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Urbanization, Energy Consumption and CO_2 Emissions in Sub-Saharan Countries: A Panel Cointegration and Causality Analysis

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Abstract

Carbon dioxide (CO_2) emissions as a main determinant of environmental pollution have been frequently dealed with by research scholars and policy-makers. This study investigates the cointegration and dynamic causal relationship between urbanization, energy consumption and carbon dioxide (CO_2) emissions in Sub-Saharan countries for the period between 1985 and 2010. Pedroni and Kao cointegration methods and Granger causality test based on vector error correction model (VECM) are employed to conduct this empirical analysis. The results show that there exists a cointegration relationship between the variables over the period. It is also found that there exists bi-directional Granger causality between some variables in the the long-run as well as in the short-run such as, between energy consumption and CO_2 emissions. The results imply that energy consumption and urbanization are the main determinants of environmental pollution in these countries. and a series of policy measures related to urbanization and energy should be taken to decrease the environmental degradation.

Keywords: CO_2 emissions, urbanization, energy consumption, panel cointegration, panel Granger causality.

JEL Classification: C23, O1, Q43, Q56

1. Introduction

Climate change and greenhouse gases (GHG) emissions are the most challenging problems of the world. Carbon dioxide (CO_2) is accepted to be the main source of GHG emissions and has taken a great attention in the recent years. The amount of CO_2 emissions in developing countries from energy consumption is significantly increasing over the period being examined in this study. CO_2 emission trends are expected to continue in these countries (Hossain, 2011; Al-mulali and Binti Che Sab, 2012). In addition, according to United Nations Population Division (2014) the world has witnessed the rapid urbanization process since 1950. There exists considerable variations across regions in rates of urbanization. However, Africa and Asia are the fastest urbanizing regions in the world and expected to be 56 and 64 per cent urban, respectively, by 2050. Most of the empirical studies such as Martinez-Zarzoso (2008), Halicioglu (2009), Acaravci and Ozturk (2010), Saboori and Sulaiman (2012), Sadorsky (2014), and Kasman and Duman (2015) employ the variables of urbanization and energy consumption as the main determinants of environmental pollution (or CO_2 emissions). Rapid urbanization can affect economic growth, energy consumption and environmental degradation in developing countries. On the other hand, a higher level of energy consumption can lead to greater economic activity and increase CO_2 emissions. If urbanization and energy consumption significantly causes environmental pollution then this will have implications for policy makers (Sadorsky, 2014).

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The main aim of the present study is to investigate the cointegration and causal relations between urbanization, energy consumption and CO_2 emissions in Sub-Saharan countries from 1985 to 2010. The panel unit root tests presented by Levin, Lin and Chu (2002) and Im, Pesaran and Shin (2003) are used to examine the stationarity properties of the variables. Pedroni (1999) and Kao (1999) cointegration methods are used to test the presence of long run relationship between the variables. In addition, the Granger causality test based on vector error correction model (VECM) are employed to investigate the causal relationships between the variables. The summary of selected studies related to CO_2 emissions reported in Table 1 shows that there exists limited empirical results with Sub-Saharan countries. For this reason, this study can provide empirical evidences and important policy implications related to Sub-Saharan countries.

