The criticality of growth, urbanization, electricity and fossil fuel consumption to environment sustainability in Africa

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Abstract

While most African economies are primarily sandwiched with the seemingly unsurmountable task of attaining consistent economic growth and unhindered energy supply, the enormous threat posed by environmental degradation has further complicated the economic and environmental sustainability drive. In this context, the present study examines the effect of economic growth, urbanization, electricity consumption, fossil fuel energy consumption, and total natural resources rent on pollutant emissions in Africa over the period 1980-2014. By employing selected African countries, the current study relies on the Kao and Pedroni cointegration tests to cointegration analysis, the Pesaran's Panel Pooled Mean Group-Autoregressive distributive lag methodology

(ARDL-PMG) for long run regression while Dumitrescu and Hurlin (2012) is employed for the detection of causality direction among the outlined variables. The study traces long run equilibrium relationships between examined indicators. The ARDL-PMG results suggest a statistical positive relationship between pollutant emissions and urbanization, electricity consumption and non-renewable energy consumption. Dumitrescu and Hurlin (2012) Granger causality test lends support to the long-run regression results. As bi-directional causality is observed between pollutant emissions, electricity consumption, economic growth and pollutant emissions while a unidirectional causality is apparent between total natural resources rent and pollutant emission. Based on these results, several policy implications for the African continent were suggested. (a) The need for a paradigm shift from fossil fuel sources to renewables is encouraged in the region (b) The need to embrace carbon storage and capturing techniques to decouple pollutant emissions from economic growth on the continent's growth trajectory. Further policy insights are elucidated.
Keywords: non- renewable energy consumption; electricity consumption; economic growth; panel econometrics ; Africa
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1. Introduction

Achieving economic growth and sustainable development is the major goal of both developed and developing economies. Amidst this drive are some obstacles that hinder the achievement of such a goal. While environmental degradation related issues are the most common controversial threat to reaching the desired sustainable development level, there is a complex relationship between economic growth and environmental degradation (Jamel & Derbali, 2016). Environmental degradation is on the rise due to climate change and global warming resulting from the emission of Greenhouse gas (GHG's) vis-a-vis carbon dioxide (CO_2) emissions (Alam *et al.,* 2012) and this has led to many problems such as poor water and air quality, desert encroachment, low life expectancy and high infant and maternal mortality rates especially in developing nations. There is substantial evidence of global warming and climate change across the globe, noting that Africa is not an exemption. The Intergovernmental Panel on Climate Change (IPCC) reported that compared to other parts of the world, Africa is more susceptible to global warming and climate change predicting that there will be a reduction from 50% to 30% of the population with access to water and a 20% fall in the agricultural output across the continent (IPCC, 2013).

Furthermore, the 2018 Assessment Report of the Intergovernmental Panel on Climate Change (IPCC,2013) project that land temperatures over Africa will rise faster than the global average, especially in the more arid regions of the continent. Moreover, the increase in minimum temperatures will be greater than the maximum temperatures, which is evident in that relative to the late 20^{th} century, mean annual temperature for the last decades is higher by 2 °C and projected to reach between 3°C and 6°C by the end of the century. Energy is an important factor in all economic activities and economic growth (Salam, 2006; Alege, et al, 2016; Sinha *et al*., 2017), most importantly in Africa; stable electricity supply cannot be ignored when aiming towards economic growth and development. In Africa, over 620 million people do not have access to electricity; while for cooking, about 730 million rely on traditional solid biomass (Ouedraogo, 2017). There has been a 45% increase in Africa's economic growth and energy consumption since the year 2000 (International energy outlook, 2014). Fossil fuel energy source has led to two major problems for developing economies: increase emission of CO_2 and high depletion of non-renewable energy resources (Sinha *et al*., 2017). In the next 25 years Africa's energy use is expected to be influenced by a fast growing population and high economic activities and this will in turn affect world energy markets (International energy outlook, 2018). As much as studies have shown a positive link between economic growth and energy consumption, others have shown that higher energy consumption leads to higher carbon dioxide emissions due to fossil fuel consumption which is unfriendly to the environment (Yusuf, 2014; Energy Information Administration, 2015).

