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C02 Emissions and Economic Growth: A Panel Data Analysis Evidence from Developing African Countries

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Abstract

This paper tests the Environmental Kuznet Hypothesis using data from 23 African countries for the period 1980–2019 in the Pedroni approach to panel cointegration analysis. The evidence suggests that both real GDP and energy consumption have a substantial effect on CO2 emission in most countries studied though energy consumption has less effect. However, in most countries, as income increases, the level of emission declines consistently with the EKC hypothesis. However, the econometric result, their interpretation, and their likely policy implications have to be taken with caution since there is a high degree of heterogeneity among the countries in terms of energy consumption, real income as well as CO2 emissions. This is more so when the analysis of the trend in the growth of the three variables used in estimation and the estimated results of fully modified OLS show large divergence among countries. However, the study recommends that, since a great number of economies in the study buttressed the EKC, therefore, the current policy on growth and energy consumption may be pursued without necessarily affecting the quality of their

environment. However, other countries should implement strong regulatory and market-based policies on highly energy-intensive sectors to reduce their current level of emissions and attain sustainable, environment-friendly growth.

Keywords: Environment Kuznet, Africa Panel cointegration

Introduction

In the economics of the African energy market, three crucial trends have policy implications for both energy and environmental policy formulations. First, Africa has the fastest-growing population and some of the fastest-growing economies globally. It also produces and consumes a large fraction of the world's fossil fuels. Therefore, the economic growth of many African economies will transmute into a mammoth increase in demand for energy and carbon emissions.

Secondly, the fraction of fossil fuels in the total energy mix of Africa has been rising, and this induces rising carbon emissions. As most of these economies cannot carry out their economic operations without fossil fuels, because they greatly depend on them; and it is seen as an entitlement to access fossil fuels at an affordable price.

Thirdly, many developing countries see global warming as an issue of little or no importance, caused by and to be dealt with by the industrialized nations. Indeed, some even argue that it is a conspiracy by the industrialized nations to impede their development (Bartsch and Muller 2000). This assertion reinforces the reluctance of many African developing countries to formulate policies and support investment in cleaner but relatively expensive renewables and less carbon-intensive energy technologies.

Therefore, shifting from fossil fuel consumption to more environment-friendly renewables, biofuel, and nuclear energy is likely to be the best policy for climate change mitigation. In addition, African developing economies should follow separate growth routes that have to be viable and less destructive to the environment. Since energy is a crucial contributing factor to pollution, therefore, the policymakers in African countries should formulate a district policy for renewables by imposing taxes on fossil fuels and subsidizing the renewables (Gill, AR et.al, 2017).

However, the seemingly many conflicts between the desire to promote rapid/high levels of economic growth, over-reliance on fossils as a major supply of energy in these countries, and the demand for a cleaner environment from the international community raised some fundamental questions. Firstly, how should the present energy system in these countries support the transition to an inexpensive, low-carbon energy system without compromising the fundamental objective of achieving a high level of economic growth in African countries? Secondly, how can the huge amount of less carbon, renewable energy technologies be incorporated in the operation and development of a sustainable energy system that is environmentally friendly in these countries? Finally, is there any way some market-based policies such as proper pricing policies,[1] some of these are extremely expensive, and demand management policies that may require a rise in energy prices that could be used to change individual behavior in those countries to ultimately follow price signals, then be energy efficient that leads to a substantial reduction in the consumption of energy and emission of carbon?

The key basis for concern is whether the energy and environmental policymakers in these countries can summon enough courage to adopt those policies to attain the four energy policy goals, including, security, social concerns, the environment, and competitiveness without fear of backlash from the public and trade unions in these countries.

A literature survey shows that few known studies have attempted to separately investigate this issue in African countries using panel data analysis, This is one of them. Understanding the connection between energy use, income, and emission of carbon in those countries is very important for both researchers and policy-makers. For example, the findings of this research will help in understanding the importance of the global environmental agenda and how to formulate environmental policies in line with global best practices.

This paper expands on previous works on the Environment Kuznets Hypothesis in three important ways. Firstly, Although this is not the first study that focused on African developing countries, perhaps this study is an improvement on previous studies by estimating the data both in the panel and country-specific a slight deviation from most of the past studies. Secondly, this study also accounts for the heterogeneity of those countries concerning their incomes, energy utilization, and CO2 emissions by associating the trends in economic growth, energy utilization, and CO2 emission (much earlier literature on African developing countries were bivariate, considering the only relationship between income or output and energy use). See for example, see (interalia, Apergis, N., Payne, J.E., 2010, Asafu-Adjaye, J.,2000, Aqeel, A. and Butt, M.S. 2001 Glasure, Y.U., Lee, A.R., 1998, Masih, A.M.M., Masih, R. 1996, S Sa'ad 2010, Yang, H., 2000, Kraft, J., and Kraft, A., 1978).