Table 1: Summary of the Selected Empirical Studies with CO_2 Emissions

Study	Period / Country	Variable	Methodology	Cointegration	Long run causality
Kasman and Duman (2015)	1992-2010 new EU members	Energy consumption, CO_2 emissions, GDP per capita, urbanization, openness	Pedroni, Kao and Westerlund cointegration tests, Panel VECM Granger causality	Yes	E↔C; U→C U→E
Begum et al. (2015)	1970-2009 Malaysia	Energy consumption, CO_2 emissions, GDP per capita, population	ARDL bounds testing, VECM Granger causality	Yes	-
Shahbaz et al. (2014)	1975-2011 United Arab Emirates	Energy consumption, CO_2 emissions, GDP per capita, urbanization, exports	ARDL bounds testing, VECM Granger causality	Yes	E↔C U↔C
Wang et al. (2014)	1995-2011 30 Chinese provinces	Energy consumption, urbanization, CO_2 emissions	Pedroni cointegration, Panel DOLS, Panel VECM Granger causality	Yes	E↔C; U↔C U↔E
Ozcan (2013)	1990-2008 12 Middle East countries	Energy consumption, CO_2 emissions, GDP per capita	Westerlund cointegration, Panel VECM Granger causality	Yes	E→C
Arouri et al. (2012)	1981-2005 Middle East and North African countries	Energy consumption, CO_2 emissions, GDP per capita	Westerlund-Edgerton cointegration, Panel VECM Granger causality	Yes	-
Hamit-Haggar (2012)	1990-2007 Canadian industrial sector	Energy consumption, GHG emissions, GDP	Pedroni and Westerlund cointegration, Panel VECM Granger causality	Yes	E→C
Hossain (2012)	1960-2009 Japan	Energy consumption, CO_2 emissions, GDP per capita, urbanization, openness	ARDL bounds testing, VECM Granger causality	Yes	E↔C U→C
Al-mulali (2011)	1980-2009 MENA countries	Energy consumption, CO_2 emissions, GDP	Pedroni, Johansen and Kao cointegration, Panel VECM Granger causality	Yes	E→C C→E
Hossain (2011)	1971-2007 NIC	Energy consumption, CO_2 emissions, GDP per capita, urbanization	Johansen panel cointegration, Panel VECM Granger causality	Yes	-
Sharma (2011)	1985-2005 69 countries	Energy consumption, CO_2 emissions, GDP per capita, urbanization, openness	Panel GMM	-	-
Hatzigeorgiou et al. (2011)	1977-2007 Greece	Energy intensity, CO_2 emissions, GDP	Johansen cointegration, VECM Granger causality	Yes	E↔C

Notes: The table is constituted from us. C, E and U indicate CO_2 emissions, energy consumption and urbanization, respectively. $\rightarrow$ and $\leftrightarrow$ denote uni-directional and bi-directional causality, respectively.

2. Literature Review

Environmental quality and its determinants have been debated for a long time by theorists and policy-makers in both developing and developed countries. Actually, this debate has appeared through the environmental Kuznets curve (EKC) hypothesis. According to Acaravci and Ozturk (2010) EKC hypothesis suggests that there exists an inverted U-shaped relationship between environmental pollution and per capita inome. This means that in the early of ecomic growth environmental pollution increases.

However, if a country reaches a certain level of income, environmental pollution starts to decrease. The studies that concentrate on the link between economic growth and environmental degradation (or EKC hypothesis) include Akbostanci et al. (2009) for Turkey, Halicioglu (2009) for Turkey, Acaravci and Ozturk (2010) for Turkey, Pao and Tsai (2010) for BRIC countries, Jalil and Feridun (2011) for China, Pao and Tsai (2011) for Brazil, Shahbaz et al. (2013) for South Africa. However, empirical results are inconclusive. In these studies SO_2 and CO_2 are used as the main indicators for environmental pollution. EKC literature also uses the variable energy consumption as a determinant of environmental pollution. There exists close relationships between energy consumption, environmental pollution and economic growth. Energy consumption is an essential factor for industrial development and economic growth in all countries. However, high energy consumption may lead to high CO_2 emissions and environmental pollution (Halicioglu, 2009). Employing ARDL bounds test and VECM Granger causality approach, Acaravci and Ozturk (2010) examine the causal links between energy consumption, economic growth and CO_2 emissions in nineteen European countries. The results of bounds-F test for cointegration test show that there exists a long run relationship between the variables. The results also show that energy consumption positively affects CO_2 emissions in Denmark, Germany, Greece, Italy and Portugal. There exists a negative link between economic growth and CO_2 emissions in Denmark and Italy. Saboori and Sulaiman (2013) investigate the relationship between economic growth, energy consumption and CO_2 emissions in selected Association of Southeast Asian Nations (ASEAN countries) from 1971 to 2009. ARDL bounds test results reveal the presence of a cointegration relationship between the variables. There exits a positive relationship between CO_2 emissions and energy consumption in both the long and short-run. The VECM Granger causality test results reveal that there exists bi-directional causal link between energy consumption and CO_2 emissions in all ASEAN countries.

