 emissions. This is important

Table 1 Variable list and description

Variables	Description	Source
CO_2	CO_2 emissions (metric tons per capita)	World Bank (2020)
GDP	Gross domestic product per capita (constant US$)	World Bank (2020)
Trade	Trade (percentage of GDP)	World Bank (2020)
URB	Urban population (percentage of total population)	World Bank (2020)
RE	Renewable energy consumption	World Bank (2020)

Source: authors' compilation

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Table 2 Cross-sectional dependence tests

Test	Statistic	Probability value
Pesaran CD	− 1.296	0.1949
Frees	4.792	0.1248
Friedman	14.549	0.9978

Source: authors' computation

for policy formulation because the QR aids in the articulation of countries in sub-Saharan Africa with low level of CO_2 emissions, intermediate level of CO_2 emissions, and high level of CO_2 emissions. Solving the optimization problem in Eq. (2), we obtain the θth quantile estimate of CO_2 emissions.

$$\underline{min}_{\beta\epsilon R^k}\left[\begin{matrix}\Sigma\theta|y_i-x_i\beta| \\ i\epsilon\{i:y_i\geq x_i\beta\}\end{matrix}+\begin{matrix}\Sigma(1-\theta)|y_i-x_i\beta| \\ i\epsilon\{i:y_i<x_i\beta\}\end{matrix}\right] \quad (5)$$

where $\theta\in(0,1)$. According to Asongu and Nwachukwu (2016), the QR minimizes the weighted sum of absolute deviation along different quantiles. In this study, we concentrate on the 10th quantile, the 25th quantile, the 50th quantile (the median), the 75th quantile, and the 90th quantile in order to understand how the regressors in the model affect the level of CO_2 emissions based on initial levels of CO_2 emissions in the countries under observation. We also estimate a long-run static regression of the ordinary least square type with heteroskedasticity and autocorrelation consistent (HAC) standard errors. This is important to gauge the quantile regression results and necessary due to the presence of long-run cointegrating relationship between economic growth, international trade, urbanization, and CO_2 emissions.

Table 4 Panel unit root test (b)

Variables	PP-Fisher			
	Intercept		Intercept/trend	
	Level	First difference	Level	First difference
CO_2	58.2659	665.325***	100.222***	733.035***
GDP	43.3066	448.704***	91.6194**	690.434***
Trade	131.811***	646.976***	646.976***	1746.22***
URB	159.262***	122.282***	374.923***	711.370***
RE	2.0727	536.143***	88.8348**	417.949***

Source: authors' computation

Asterisks *** and ** represent statistical significance at 1% and 5% respectively

Dumitrescu and Hurlin Granger non-causality test

The study drives further into the empirical analysis by examining the direction of causality among the regressors in our econometric models with the regressand (CO_2) employing the Dumitrescu and Hurlin (2012) Granger non-causality test procedure. This test helps in explaining whether the regressors in the econometric model can be employed to forecast future values of CO_2 emissions. This procedure is necessary for CO_2 reducing policies in Africa. The Dumitrescu and Hurlin (2012) test allows the coefficients to be different across cross-sections such that:

$$a_0, i\neq a_0, j, a_1, i\neq a_1, j, \ldots, a_n, i\neq a_n, j, \forall i, j \quad (6)$$

$$b_1, i\neq b_1, j, \ldots, b_n, i\neq b_n, j\forall i.j \quad (7)$$

The test is then computed running the Granger causality regression in its simplest form for each of the cross-sections. The average of the test statistics is then computed. This test statistics is known as Wbar and the standardized version is regarded as the Zbar.