Urbanization is another important contributor to economic growth (Gasimli et al., 2019). Urbanization-driven population increase, industrialization (Uttara et al., 2012), income and overexploitation of natural resources are associated with deterioration in significant environmental indicators pertaining to, *inter alia*, air, soil, water and forest quality. A high population growth rate, which increases the depletion of environmental resources and the deterioration of environmental quality may result in poverty, high fertility rates and environmental degradation. Hence, reinforcing one another in a negative spiral path and undermining future economic development. As the population size increases, individuals within the society exert pressure on limited available resources for survival (Ityavyar & Thomas, 2012). There are conflicting studies as to the impact of urbanization on the environment. Some studies (Wu et al., 2016; International Energy Agency, 2010; Katircioglu & Katircioglu, 2017) observed a negative relationship between them while others (Azam & Khan 2016; Tupy, 2015; Effiong, 2016) argued that urbanization might reduce environmental degradation due to efficient resource consumption and enhancement of environmental quality. According to the 2018 sustainable development report, in 2016, 91% of the urban populace were breathing air that did not meet with the World Health Organization (WHO) air quality guidelines; over 50% were exposed to 2.5 times air pollution levels higher than the safety standard and about 4.2 million deaths was due to air pollution. More than half of the world's population resides in cities since 2007; although the cities are only 2 % of the earth's surface, it is responsible for almost 75% of the world's resource consumption and this trend will increase in Africa over the next decade as a result of high urbanization rates (Madlener & Sunak, 2011).

This study aims to examine the impact of economic growth, urbanization, electricity and fossil fuel consumption on the environment for 13 Sub-Saharan African countries (Angola, Benin

Republic, Botswana, Cameroon, Mauritius, Congo Republic, Cote d'Ivoire, Ethiopia, Ghana, Kenya, Nigeria, South Africa, and Zimbabwe) over the period 1980-2014. The study contributes to the existing literature in quite a number of ways. First, this study employs a multidimensional dataset approach for thirteen Sub-Saharan African countries by shading more light on Africa's environmental condition by combining the effect of economic growth, urbanization, electricity and fossil fuel consumption on the environment. The choice of these countries is based on the availability of important variables required for the study, most especially carbon dioxide emission, fossil fuel consumption and urbanization. Second, this study examines both the short- and long run relationships using Pooled Mean Group test with dynamic autoregressive distributive lag (ARDL) specifications, and panel Granger causality tests. In so doing, three distinct models that sort to carefully guide the impact of non-renewable and electricity energy consumption were employed. Lastly, the study offers policy recommendations based on the findings for sub-Saharan Africa, hence, providing a pathway towards sustainable development within the continent.

The remaining part of the study is organized thus: Section two summarizes the literature survey, section three outlines data and methodology employed in the study, section four offers results and discussion while section five presents the conclusion and policy recommendations based on the findings of the study.

2. The Related Studies

Energy consumption over the years has been identified to trigger economic growth (EIA, 2018). There have been well-documented studies in the energy literature on the nexus between gross domestic product (GDP) and several macro-economic indicators with different econometrics procedures. The literature can be categorized into four groups in terms of their causality direction. Namely (a) Growth-induced hypothesis (b) Conservative hypothesis (c) Feedback hypothesis and

(d) Neutrality hypothesis[1]. The seminal study of Kraft and Kraft (1978) was the first documented work in the literature on the nexus between gross national product (GNP) and energy. In the study, a unidirectional causality was observed from GNP to energy while neutrality was seen between energy and GNP. The study of Kraft and Kraft (1978) has been the basis of several other works in the field (Alola, 2019; Alola *et al*., 2019; Bekun *et al*., 2019; Balsalobre-Lorente *et al*., 2019; Akadiri *et al*., 2019; Alola & Alola, 2018, Akadiri *et al*., 2019; Asumadu-Sarkodie & Owusu, 2017; Asongu *et al*., 2017; Asongu *et al*., 2016). A great number of studies exist on the theme under consideration, with most of them focusing on the Environmental Kuznets Curve (EKC) hypothesis phenomenon. The EKC phenomenon conceptualizes that there exists an inverse relationship between economic growth and environmental degradation.

Furthermore, studies have augmented the income-carbon function with several other macro-economic indicators like foreign direct investment, urbanization, information communication technology, financial development and more recently demographic indicators like population growth among others. For instance, Balsalobre-Lorente and Shahbaz (2016) explored the nexus between carbon-income with the addition of research and development (R&D), energy innovation and trade openness. The study findings confirm an inverse association between research, development, and environmental degradation over the investigated period. This position is also affirmed for European Union Five (EU-5) countries by the study of Balsalobre-Lorente et al. (2018). Furthermore, Sinha et al. (2017) examined a panel of the Next Eleven (N-11) countries and confirm an inverse nexus between CO_2 and trade openness. However, other studies like Akadiri *et al.* (2019) have confirmed a positive relationship between economic growth and CO_2

[1] Interested reader can see the studies of Ozturk (2010) literature survey and study of Bekun and Agboola (2019) for more insights on the literature divide.

emissions using ARDL methodology. For single country on the theme, Bekun and Agboola (2019) explore the nexus between energy (electricity), CO_2 emissions and economic growth using Maki (2012) cointegration approach and trace a long run equilibrium relationship between the underlying variables. The study's long run regression suggests that economic growth has a detrimental environmental impact on economic growth as observed for the Nigeria economy. Balcilar et al. (2019) derived similar empirical outcomes from the conducted studies for Zimbabwe by Samu et al. (2019) and Pakistan. Both studies support the findings of Bekun and Agboola (2019).