Using panel FMOLS method, Saboori et al. (2014) analyze the links between energy consumption, CO_2 emissions and economic growth in OECD countries over the period 1960-2008. The study indicates that there exists bi-directional positive relationship between economic growth and CO_2 emissions in the long run. The study also indicates that there exists long run bi-directional positive link between energy consumption and CO_2 emissions.Using panel causality tests, Cowan et al. (2014) deals with the causal links between electricity consumption, economic growth and CO_2 emissions in the BRICS countries from 1990 to 2010. It is found that there exists a Granger causality running from economic growth to CO_2 emissions in South Africa and from CO_2 emissions to economic growth in Brazil. In addition, Granger causality from electricity consumption to CO_2 emissions is found in India. A number of theories focus on the link between urbanization and natural environment. Sadorsky (2014) explores three theories on the relationship between urbanization and natural environment. These are well known as ecological modernization, urban environmental transition and compact city theories. According to the theory of ecological modernization, urbanization is a very important process of social transformation. As societies move from low to middle stages of development, economic growth is the primary goal of economy and environmental problems may emerge. In higher stages of development, environmental pollution becomes more important. Urbanization may reduce the impact of economic growth on the environment. The theory of urban environmental transition investigates the relationship between environmental issues and urbanization at the city level. In this theory, cities often become wealthier by industrial manufacturing and can cause to industrial demage. On the other hand, environmental regulations and technological innovations may lessen industrial pollution. The compact city theory deals with the benefits of urbanization. Higher urbanization may facilitate economies of scale for public infrastructure and environmental pollution may lessen by these scale economies. These theories suggest that urbanization may have positive and negative effects on the natural environment. Empirical studies have generally investigated the relationship between urbanization, energy consumption, and CO_2 emissions. For example, Cole and Neumayer (2004) deal with the relation between population size, other demographic factors and pollution from 1975 to 1998.

Using the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model, panel regression results reveal that urbanization pozitively affects CO_2 emissions. Martinez-Zarzoso (2008) analyzes the relationship between urbanization and CO_2 emissions in developing countries. The study covers the period 1975-2003 for different groups of countries. In the low-income countries the urbanization elasticity of CO_2 emissions is higher than the others. In the middle-income countries the elasticity is 0.72 whereas it is negative for the upper-income countries. Poumanyvong and Kaneko (2010) examine the impacts of urbanization on energy use and CO_2 emissions over the period 1975-2010. The study employs the STIRPAT model and panel data of 99 countries. The panel regression results show that urbanization decreases energy consumption in the low-income group, while it increases energy consumption in the middle and high income groups.

The panel regression results also show that urbanization increases CO_2 emissions in all income groups. Parshall et al. (2010) models the link between energy consumption and CO_2 emissions at the urban scale. By applying spatial analysis, the study finds that urbanisation is one of the most important factors affecting energy consumption in United States. Madlener and Sunak (2011) investigate the effects of urbanization on urban structures and energy demand in less developed countries. The results indicate that urbanization is a key factor of economic development and increases energy demand. Lu and Huang (2011) test the impact of urbanization on CO_2 emissions in case of China from 1980 to 2009. The Granger causality test results reveal that urbanization Granger causes CO_2 emissions. The results of Granger causality test based on VECM indicate that there exists a Granger causality running from urbanization to CO_2 emissions in the long run. There exists no relationship between the variables in the short run. Employing ARDL bounds testing approach and VECM Granger causality test, Hossain (2012) analyzes the causal links between energy consumption, economic growth, foreign trade, urbanization and CO_2 emissions over the period 1960-2009. It is found that there exists a cointegration relationship between the variables. It is also found that there exists a positive relationship between energy use and CO_2 emissions in the long run. The results show that there exists a long run bi-directional causal link between energy consumption and CO_2 emissions. The results also show that there exists a long run Granger causality running from urbanization to CO_2 emissions.