Discussion of results

This section begins with the test for cross-sectional dependence in our econometric model. Table 2 presents the test

Table 3 Panel unit root tests (a)

Variables	IPS				ADF-Fisher			
	Intercept		Intercept/trend		Intercept		Intercept/trend	
	Level	F.Diff	Level	F.Diff	Level	F.Diff	Level	F.Diff
CO_2	0.5996	− 15.4643***	− 2.6297***	− 11.3757***	61.6416	357.183***	97.0050**	250.974***
GDP	3.7839	− 11.6474***	− 1.8557**	− 8.7030***	45.1343	268.788***	94.0493**	202.762***
Trade	− 1.9508**	− 15.8082***	− 0.7752	− 13.0397***	81.4445	365.973***	74.2729	286.067***
URB	11.0163	− 2.5922***	3.9789	− 40.2188***	55.5081	93.4389**	105.077***	335.634***
RE	2.0727	− 13.0314***	− 2.1885**	− 8.7855***	44.3247	298.375	87.1121*	201.122***

Source: authors' computation

Asterisks ***, **, and * represent statistical significance at 1%, 5%, and 10% respectively. *F.Diff*, first difference

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Table 5 Pedroni panel cointegration test

	Statistic	Probability	Weighted Statistic	Probability
Panel v-statistic	− 0.0483	0.5193	− 2.0064	0.9776
Panel rho-statistic	− 1.5934*	0.0555	− 1.1258	0.1301
Panel PP-statistic	− 7.3289***	0.0000	− 7.5257***	0.0000
Panel ADF-statistic	− 3.4099***	0.0003	− 4.7576***	0.0000
Group rho-statistic	1.3817	0.9165		
Group PP-statistic	− 6.0541***	0.0000		
Group ADF-statistic	− 3.1212***	0.0009		

Source: authors' computation

Asterisk *** and * represent statistical significance at 1% and 10% respectively

result of Pesaran, Frees, and Friedman. Based on the probability values which are greater than conventional levels of statistical significance, it is revealed that the econometric model is free from cross-sectional dependence.

This suggests that the follow-up procedures would be based on first-generation panel data estimation. Table 3 reveals the IPS (2003) panel unit root test results and the ADF-Fisher panel unit root test results. It is revealed that the natural logarithm of CO_2 after first difference under the IPS unit root test and under the intercept assumption but stationary in levels and first difference under the intercept and trend assumption at 1% level of statistical significance. Similar finding is revealed in the ADF unit root test results. It is also revealed that the natural logarithm of GDP is stationary after first difference under the intercept specification but stationary in levels and first difference under the intercept/trend unit root specification.

International trade is observed to be stationary only after first difference in both unit root tests and in both unit root specifications. Similar finding is revealed for urbanization except for the ADF-Fisher unit root test which is revealed to be stationary in levels and after first difference under the intercept/trend unit root specification.

We collaborate the results of Table 3 with that of Table 4 employing the PP-Fisher panel unit root test. Findings reveal stationary at first difference for all the variables in the econometric model. These results mean that we can examine a long-run association between CO_2 emissions and the regressors in the model. Three panel cointegration procedures are employed as highlighted in the method section. The result of the Pedroni cointegration test in Table 5 reveals 11 statistics results (inclusive of the weighted statistic). It is revealed that while 7 of the test statistic values are significant, only 4 are shown not to be significant based on their probability values. This conclusively says that there is a long-run relationship existing between the regressors in the model and CO_2 emissions.

Furthermore, the results from Table 6 and 7 support this conclusion. It is revealed in Table 6 that there are more than four cointegration equations based on the trace test and the maximum eigenvalue test. The statistic values are revealed to be significant at 1% level. The Kao cointegration test in Table 7 also reveals a probability value which denotes statistical significance at 1% level, with an ADF t-statistic of − 3.5714.

Table 8 presents the result of the OLS and quantile regression estimates of the relationship between economic growth, international trade, and urbanization in sub-Saharan Africa. It is revealed from the OLS estimate that GDP is a determining factor on the level of CO_2 emission in the region. A percentage increase in GDP leads to a 0.98 percentage increase in CO_2 emissions. This result shows an almost complete pass through

Table 6 Johansen-Fisher panel cointegration test

Hypothesized No. of CE(s)	Fisher Stat. (trace test)	Probability	Fisher Stat. (max-eigen test)	Probability
None	702.1***	0.0000	396.6***	0.0000
At most 1	381.0***	0.0000	218.8***	0.0000
At most 2	212.5***	0.0000	141.5***	0.0000
At most 3	132.2***	0.0000	111.0***	0.0008
At most 4	112.9***	0.0005	112.9***	0.0005