In Malaysia, Shahbaz *et al*. (2016) investigated the nexus between CO_2 emissions, urbanization, energy consumption from 1970–2011 on a quarterly basis using the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) methodology. The study adopts the vector error correction model (VECM) causality and Bayer and Hanck combined cointegration methods to explore the relationship between the outlined variables. The study of Shahbaz *et al*. (2016) confirms equilibrium relationship between the variables. The study empirical finding suggests that economic growth and energy consumption increase CO_2 emissions. However, an inverse nexus is apparent between urbanization and CO_2 emissions for the sampled period. This outcome was confirmed by the VECM-Granger causality test results.

For panel of studies on the carbon-income nexus, Hanif (2018) further added consumption of fossil fuels, urbanization; renewable energy consumption and its effect on environmental quality over 20 years for emerging countries in Africa. The study findings validated the EKC hypothesis over the sampled period, as consumption of fossil fuel energy, urbanization contribute significantly to increased CO_2 emissions. Finally, the study submits that renewable energy consumption improves the quality of the environment in Africa. Although the concept of EKC was not considered in the recent study of Alola & Sarkodie (2019), the study however incorporated the natural resource rent among other environmental determinants for the case of the European Union. Also, the study of Wang and Dong (2019) investigated the relationship between ecological footprint (i.e. a more composite indicator for environmental degradation), urbanization and economic growth for Sub-Saharan African countries over the period 1990–2014. The study adopted the Augmented mean group estimator and the corresponding findings suggest that urbanization, nonrenewable energy consumption are key determinants of environmental degradation in SSA countries. In a similar study conducted for European Union Sixteen (EU-16) countries (Alola et al., 2019; Bekun et al., 2019), natural resources rent and renewable energy consumption contribute to increase the quality of the environment.

Given the recent trajectory of the literature after the seminal study of Kraft and Kraft, the studies have placed less emphasis on the outlined variables in the current study especially for the case of African countries. Accordingly, African countries have interesting energy dynamics. All the aforementioned variables provide far-reaching outcomes, with some studies confirming the EKC hypothesis (Saint et al., 2019; Gokmenoglu & Taspinar 2018; Katircioglu & Katircioglu 2018; Katircioglu et al. 2018 while a few others have failed to confirm the EKC hypothesis (Mukhopadhyay, 2008; Dietzenbacher & Mukhopadhyay, 2007). Yet the results from the literature are incomplete with the divergent empirical nexuses. Thus, the need to re-investigate the theme in Africa where little or no attention has been documented is timely and pivotal to the energy economic literature for both stakeholders and policymakers by the incorporation of urbanization and other macroeconomic indicators in the African context.

3. Data and Methodology

3.1 Data

This investigation employs balanced annual panel data for selected thirteen (13) African states over the period 1980-2014. In this case, carbon dioxide (CO_2 is measured in kilotons) which is used as a proxy for carbon emissions is the dependent variable. Also, the independent variables employed are the gross domestic product per capita (GDPC measured in USD constant 2010), total natural resource rent (NRT measured as percentage of GDP), urbanization (URB is the urban population and ratio of total population), non-renewable energy consumption (NEC is measured as kilogram oil equivalent per capita), and electricity energy consumption (ELE measured in kilowatt per hour). The panel of selected African countries considered in this study is restricted to Angola, Benin, Botswana, Cameroon, Republic of Congo, Cote d'Ivoire, Ethiopia, Ghana, Kenya, Mauritius, Nigeria, South Africa, and Zimbabwe, obviously due to data availability. Furthermore, the variable descriptions (the classification with units, sources of the variables), the common statistics, and the correlation properties of the aforementioned variables are respectively illustrated in Table 1, Table 2, and Table 3.

Table 1: Data Description

Variables' Names	Codes	Sources
Carbon dioxide emissions	CO_2	World development indicator
Real Gross domestic product	GDPC	World development indicator
Total natural rent	NRT	World development indicator
Urbanization	URB	World development indicator
Electricity energy consumption	ELE	World development indicator
Nonrenewable energy consumption	NEC	World development indicator

Table 2: Summary statistics of the variables

	CO_2	GDPC	NRT	URB	NEC	ELE
Mean	39305.89	6958.16	13.79	39.22	16733.55	13471
Median	5346.49	1348.48	7.67	41.05	472.83	173.13
Maximum	503112	2142693	63.55	66.37	7298927	583360
Minimum	407.04	163.62	0.001	10.41	220.07	17.567
Std. Dev.	101255	100365	14.82	13.80	342146.9	273455
Skewness	3.22	21.25	1.51	-0.21	21.26	21.26
Kurtosis	12.21	452.65	4.31	2.28	452.10	452.99
Observations	455	455	455	455	455	455

Notes: The *co$_2$, gdpc, nrt,urb, nec and ele* are respectively the carbon dioxide, gross domestic product per capita, total natural rent, urbanization, non-renewable energy consumption, and electricity energy consumption. Also, Std. Dev is the Standard deviation from the mean estimate.