Martinez-Zarzoso and Maruotti (2012) examine the impact of urbanization on CO_2 emissions in developing countries over the period 1975-2003. The study uses an extended version of the STIRPAT model. The study provides evidence that there exists an inverted-U shaped relationship between urbanization and CO_2 emissions. Using the STIRPAT model, Poumanyvong et al. (2012) analyze the impact of urbanization on transport energy use for low, middle and high income countries from 1975 to 2005. The results indicate that urbanization affects road energy consumption positively. However, the magnitude of its effect varies among these income groups. Hassan and Morteza (2013) investigate the effects of urbanization on energy consumption and CO_2 emissions in Middle East and North Africa (MENA) countries. The results show that the impacts of urbanization on energy consumption and CO_2 emissions vary between the oil-exporting and non-oil-exporting countries. It is found that there exists a positive relation between urbanization and CO_2 emissions. It is also found that there exists a positive link between energy consumption and CO_2 emissions. Sadorsky (2014) analyzes the effect of urbanization on CO_2 emissions in emerging countries by using panel regression techniques. It is found that the coefficients on energy intensity and affluence variables are positive and statistically significant. It is also found that urbanization is positive but statistically insignificant. Using a panel data models, Wang et al. (2014) examine the relationship between urbanization, energy consumption, and CO_2 emissions from 1995 to 2011 for 30 Chinese provinces. The results indicate that there exists a long run bi-directional positive relationship between urbanization, energy consumption, and CO_2 emissions. The results also indicate that there exists a bi-directional causal relationship between urbanization, energy consumption, and CO_2 emissions in the long run. Kasman and Duman (2015) deal with the relationship between energy consumption, CO_2 emissions, economic growth, trade openness and urbanization in the new EU member and candidate countries for the period 1992-2010. This relationship is examined by panel unit root, cointegration and causality tests. It is found that there exists a long-run bi-directional causal relation between energy consumption and CO_2 emissions and a long-run uni-directional causal relation running from urbanization to CO_2 emissions. It is also found that there exists a long-run uni-directional causal relation running from urbanization to energy consumption.

3. Model and Data

Baltagi (2005) presents many advantages of the panel data models. For these reasons, this study uses the panel model over the period 1985-2010 and annual data derived from World Bank, World Development Indicators (2015) online data base.

In this study, in nineteen Sub Saharan African countries have examined, namely Angola, Benin, Bostwana, Cameroon, Republic of Congo, Cote d'Ivoire, Ethiopia, Gabon, Ghana, Kenya, Mozambique, Nigeria, Senegal, South Africa, Sudan, Togo, Zimbabwe and Democratic Republic of Congo. To investigate the relationship between urbanization, energy consumption and CO_2 emissions, two models will be employed. Following from Wang et al. (2014) these models can be established as follows:

$$CO_{2it} = \alpha + \beta_1 ENERGY_{it} + \beta_2 URBAN_{it} + \varepsilon_{it} \quad (1)$$

$$ENERGY_{it} = \alpha + \beta_3 URBAN_{it} + \beta_4 CO_{2it} + \varepsilon_{it} \quad (2)$$

where, CO_2 is per capita CO_2 emissions (metric tons); *ENERGY* is per capita energy consumption (kg of oil equivalent); *URBAN* is the share of urban population as an indicator of urbanization. α is the intercept term; β_1, β_2, β_3 and β_4 are the slope coefficients of the models; *t* is time; *i* is the cross section unit (*i*th country); ε_{it} is the regression error term. The descriptive statistics and correlation matrix of the variables are presented below in Table 2.

Table 2: Descriptive Statistics and Correlation Matrix (Panel data: 1985-2010)

Statistics / Variables	CO_2	*ENERGY*	*URBAN*
Mean	1.043	640.141	38.710
Median	0.336	416.215	37.044
Std. dev.	2.087	545.948	14.405
Min.	0.031	207.759	11.453
Max.	10.355	2961.354	85.697
Skewness	3.295	2.744	0.834
Kurtosis	12.977	10.381	4.100
Observations	494	494	494
CO_2	1.000		
ENERGY	0.953	1.000	
URBAN	0.444	0.470	1.000