Source: authors' computation

Asterisk *** represents statistical significance at 1%

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Table 7 Kao panel cointegration test

ADF t-statistic	Probability
− 3.5714***	0.0002

Source: authors' computation

Asterisk *** represents statistical significance at 1%

between GDP to CO_2 emissions. In the quantile regression estimate, it is however revealed that GDP has a more pronounced positive influence in the 25th quantile, i.e. countries where the initial levels of CO_2 emissions are considerably low. GDP is also revealed to exert stronger influence in the 75th and 90th quantile which are countries where the existing levels of CO_2 emissions are high. Furthermore, GDP has the lowest impact on CO_2 emissions in countries where the existing level of CO_2 emission is at its lowest level—the 10th quantile.

It can also be seen that renewable energy consumption has a negative influence on CO_2 emissions in sub-Saharan Africa across the observed quantiles. However, the negative influence of renewable energy is pronounced in countries where the initial level of CO_2 emission is at its highest level—the 90th quantile. This means that the adoption of renewable energy in sub-Saharan African countries is highly important for the reduction of CO_2 emissions with reference to high emitting CO_2 countries in the region. Renewable energy exerts a lower influence on CO_2 emissions in the 25th and 50th quantile.

Furthermore, it is observed that international trade reduces CO_2 emissions in countries where the initial level of CO_2 emission is at its lowest level, as well as in countries where the initial levels of CO_2 emission are at its highest levels—75th and 90th quantile. It is observed that there is a positive association between international trade and CO_2 emissions in the 25th and 50th quantile. Across all quantiles, urbanization is revealed to propel CO_2 emissions positively and significantly in sub-Saharan Africa. However, urbanization is revealed to significantly propel CO_2 emissions in countries where the initial level of CO_2 emission is at its lowest level—the 10th quantile. A further collaboration of these results is revealed in the quantile plots in Fig. 3.

The quantile plots also take into consideration quantiles observable within 0.10 to 0.90. These figures are in tandem with the estimates in Table 8.

Finally, the study estimates the Granger causality test as obtained in Table 9. It is revealed that across the observed estimates, a bidirectional causality exists between CO_2 emissions and the regressors in the model at conventional level of statistical significance. It portrays an intuition where the regressors in the model and CO_2 emissions can be utilized to forecast future values of each other. This is particularly necessary for policy direction pertaining to CO_2 emissions for improving the quality of the environment.

Conclusion

This study empirically analysed the role of economic growth, international trade, and urbanization on CO_2 emissions in SSA. The study utilized 34 SSA countries in a balanced panel data framework for the period 1990 to 2016 based on the

Table 8 Panel quantile regression

Variables	OLS	Q.10	Q.25	Q.50	Q.75	Q.90
GDP	0.9876***	0.9128***	1.0179***	0.9343***	0.9615***	0.9582***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
RE	− 0.0124***	− 0.0118***	− 0.0069***	− 0.0079***	− 0.0117***	− 0.0191***
	(0.008)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Trade	− 0.0013	− 0.0051***	0.0011	0.0021***	− 0.0005	− 0.0028**
	(0.677)	(0.001)	(0.221)	(0.002)	(0.463)	(0.037)
URB	0.0096*	0.0202***	0.0083***	0.0097***	0.0096***	0.0072**
	(0.098)	(0.000)	(0.000)	(0.000)	(0.000)	(0.031)
Constant	− 7.5949***	− 7.9266***	− 8.5557***	− 7.7342***	− 7.2118***	− 6.1651***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R^2/pseudo R^2	0.8621	0.5255	0.5964	0.6471	0.6869	0.6853
F-statistic	152.53***					
	(0.0000)					
VIF	2.37					
Observations	918	918	918	918	918	918

Source: authors' computation

Asterisks ***, **, and * denote statistical significance at 1%, 5%, and 10% respectively. OLS standard errors are HAC. *VIF*, variance inflation factor