Table 3: Correlation Matrix

	CO_2	GDPC	NRT	URB	NEC	ELE
CO_2	1.00					
GDPC	0.28*	1.00				
NRT	0.19*	-0.34*	1.00			
URB	0.17*	0.63*	-0.06*	1.000		
NEC	0.52*	0.43	-0.21*	0.10*	1.00	
ELE	0.41*	0.65*	-0.44*	0.46*	0.77*	1.00

Notes: The *co$_2$, gdpc, nrt, urb, nec and ele*are respectively the carbon dioxide, gross domestic product per capita, total natural rent, urbanization, non-renewable energy consumption, and electricity energy consumption. Also, the * indicate the 1% statistical significant level.

3.2 Methodology

In recent times, the determinants of environmental degradation in Africa have been studied and the statistical evidence often suggesting that economic growth, population or urban population, energy consumption are among the main decomposed factors (Asumadu-Sarkodie & Owusu, 2017; Hanif, 2018; Wang & Dong, 2019). Given the STIRPAT conceptual model ($I = \alpha P^b A^c T^d e$), other factors are being investigated within the framework of environmental degradation and/or sustainability for different case studies (Alola & Alola, 2018; Alola, 2019a, 2019b; Alola, Alola, Bekun & Sarkodie, 2019; Alola & Saint Akadiri, 2019; Alola, Yalçiner, Alola & Saint Akadiri, 2019; Bekun & Agboola, 2019; Bekun, Alola & Sarkodie, 2019; Alola et al., 2019; Saint Akadiri et al., 2019). In the case of the current study, and with the aforementioned theoretical undertone, electricity energy consumption (*ele*) urbanization (urb), non-renewable energy consumption (*nec*), total natural resource rent (*nrt*) and gross domestic product per capita (*gdpc*) are investigated as decomposition of environmental degradation in 13 selected African countries. As such, the model under investigation in the present study is uniquely provided as:

$$CO_{2i,t} = f\,(gdpc_{i,t}, urb_{i,t}, nec_{i,t}, nrt_{i,t}\ e_{i,t}) \tag{1a}$$

$$CO_{2i,t} = f\,(gdpc_{i,t}, ele_{i,t} urb_{i,t}, nrt_{i,t}\ e_{i,t}) \tag{1b}$$

$$CO_{2i,t} = f\,(gdpc_{i,t}, ele_{i,t} urb_{i,t}, nec_{i,t}, nrt_{i,t}\ e_{i,t}) \tag{1c}$$

where1a, 1b, and 1c are respectively the estimation model without the ele, without the *nec*, and with both *ele* and *nec*. Also, the $e_{i,t}$ and f are respectively the error term and the function of variable.

Then, the transformation of the above expression (equations 1a, 1b, and 1c) to natural logarithmic (l) is given by:

$$lCO_{2\,i,t} = \alpha + \beta_1 lgdpc_{i,t} + \beta_3 lurb_{i\,t} + \beta_4 lnec_{i,t} + \beta_5 lnrt_{i,t} + \varepsilon_{i,t} \tag{2a}$$

$$lCO_{2\,i,\,t} = \alpha + \beta_1 lgdpc_{i,\,t} + \beta_2 lele_{i,t} + \beta_3 lurb_{i\,t} + \beta_5 lnrt_{i,t} + \varepsilon_{i,t} \quad (2b)$$

$$lCO_{2\,i,\,t} = \alpha + \beta_1 lgdpc_{i,\,t} + \beta_2 lele_{i,t} + \beta_3 lurb_{i\,t} + \beta_4 lnec_{i,t} + + \beta_5 lnrt_{i,t} + \varepsilon_{i,t} \quad (2c)$$

for all t = 1980, …, 2014, i = 1, 2, 3, …,13 and ε is the error term. Also, α and *βs* are respectively the slope constant and the degree of response of the logarithms of the explanatory variables for each i and t, given that εis iiid ~ $N(\mu, \sigma^2)$.