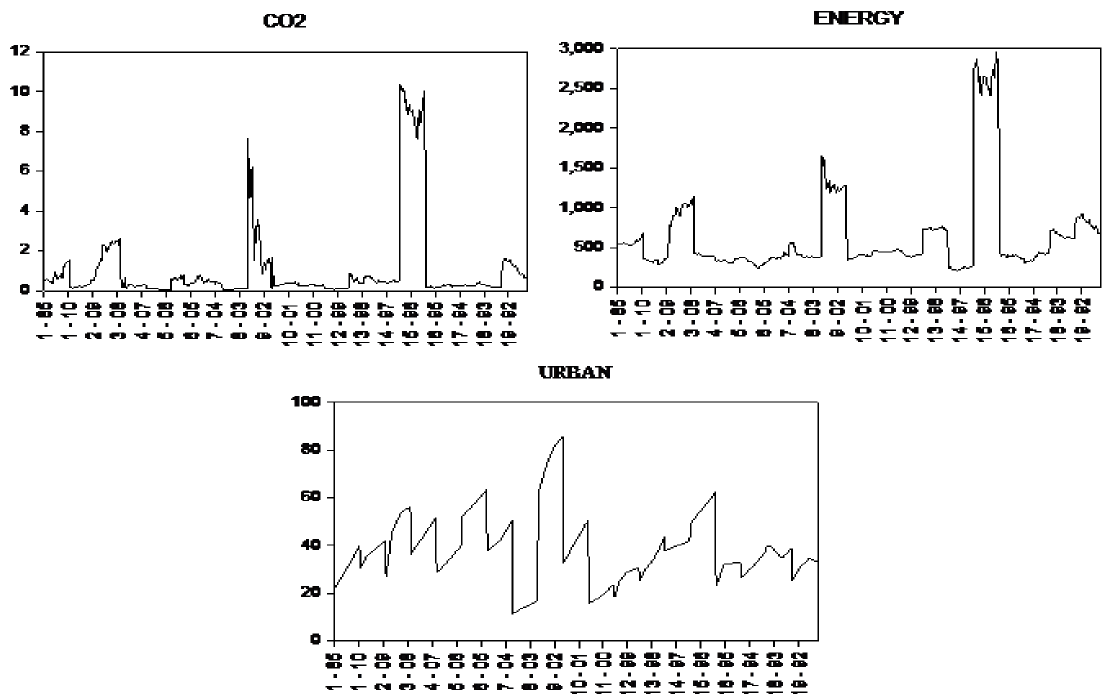

Figure 1: Trends in the Series

4. Econometric Methodology

In this study, the dynamic causal links among CO_2 emissions, energy consumption, and urbanization are investigated. The econometric strategy involves the following steps. The first step analyzes the stationarity properties of the variables through the panel unit root tests. If the variables have a unit root, the second step investigates the presence of a cointegration relationship between the variables. If a cointegration relationship between the variables is determined, the final step tests the Granger causal links between the variables through the panel VECM. In this step long and short run causality are investigated.

4.1. Panel Unit Root Tests

The unit root test is widely employed to investigate the presence of stationarity of the variables. It is well known that panel unit root tests are more powerful compared to the individual time series. There are several types of unit root tests for the panel data, namely the Breitung (2000), Hadri (2000), Levin, Lin and Chu (2002), Im, Pesaran and Shin (2003) and Fisher type tests. In this stuy, we use the panel unit root tests developed by Levin, Lin and Chu (LLC) (2002) and Im, Pesaran and Shin (IPS) (2003) to check the stationarity properties of the variables. LLC test supposes that there exists a common unit root process across the cross-sections while IPS test suggests that there exists individual unit root processes across the cross-sections. In these tests the null hypothesis is that there exists a unit root. In LLC test the alternative hypothesis is that there exists no unit root, alternative hypothesis is that some cross-sections do not have a unit root in IPS test (Pao and Tsai, 2011). The main characteristic of LLC test is that it suggets a homogeneous autoregressive root under the alternative hypothesis. Conversely, the main feature of IPS test is that it enables for a heterogeneous autoregressive coefficient under the alternative hypothesis (Hamit-Haggar, 2012).