Finally, this study adopted panel data analysis and complemented it by estimating country-specific data in a multivariate analysis using fully modified OLS against most previous studies that used single-country

[1] Market base pricing policies may also attract investment in the sector

analysis. The study is structured as follows: section two reviewed the energy consumption annual growth and trends, GDP, and co_2 emission in 23 African economies. The nexus between income, co_2 emission, and energy use in previous kinds of literature is summarized in section three. Section three summarizes the previous works on the relationships connecting energy use, income, and co_2 emission in energy literature. Section four contains a discussion of the econometric methodology adopted for the study, Section five examines econometrically, the long-run relationships amongst income, income squared, energy use, and co_2 emission using data on developing countries in Africa from 1980 to 2015. Finally, Section Six contains the conclusions and policy implications.

2.0 Trends in Energy Consumption, GDP, and Carbon Emission

From the comparison of annual average growth rates of energy use, economic growth, and co_2 emission in 23 economies in Africa. There is a high level of heterogeneity among those countries in terms of energy utilization, GDP, and co_2 emission. This diversity is a reflection of some factors including levels of economic growth, and to some extent, energy endowments among those countries. Between 1980 and 1990, the yearly average growth of energy utilization ranged from -2.6% to 0.08% in the case of low-income countries the Democratic Republic of Congo and Gabon, and to 8.2% and 5.6% in oil-producing mid-income countries of Algeria and Kenya. The two countries are higher than Africa‘s average. In the decade 1990 to 2000, while Algeria and Gabon recorded a decline in their energy consumption, Libya and Morocco saw an increase in energy consumption to 5.2% and 5.0% respectively from their previous decade, these are higher than the Africa Average of 2.6%. However, the war-ravaged Democratic Republic of Congo and low-income Cote d'Ivoire recorded a negative growth rate in their energy consumption. Comparatively, in the decade 2000 to 2016, most African countries recorded an appreciable increase in energy consumption. Angola and Algeria recorded an annual average rise in energy consumption to 6.4% and 5.6% annually from 2.4% and 1.9% annually in the decade 1990 to 2019. Similarly, for the whole of Africa, the annual average consumption of energy has increased appreciably. The Introduction states the research question, why the research is important, and briefly reviews relevant literature and previous work.

Table 1. Annual Average Growth Rates of GDP, Co_2 Emission, and Energy Consumption

Country	1980-2016			1980-1990			1991-2000			2001-2019		
	E	Y	C	E	Y	C	E	Y	C	E	Y	C
Algeria	5.1	2.7	1.8	8.2	2.8	2.2	1.9	1.7	0.1	5.6	3.7	3.0
Angola	3.8	4.7	7.0	2.9	2.5	7.8	2.4	0.8	6.2	6.4	12.0	7.4
Benin	3.4	3.8	8.1	2.0	2.7	10	1.5	4.8	10.8	6.8	5.0	5.1
Cameroon	1.8	2.7	4.3	3.2	3.3	4.8	2.3	1.4	10.2	6.7	6.6	5.6
Congo	-2.7	3.6	7.5	-1.6	4.8	4.7	0.3	1.4	-5.6	1.9	3.9	6.8
CDR	-3.4	0.2	-0.7	-2.6	0.9	0.7	-4.2	-5.6	-2.9	-4.7	3.8	2.1
Cote'dvour	2.8	1.2	2.0	-1.5	0.7	1.5	-4.0	2.3	4.7	-2.4	1.08	-1.6
Gabon	1.8	2.0	-0.2	0.08	1.8	1.8	2.2	2.0	-1.1	2.7	2.3	-1.1
Ghana	2.7	4.4	4.6	2.4	2.2	3.1	3.5	4.4	5.8	2.1	5.8	5.5
Ethiopia	2.8	4.1	4.5	3.2	1.9	5.9	2.6	2.8	1.4	2.8	8.4	6.4
Egypt	4.6	4.8	5.3	3.0	5.5	6.5	3.4	4.2	3.2	5.0	4.9	4.8
Kenya	3.1	3.4	4.6	5.6	4.1	3.1	2.3	1.9	5.8	3.3	4.1	5.5
Libya	2.4	-3.6	1.4	3.3	2.3	2.7	5.2	0.2	-0.2	4.4	5.0	2.2
Morroco	4.1	4.0	3.2	2.5	3.9	3.3	5.0	2.4	3.8	4.6	4.9	3.3
Nigeria	2.6	3.5	0.3	2.4	1.1	1.1	2.8	2.9	-0.2	2.5	6.4	-0.9
Senegal	2.6	3.2	3.4	0.3	2.6	0.3	3.0	3.1	5.6	4.6	4.1	3.0
South Africa	1.6	2.3	2.2	1.6	1.5	2.0	2.2	5.7	5.3	4.3	6.9	11
[2]Sudan	2.9	5.0	5.9	2.7	2.5	2.0	2.2	5.8	5.3	4.4	7.0	9.5
Tanzania	3.1	4.5	4.4	2.1	3.3	3.9	3.2	3.4	-0.3	3.8	6.6	8.9
Togo	3.5	2.0	3.0	3.6	1.1	0.03	4.3	2.2	9.2	2.6	2.2	0.1
Tunisia	3.6	4.0	2.9	4.1	3.6	4.4	4.3	4.7	4.2	2.7	4.4	-0.3
Zambia	2.0	2.5	-1.3	1.8	1.4	-2.8	1.5	0.7	-3.4	2.2	5.1	1.5
Zimbabwe	1.4	0.6	-0.01	2.4	4.4	5.5	0.7	2.0	-0.9	-0.4	-4.8	-3.9