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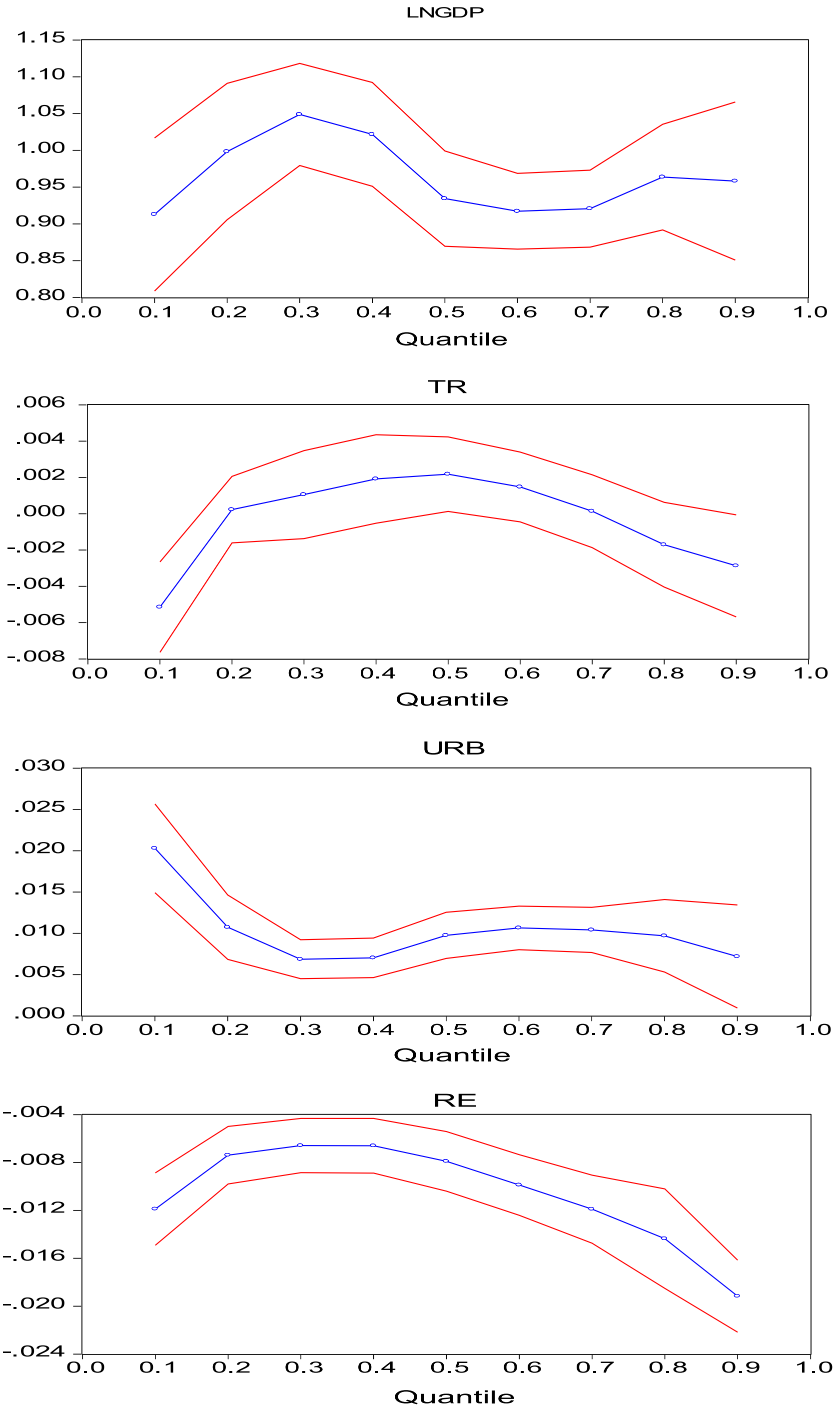
Fig. 3 Quantile plots. Source: authors' derivation