4.2. Panel Cointegration Tests

4.2.1. Pedroni (Engle-Granger Based) Cointegration Tests

If the variables have a panel unit root, the Pedroni (1999) cointegration tests can be used. We employ the Pedroni cointegration technique allowing for individual-specific fixed effects and deterministic trends to test for a long run relationship among the variables of urbanization, energy consumption, and CO_2 emissions. Pedroni cointegration tests use the regression equation as follows:

$$y_{it} = \alpha_i + \delta_{it} + \beta_1 x_{1,it} + \beta_2 x_{2,it} + ... + \beta_{ki} x_{kit} + \varepsilon_{it} \quad (3)$$

where $t = 1,...., T; i = 1,....N; j = 1,..., k;$ and y and x are supposed to be integrated of order 1 i.e. $I(1)$. a_i is the intercept term, k is the number of independent variables, t is the number of observations over time. β_1, β_2 and β_k are slope coefficients. Under the null hypothesis of no cointegration, the residuals ε_{it} will be I (1). To apply the cointegration test, the residuals are derived from Equation (3) and the following auxiliary regression for each cross section is undertaken:

$$e_{it} = \rho_i e_{it-1} + u_{it} \quad (4)$$

or

$$e_{it} = \rho_i e_{it-1} + \sum_{j=1}^{\rho_i} \phi_{ij} \Delta e_{it-1} + v_{it} \quad (5)$$

Seven statistics for cointegration developed by Pedroni (1999) can be used for testing the null hypothesis in heterogeneous panels. Of these seven statistics, four are within-dimension statistics and three are between-dimension statistics. The within dimension tests are panel v-statistic, panel ϱ-statistic, panel PP-statistic, and panel ADF-statistic. The between-dimension tests are group ϱ-statistic, group PP-statistic, and group ADF-statistic. These test statistics are constructed from the residuals, either from Eqs. (4) and (5). A total of seven statistics with varying size and power for different N and T are generated. Pedroni indicates that the standardized statistics is asymptotically normally distributed,

$$\frac{N_{N,T} - \mu\sqrt{N}}{\sqrt{v}} \rightarrow N(0,1) \quad (6)$$

where u and v are the Monte Carlo generated adjustment terms, T is the number of observations, and N is the number of units in the panel.

4.2.2. Kao (Engle-Granger Based) Cointegration Test

The cointegration tests developed by Kao (1999) and Pedroni (1999) exhibits the same basic approach. However, Kao (1999) considers cross-section specific intercepts and homogeneous coefficients during the first-stage regressors. Kao (1999) presents Dickey-Fuller and Augmented Dickey-Fuller type tests. In these tests, the null hypothesis is that there exists no cointegration. In the bivariate case Kao considers the following model

$$y_{it} = \alpha_i + \beta x_{it} + e_{it}, \; i = 1,\ldots,N; \; t = 1,\ldots,T \tag{7}$$

$$y_{it} = y_{it-1} + u_{it} \tag{8}$$

$$x_{it} = x_{it-1} + \varepsilon_{it} \tag{9}$$

a_i are the fixed effect varying across the cross-section observations, β is the slope parameter, y_{it} and x_{it} are independent random walks for all *i*. For the Augmented Dickey-Fuller test, estimated residual is

$$\hat{e}_{it} = \rho \hat{e}_{it-1} + \sum_{j=1}^{p} \varphi_j \Delta \hat{e}_{it-j} + v_{itp} \tag{10}$$

Under the null of no cointegration, the ADF test is calculated as follows

$$ADF = \frac{t_{\bar{p}} + \sqrt{6N\hat{\sigma}_r} / (2\hat{\sigma}_{0r})}{\sqrt{\hat{\sigma}_{0r}^2 / (2\hat{\sigma}_r^2) + 3\hat{\sigma}r_r^2 / (10\hat{\sigma}_{0r}^2)}} \tag{11}$$

The estimated variance is $\sigma_r^2 = \sigma_r^2 - \sigma_r^{-2}$ with estimated long run variance $\sigma_{0r}^2 = \sigma_{0u}^2 - \sigma_{0u\in}^2 \sigma_{0\in}^{-2}$. The covariance of $\omega_{it} = \begin{bmatrix} u_{it} \\ \in_{it} \end{bmatrix}$ is estimated as

$$\sum \begin{bmatrix} \hat{\sigma}_u^2 \hat{\sigma}_{0u\in} \\ \hat{\sigma}_{0u\in} \hat{\sigma}_{\in}^2 \end{bmatrix} = \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} \hat{\omega}_{it} \hat{\omega}_{it}^{'} \tag{12}$$