3.2.1 The Dynamic Pooled Mean Group test

Given the result of the stationarity test as shown in Table 4 below, the evidence of a mixed order integration of the variables justifies the use of the Pooled Mean Group (PMG). A second justification is aligned with the fact that the time period (*T*) is clearly greater than the number of the cross-sections. Therefore, a Pooled Mean Group (PMG) of the dynamic heterogeneous panel is preferably employed (Pesaran, Shin & Smith, 1999)[2]. As a preferred model that offers both short-run and long-run estimates, the PMG is advantageously a more robust model than the Generalized Method Moments (GMM) and Mean Group (MG). The PMG is employed to complement the cointegration evidence as indicated in Table A of the appendix and as such providing additional information regarding the nexus of the estimated indicators. Interestingly, the Pooled Mean Group (PMG) estimation adopts the cointegration form of the ordinary ARDL model as indicated by Pesaran, Shin and Smith (1999). When the equations (2) are simultaneously estimated according to the aforesaid model, the represented expression takes the form of

$$\Delta y_{i,\,t} = \phi_i EC_{i,\,t} + \sum_{j=0}^{q-1} \beta i,t \;\; \Delta Xi,t-j \;+\; \sum_{j=1}^{p-1} \lambda i,j \;\; \Delta yi,t-j + \varepsilon_{i,\,t} \quad (3)$$

[2] Further information on the Pooled Mean Group (PMG) group estimate is available on Pesaran, M. H., Shin, Y., & Smith, R. P. (1999). Pooled mean group estimation of dynamic heterogeneous panels. *Journal of the American Statistical Association*, *94*(446), 621-634.

where $EC_{i,t} = y_{i,t-1} - X_{i,t}\,\theta$ is the error correction, ϕ is the adjustment coefficients and θ is the long-run coefficients such that X (vector of the independent variable) = f (*lgdpc*, *lele*, *lnec, lurb*, *lnrt*) in the models. The response of the dependent variable ($Y = lCO_2$) of the aforementioned expressions 2a, 2b, and 2c yield the specifications on long-run and short-run estimates shown in Table 5.

Table 4: Panel unit root tests

Variables	LLC c	LLC t	IPS c	IPS t	Fisher-ADF c	Fisher-ADF t
ln*co*$_2$	-4.05*	-1.96**	0.30	-2.19**	40.10*	43.46**
ln*nec*	-18.23*	-89.06*	-14.77*	-45.37*	27.53	276.10*
ln*ele*	-5.41	-82.85*	3.35	-46.45*	18.04	297.36*
ln*gdpc*	-4.85*	-18.13*	-7.88*	-13.14*	39.75**	277.51*
ln*urb*	-1.13	-6.35*	1.77	-8.44*	38.22***	137.51*
ln*nrt*	-3.77*	-4.17*	-3.40*	-4.08*	-3.40*	-4.08*
Δln*co*$_2$	-19.87*	16.18*	-19.89*	-18.56*	309.68*	283.7*
Δln*nec*	-200.43*	-180.16*	-68.25*	-67.75*	235.22*	452.87*
Δln*ele*	-1.67**	0.89	-19.18*	-18.99*	283.35*	345.44*
Δln*gdpc*	-132.06*	27.73*	-47.03*	-7.83*	130.76*	107.80*
Δln*urb*	-2.06**	-0.59	-1.27	0.51	33.80	21.78
Δln*nrt*	-20.03*	-18.40*	-20.32*	-19.14*	319.63*	292.04*

Notes: *, ** and *** are statistical significance at 1%, 5% and 10% respectively. **Δ** indicates first difference. Lag selection by SIC of maximum of 4 in all estimations.LLC, IPS and Fisher-ADF are the Levin, Lin and Chu (2002); Im, Pesaran and Shin (2003); Fisher-ADF by Maddala& Wu (1999) panel unit root tests. Automatic lag selection is adopted for the estimations. Also, the *co*$_2$*, gdpc, nrt, urb, nec and ele*are respectively the carbon dioxide, gross domestic product per capita, total natural rent, urbanization, non-renewable energy consumption, and electricity energy consumption while the ln is the logarithmic values of the variables.

Table 5: Pooled Mean Group Test with Dynamic ARDL specifications

Long-run	ln*gdpc*	ln*nrt*	ln*urb*	ln*nec*	ln*ele*	ECT(-1)
Model a	0.55*	-0.06*	0.90*	**0.36***	**---**	**-0.68****
Model b	0.39*	-0.23*	0.39**	---	**1.11***	**-0.38***
Model c	0.27*	-0.11*	0.10*	**1.36***	**0.37***	**-0.***
Short-run of cross-sections (Model b)						
Angola	0.93*	0.37*	---		-1.07*	0.31*
Benin Republic	---	-0.39*	---		---	-0.12*
Botswana	-0.49*	0.07*	---		-1.62*	-0.68*
Cameroon	---	0.53*	---		---	-0.65**
Congo Republic	-4.11**	0.27*	---		1.03*	-0.22*
Cote d'lvoire	---	0.28*	---		-0.46**	-1.45*
Ethiopia	0.71*	0.04*	---		0.28*	-0.32*
Ghana	-1.27*	0.05*	---		0.30*	0.01
Kenya	---	-0.23*	---		-1.78*	-1.11*
Mauritius	---	0.10*	---		0.69*	-0.13*
Nigeria	---	---	---		---	-0.13**
South Africa	---	0.01*	---		---	-0.79*
Zimbabwe	0.55**	0.12*	---		-0.77**	-0.61*