availability of data. The empirical strategy began with the test for cross-sectional dependence in the model utilizing the Pesaran CD test, the Frees test, and the Friedman's test. The results revealed the existence of cross-sectional independence among the variables in the model. Stationary tests for each of the variables where handled using the first-generation panel unit root test of Im et al. (2003), the ADF-Fisher unit root test and the PP-Fisher unit root test. The findings from the panel unit root test indicate that all the variables in the model are stationary after first difference. This means a plausibility of a long-run cointegrating relationship among the variables in the model. The study utilized the Pedroni cointegration test, the Johansen-Fisher cointegration test, and the Kao cointegration test. The results revealed the presence of cointegration among the variables in the model. Long-run estimate employing the quantile regression revealed that across the quantiles, economic growth significantly drives the emission of CO_2 emissions in sub-SSA with a more substantial effect in the 25th quantile.

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Table 9 Dumitrescu and Hurlin (2012) panel Granger non-causality test

Null hypothesis	W-Stat.	Zbar-Stat.	Probability	Direction of causality
GDP does not homogeneously cause CO_2	5.1272	6.8179	0.0000	Bi-directional
CO_2 does not homogeneously cause GDP	3.1301	2.1309	0.0331	
Trade does not homogeneously cause CO_2	4.2361	4.7265	0.0000	Bi-directional
CO_2 does not homogeneously cause Trade	4.2205	4.6898	0.0000	
URB does not homogeneously cause CO_2	7.7319	12.9308	0.0000	Bi-directional
CO_2 does not homogeneously cause URB	6.0811	9.0564	0.0000	
RE does not homogeneously cause CO_2	3.2560	2.4262	0.0153	Bi-directional
CO_2 does not homogeneously cause RE	2.9937	1.8106	0.0702	

Source: authors' computation

Renewable energy consumption significantly reduces the emissions of CO_2 in SSA with a more pronounced effect in the 10th and 90th quantiles. International trade significantly reduces CO_2 emissions in the 10th and 90th quantiles but significantly increases CO_2 emissions in the 50th quantile. Urbanization increases CO_2 emissions significantly across the observed quantiles with a more adverse effect in the 10th quantile, i.e. in countries where the existing level of CO_2 emission is low. Further findings from the Granger causality test reveal a bi-directional causality running from the explanatory variables and the emissions of CO_2 in SSA.

Based on these findings, the study recommends that (1) there is a need to adopt green technology in the production sector in order for the emissions of CO_2 to be abated as countries in SSA grow; (2) tax holidays for green energy use should be encouraged in the production sector as well as green energy manufacturing industries so as to attract industries to use renewable energy in production; (3) there is the need to improve on trade liberalization to improve international trade in countries where the existing level of CO_2 emission is at its lowest and highest levels; however, in countries where the existing level of CO_2 emission are at the intermediate level, trade restriction policies should be implemented in order to abate the emissions of CO_2; (4) it is important that governments in sub-Saharan reduce the level of urbanization. Improving economic opportunities in the rural areas and providing good infrastructure in rural areas can help reduce the migration of Africans from rural communities to urban areas. These policies are particularly important for countries where the initial level of CO_2 emission is at its lowest level; (5) the bi-directional causality between CO_2 emission and the regressors in the model entails the need for taking into consideration the past values of the regressors in the model when predicting present value of CO_2 emissions in SSA.

One of the grey areas of this study lies in not considering some of the determinants of CO_2 emissions in SSA. Data availability was also an issue as we could only consider thirty-four countries. Future studies may want to consider the impact of technological innovation and biomass production on CO_2 emissions, and the various determinants of CO_2 emissions, such as technical progress, broad-based financial development, and human capital may be taken up.

Author contribution Chimere Iheonu formal analysis and discussion of results. Ogochukwu Anyanwu wrote the introduction. Kingsley Odo reviewed the required literature. Solomon Nathaniel wrote the methodology and provided relevant policy recommendations.

Data availability Data for this study is available based on request.

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

Appendices

Annex 1:

Lists of countries

Benin, Botswana, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Eswatini, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, South Africa, Sudan, Tanzania, Togo, Uganda, Zimbabwe.

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