And the long run covariance is determined using the usual kernel estimator

$$\hat{\Omega} = \begin{bmatrix} \hat{\sigma}_{0u}^2 \hat{\sigma}_{0u\in} \\ \hat{\sigma}_{0u\in} \hat{\sigma}_{0\in}^2 \end{bmatrix} = \frac{1}{N} \sum_{i=1}^{N} \left[\frac{1}{T} \sum_{i=1}^{T} \hat{\omega}_{it} \hat{\omega}_{it}^{'} + \frac{1}{T} \sum_{\tau=1}^{\infty} k(\tau / b) x \sum_{t=\tau+1}^{T} \hat{\omega}_{it} \hat{\omega}_{it-1}^{'} + \hat{\omega}_{it-\tau} \hat{\omega}_{it}^{'} \right] \tag{13}$$

where *k* is one of the supported kernel function and *b* is the bandwidth.

4.3. Panel Granger Causality Test

The cointegration tests imply the existence of long run and causal relationship but it does not inform about the direction of causal relationship between the variables. If the variables are cointegrated, the Granger causality can be employed to investigate the causal relationships. We use the Granger causality test based on VECM approach developed by Engle and Granger (1987) to examine the causal relationship between urbanization, energy consumption, and CO_2 emissions. In this test the error correction term (ECT) is included to the VAR system as an additional variable. The VECM approach well known as the augmented Granger causality test is able to investigate both long and short run causal relationships.

The VECM for panel data can be written as follows:

$$\begin{bmatrix} \Delta CO_{2it} \\ \Delta ENERGY_{it} \\ \Delta URBAN_{it} \end{bmatrix} = \begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} + \sum_{k=1}^{p} \begin{bmatrix} \beta_{11k} \beta_{12k} \beta_{13k} \\ \beta_{21k} \beta_{22k} \beta_{23k} \\ \beta_{31k} \beta_{32k} \beta_{33k} \end{bmatrix} \begin{bmatrix} \Delta CO_{2it} \\ \Delta ENERGY_{it-k} \\ \Delta URBAN_{it-k} \end{bmatrix} + \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \end{bmatrix} ECT_{it-1} + \begin{bmatrix} \varepsilon_{1it} \\ \varepsilon_{2it} \\ \varepsilon_{3it} \end{bmatrix} \tag{14}$$

where *i* = 1, 2, .., *n*; *t* = *p*+1, *p*+2, *p*+3, …, *T*. The *C*'s, β's and γ's are the parameters to be estimated. Δ is the first difference operator, ECT_{it-1} is the lagged error correction term derived from the cointegrating equation and ε's are the white noise error terms.

The coefficient of ECT indicates the presence of a long-run equilibrium relationship among the variables. By applying a joint test of the coefficients based on the the *F*-test, short run causality is determined. On the other hand, the long run causality is established through the significance of the lagged error correction term based on the *t*-test.

5. Empirical Results

The results of LLC and IPS tests are summarized in Table 2. The results indicate that the variables CO_2, ENERGY and URBAN are not stationary at the level but stationary at the first difference level of significance (5%). This implies that the three variables contain a panel unit root and integrated of order 1. This also implies that the panel cointegration tests can be applied to test the long run relationship between the variables.

Table 3: Panel Unit Root Test Results

	Level	First difference
Levin, Lin and Chu t*-stat		
CO_2	-1.519	-19.393***
ENERGY	-0.885	-17.953***
URBAN	-1.133	-6.695***
Im, Pesaran and Shin W-stat		
CO_2	-1.035	-20.224***
ENERGY	-1.140	-15.924***
URBAN	1.076	-6.926***

Notes: The panel unit root tests with intercept are carried independently; the optimal lag lengths are obtained automatically with the AIC.
*** indicates significance at 1% level.

Table 4 reviews the results of Pedroni cointegration test for the CO_2 and ENERGY models. It is found that most of the statistics reject the null hypothesis of no cointegration. These results show that there exists a long run relationship between urbanization, energy consumption and CO_2 emissions in the countries under examination.