Notes: Model ***a***: ARDL (5, 4, 4, 4,4) with maximum lag selection of 3 by Akaike Information Criterion and 416 numbers of observations and Model b: ARDL (4, 4, 4, 4, 4)with maximum lag selection of 3 by Akaike Information Criterion and 442 numbers of observations. *and**are the statistical significance level at 1% and 5% respectively. Also, the co_2, *gdpc, nrt, urb, nec and ele*are respectively the carbon dioxide, gross domestic product per capita, total natural rent, urbanization, non-renewable energy consumption, and electricity energy consumption while the ln is the logarithmic values of the variables.

3.2.2 RobustnessTests

In the process of affirming the significance and robustness of the above investigation, this study employs a heterogeneous non-causality test by Dumitrescu and Hurlin (2012) to investigate the causality between the variables. The dataset has a larger *T* dimension (25 years) compared to the dimension of *N* (13 countries), thus the use of asymptotic distributions is justified. Preferably, this test technique is considered since the Monte Carlo simulation created through the approach is suitable even in the presence of a cross-section dependency (CSD). Indicatively, the result of the CSD does not have a significant effect on the robustness of the estimates. In addition, this model is built on vector autoregressive model (VAR) and suitable for a balanced and heterogeneous panel. The panel linear model where a pair-up of the variables as $y_{i,t}$ and $x_{i,t}$ is presented as:

$$y_{i,t} = \sum_{r=1}^{R} \beta_i^{(k)} y_{i,t-r} + \sum_{r=1}^{R} \gamma_i^{(k)} x_{i,t-r} + \varepsilon_{i,t} \quad (4)$$

such that k denotes the lag length, $\beta^{(k)}$ is the autoregressive parameter, and $\gamma^{(k}$ is the regression coefficient that adjusts within the group with a normal, independent and identically distributed error term ($\varepsilon_{i,t}$)for each cross section (*i*) at the time (*t*). Given that the null hypothesis for non-causality and the alternative hypothesis are respectively H_o and H_1, the expression is given as:

$H_0 = \gamma_i = 0, \forall i = 1, 2, \ldots, N$

$H_1 = \gamma_i = 0, \forall i = 1, 2, \ldots, N_1; \gamma_i \neq 0, \forall i = N_1 + 1, N_1 + 2, \ldots, N$

given that $\gamma_i = (\gamma_i^1, \ldots, \gamma_i^R)$, $N_1 = N$ indicates that causality of any member of the panel but $N_1 = 0$ indicates causality within cross-sections as the value N_1/N is reasonably less than one[3]. The estimate of the Granger causality test is presented in Table 6.

[3] Further details of Granger causality by Dumitrescu E I and Hurlin C (2012) are available in Dumitrescu, E.I. and Hurlin, C., 2012. Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, *29*(4), pp.1450-1460.

Table 6: Panel Granger causality results by Dumitrescu and Hurlin (2012)

Null hypothesis	w-stat	Direction of causality
ln*ele*→lnco_2	8.64**	with feedback
lnco_2→ln*ele*	9.86*	
ln*gdpc*→lnco_2	8.14*	with feedback
lnco_2→ln*gdpc*	10.33*	
ln*nrt*→lnco_2	7.21*	without feedback
lnco_2→ ln*nrt*	5.63	
ln*nec*→lnco_2	9.73*	without feedback
lnco_2→ ln*nec*	5.03	
ln*gdpc*→ln*ele*	8.50	with feedback
ln*ele*→ ln*gdpc*	8.63	
ln*urb*→ln*ele*	10.01*	with feedback
ln*ele*→ln*urb*	13.49*	
ln*nec*→ln*ele*	9.58*	without feedback
ln*ele*→ln*nec*	6.47	
ln*gdpc*→ln*nrt*	8.27**	without feedback
ln*nrt*→ ln*gdpc*	7.02	
ln*gdpc*→ln*urb*	12.12*	with feedback
ln*urb*→ ln*gdpc*	10.31*	
ln*urb*→ln*nrt*	9.28*	with feedback
ln*nrt*→ln*urb*	8.10*	
ln*nec*→ln*urb*	9.88*	with feedback
ln*urb*→ln*nec*	8.46**	

Notes: * and **are statistical significance level at 1% and 5% respectively and a lag selection of 5 is employed for the Granger causality estimate. Also, the co_2, *gdpc, nrt, urb, nec and ele*are respectively the carbon dioxide, gross domestic product per capita, total natural rent, urbanization, non-renewable energy consumption, and electricity energy consumption while the ln is the logarithmic values of the variables.

4. Results and Discussion

The preliminary estimates that include the common statistics and the correlation estimates which are respectively presented in Tables 2 and 3 gave a priori information about the variables under consideration. Given that the skewness and the kurtosis are significant, the correction (see Table 3) between carbon emissions and the independent variables are significant. In the same vein, the correlation estimate suggests that there is less concern of correlation among the independent variables. In addition to the preliminary test, the unit root tests employed are the Levin, Lin and Chu (2002); the Im, Pesaran and Shin (2003); and the Fisher-ADF by Maddala & Wu (1999) techniques as indicated in Table 4. The result of the unit root test paved the way for the use of the Pooled Mean Group (PMG) of the Autoregressive Distributed Lag (ARDL) to be conducted.

Importantly, the long-run estimates from the three models (see Table 5) present an interesting overview of nexuses between economic growth (gdpc), electricity consumption (ele), non-renewable energy (nec), total resource rent (nrt), and urbanization of pollutant emissions in Africa. In the first case (indicated as Model a in Table 5), the *gdpc*, *nrt*, and *urb* are observed to have significant impact on CO_2 emissions in the long-run. Although the impact of *nrt* on the CO_2 emissions is unexpectedly negative, the *gdpc*, *nrt*, *nec* and *urb* all exerts positive and significant impacts in the panel of countries. The result implies that a 1% increase in economic growth, total natural resource rent, non-renewable energy consumption, and urbanization is respectively responsible for 0.27% increase, 0.11% decline, 1.34% increase and 0.09% increase in the emission of CO_2 in the panel of estimated African countries. Although Wang and Dong (2019) did not incorporate total natural resource rent in their investigation, the result of their investigation based on the Augmented Mean Group (AMG) is close to that of the current study. Accordingly, Wang and Dong (2019) found that a unit increase in the economic growth, non-renewable energy consumption, and urbanization will cause a respective rise of 0.205%, 0.23% and 0.395% in the ecological footprint. The nexus between CO_2 emissions with the independent variables presents similar results which have been examined in other studies (Shahbaz et al., 2016; Asumadu-Sarkodie & Owusu, 2017; Hanif, 2018).

Furthermore, the second case (Model b of Table 5) where electricity energy consumption (*ele*) is incorporated in lieu of non-renewable energy consumption equally presents a very interesting and peculiar result for the African case. Similar to the earlier result (with NEC), the impacts of economic growth (*gdpc*), *urb*, and *ele* on CO_2 emissions are positive and statistically significant. In this scenario, a 1% increase in the *gdpc, urb* and *ele* will expectedly cause a respective increase of 0.39%, 0.39% and 1.11% in kilotons of CO_2 emissions in the panel of the selected African countries. Consistent with Inglesi-Lotz & Dogan (2018), this study infers that electricity energy consumption in Africa is a significant contributor to the environmental degradation of the continent. Also, the aforesaid observation is similar to the above scenario where non-renewable energy consumption is a significant determinant of pollutant emissions (model a) and that of other studies (Cowan et al., 2014; Salahuddin, Gow & Ozturk, 2015; Wang & Dong, 2019). The implication is that economic growth and expansion in African countries are still known causative agent of pollutant emissions and that the sampled African countries are yet to attain the growth-led environmental sustainability threshold. This tendency applies to non-renewable energy consumption and electricity consumption, because the main source of energy for industrial production, residential, commercial, and transportation use among others in Africa is still largely from the fossil fuel, thus resorting to environmental degradation.

However, the third model c which allows the incorporation of both the non-renewable energy consumption and electricity energy consumption did not yield a different result compared to the two previously illustrated ones. In this case, all the independent variables continued to show a positive and statistically significant effect on the carbon emissions except for the impact of total natural resource rent that remains negative in the long-run. Moreover, the investigation further presents the short-run relationships between the variable of concern as indicated in Table 5. Indicatively, economic growth in Angola, Botswana, Congo Republic, Ethiopia, Ghana, and Zimbabwe are observed to induce significant levels of pollutant emissions in the sampled countries. Also, the short-run scenario indicates that the endowment of the natural resource rent in all but Benin-Republic and Kenya is a trigger agent for pollutant emissions.