Table 4: Pedroni Cointegration Test Results

p		
Sample: 1985 2010		
Observations: 494		
Cross-sections: 19		
Lag selection on SIC: Fixed at 4		
Test statistics	*CO_2* model	*ENERGY* model
Alternative hypothesis: common AR coefs. (within-dimension)		
Panel v-statistic	-0.900	-0.128
Panel rho-statistic	-2.493***	-2.882***
Panel PP-statistic	-8.737***	-4.495***
Panel ADF-statistic	-13.488***	-4.590***
Alternative hypothesis: individual AR coefs. (between-dimension)		
Group rho-statistic	-1.547*	0.457
Group PP-statistic	-6.125***	-1.199
Group ADF-statistic	-6.630***	-1.839**

Notes: *** indicates significance at 1% level.
** indicates significance at 5% level.
* indicates significance at 10% level.

Tablo 5 reviews the results of Kao cointegration test for the CO_2 and ENERGY models. It is found that the ADF test statistic is significant rejecting the null hypothesis of no cointegration. This result implies that there exists a cointegration relationship between the variables. The results are consistent with Wang et al. (2014) for 30 Chinese provinces.

Table 5: Kao Cointegration Test Results

Kao residual cointegration test		
Sample: 1985 2010 Observations: 494 Cross-sections: 19 Lag selection on SIC: Fixed at 4		
Test statistics	CO_2 model	*ENERGY* model
ADF	1.432*	-1.674**

Notes: ** indicates significance at 5% level.
* indicates significance at 10% level.

This study uses the Granger causality test based on VECM. The panel Granger test results are reported in Table 6. The results indicate that, based on error correction term *ECT (-1)*, there exists a bi-directional causality between energy consumption and CO_2 emissions in the long run. The results also indicate that there exists bi-directional long run causality between energy consumption and urbanization. In the long run it is found a bi-directional causality between urbanization and CO_2 emissions. In the long run it is also found bi-directional causality between energy consumption and urbanization. These findings are confirmed by Wang et al. (2014) for Chinese provinces. In the short run it is found that a bi-directional causality between energy consumption and CO_2 emissions. These results reveal that energy consumption and urbanization cause environmental degradation and are the main determinants of the environmental quality in these countries.

Table 6: Panel Granger Causality Test Results

	Short-run (*F*-statistic)			**Long-run (*t*-statistic)**
Dependent variable	ΔCO_2	$\Delta ENERGY$	$\Delta URBAN$	*ECT(-1)*
ΔCO_2	-	2.539**	0.514	-4.971***
$\Delta ENERGY$	10.495***	-	0.531	-5.911***
$\Delta URBAN$	0.454	-0.004	-	-5.663***

Notes: *** indicates significance at 1% level.
** indicates significance at 5% level.

6. Conclusion

This study deals with the links between energy consumption, urbanization and CO_2 emissions in nineteen Sub Saharan African economies using the data set covering the period spanning from 1985 to 2010. This study uses Pedroni and Kao panel cointegration approach to test the long run relationship between the variables. The study also employs the VECM Granger causality test to determine the dynamic causal relations between the variables. The cointegration test results show that there exist a long run relationship between the energy consumption, urbanization, and CO_2 emissions. From the VECM Granger causality test results, a bi-directional Granger causality is observed between the energy consumption, urbanization, and CO_2 emissions in the long run. In addition, the results indicate that there is a bi-directional Granger causality energy consumption and CO_2 emissions in the short run. The results provide empirical evidence that energy consumption and urbanization are the main determinants affecting the environmental quality in Sub-Saharan countries. In order to decrease CO_2 emissions or environmental pollution, a series of measures should be taken into consideration by the policy-makers. They may control urbanization and enegy consumption to improve environmental quality. They may also apply more strict environmental and energy policies. They may develop some new policies that focus on the alternative sources of energy.

Specifically, they may enhance the share of clean energy in total energy consumption. In addition, they should utilize energy protection policies. It may also be very vital to achive a moderate and planned urbanizaton level for these countries.

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