In general, the current study further deepened the aforementioned related studies in few dimensions. While the study considered the implication of the income per person (GDP per capita), urbanization, natural resource rent, and electricity consumption on environmental quality, the case of the panel of African country significantly adds to the novel contribution of the study. Importantly, it is interesting as well curious to observe a negative and significant long-run estimates of the nexus of *nrt* and CO_2 as against an expected positive relation such as in the study of Bekun, Alola & Sarkodie (2019). Considering the case the case of Africa as observed in this study, the negative impact of the *nrt* could be attributed to the effect of multi-million dollars environmental-legal tussles involving multinational companies especially in the natural resources-producing African states. For instance, the multimillion dollars litigation against Shell Company in Nigeria serves as a potential catalyst for the adoption of a more environmentally cautious approach to production as against the supposed business-as-usual approach. This implies that exploration activities could in somewhat be a catalyst to the improvement of environmental quality especially in the long run for the examined panel of African countries. However, considering that the improvement of the standard of living and the increase in urbanization, electricity energy and non-renewable energy consumption triggers environmental degradation, this suggests a challenging environmental sustainability pathway for the African states.

4.1 Robustness Evidence

The evidence of the relationship between the environmental degradation vis-à-vis $CO_2$and economic growth, non-renewable energy consumption, electricity energy consumption, urbanization, and total natural resource rent is complimented with the Granger causality estimates indicated in Table 6. In this investigation, both economic growth (*gdpc*) and electricity energy consumption (*ele*) have feedback effects with CO_2emissions, thus implying that the historical information of gdpc and ele are significant enough to explain the future dynamics of CO_2 emissions in the panel countries. On the other hand, the previous values of non-renewable energy consumption and natural resource rent are good at explaining the future dynamics of CO_2 emissions but without feedback. However, the study illustrates a feedback Granger causality between *gdpc* and *urb*, *nrt* and *urb*, *nec* and *urb*, and *ele* and *urb* while the Granger causality from nec to ele and from *gdpc* to *nrt* are all without feedback.

5. Conclusion and Policy Direction

The present study complements the existing studies on the income-carbon function by the incorporation of urbanization, electricity consumption, non-renewable energy consumption, total natural resources rent and economic growth in the African context, which has received little attention in the energy economic literature in recent times. The current study explores the nexus between the outlined variables within a balanced panel setting over selected African countries from 1980 to 2014. The Kao and Pedroni cointegration test shows cointegration among the variables under consideration. Subsequently, the long-run regression suggests a positive and statistically significant relationship between electricity consumption and pollutant emissions, non-renewable energy consumption and pollutant emissions, urbanization and pollutant emissions, economic growth and pollutant emissions. On the contrary, an inverse relationship is observed between total natural resources rent and pollutant emissions over the sampled period.

The empirical results have far-reaching outcomes. For instance, the positive relationship that exists between economic growth and pollutant emissions. This implied that the selected African countries are at the scale stage of their growth trajectory as outlined in the study of (Shahbaz & Sinha, 2019). This suggests that at the initial stage of their growth path, emphasis is on economic growth relative to quality of the environment. This is true for the selected countries as focus is on increase in aggregate output (GDP). A similar pattern is seen as increased urban population, electricity consumption and non-renewable energy consumption contribute positively to increase pollutant emission.

By implication, this empirical finding is revealing for stakeholders, policy makers and government administrator who formulate and design energy blue print. This is a call for more pragmatic steps on the part of African government administrators to intensify commitment to more energy and environmental treaties like the Kyoto Paris Agreement and Kyoto protocol submission. This is in a bid to abate the emissions of carbon dioxide in the African space. This position was resonated in the study of Emir and Bekun (2019) for the Romanian economy, as Romania has met her renewable energy target. Thus, the need to switch to other cleaner and environmental friendly energy sources like solar energy, biomass, hydro energy are encouraged in Africa.

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Appendix I

Table A: Pedroni cointegration test results

Alternative hypothesis: Common AR coefficients.(within-dimension)				
	Stat	*Prob.*	*W.Stat*	*Prob.*
Panel v-Statistic	-1.207	0.886	-1.087	0.831
Panel rho-Statistic	-0.238	0.406	-0.181	0.428
Panel PP-Statistic	-3.625*	0.000	-3.989*	0.000
Panel ADF-Statistic	-1.951*	0.026	-2.472*	0.007
Alternative hypothesis: individual AR coefficients. (between-dimension)				
Group rho-Statistic	0.403	0.656		
Group PP-Statistic	-4.566*	0.000		
Group ADF-Statistic	-1.756**	0.040		

Note: Reject the null hypothesis for no cointegration, thus there is cointegration. Also, * and **are statistical significance level at 1% and 5% respectively.

Kao cointegration test

	t-Stat	Prob.
ADF	-3.467*	0.0003
Residual variance	0.045	
HAC variance	0.025	

Note: Reject the null hypothesis for no cointegration, thus there is cointegration. Also, * and **are statistical significance level at 1% and 5% respectively