3.0 Summary of Existing Literature

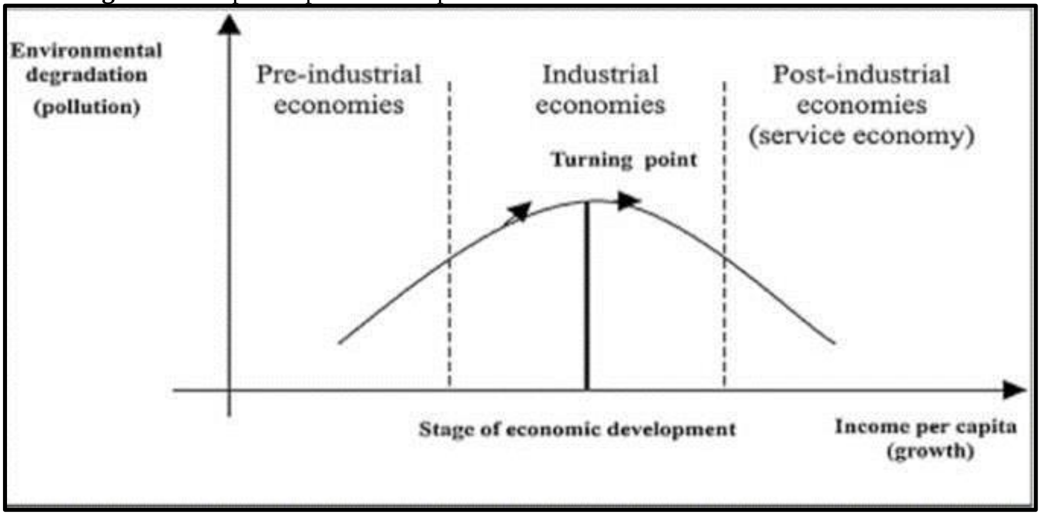
A plethora of research exists in energy economics, specifically on economic growth, energy utilization, and pollution. However, Kraft and Kraft (1978) is considered to be the earliest literature. Two dominant areas of research have emerged over the last few decades. The earliest field of research that emphasizes the energy consumption and output growth relationship struggles to delve into whether economic growth accelerates energy utilization or vice versa.

The second line of research was driven by the global concern for the quality of the environment due to economic growth (and more recently, energy) related activities on the quality of the environment. These studies tried to create the connections between toxic emissions, energy utilization, and income by assessing the authenticity of the environmental Kuznets curve (EKC) hypothesis. However, the EKC hypothesis that was gotten from

[2] Including South Sudan

Kuznets (1955), states that environmental degradation may follow the same income dependence as income inequality and environmental degradation be apt to follow the same income dependence as income inequality and tends to become poorer as a nation's economy stabilizes, middle-income level increases, and then gradually improves at higher levels.

Fig. 1. Development process and pollution: The Environmental Kuznets Curve



Source: Panayotou, (1993)

The EKC hypothesis predicted that anytime a toxic indicator is plotted alongside income per capita will behave like an inverted-U-shaped was suggested and first used by Grossman and Krueger (1991), Grossman (1995), and Panayotou (1993) described the association between the quality of the environment and economic development in Figure 1.

The empirical findings from those studies revealed mixed results. These could be attributed largely to the econometric methodology Nguyen-Van, Phu (2010), and to some extent to the scope of coverage of the variables used and the data set employed by these researchers. Table 2 presents a summary of some of the existing studies on the relationship between CO2 emissions, income, and energy utilization in developing economies.

The association between co_2 emission, energy, and income in the existing literature includes, among others, Perman and Stern (2003), who assessed the EKC hypothesis using panels in 74 countries. The study regressed per capita Sulphur dioxide alongside per capita income and its square. Evidence from their study, suggests that an inverted U shape EKC hypothesis exists among the countries. Nguyen-Van, and Phu (2010), used a semiparametric panel data analysis to assess the connectedness between per capita energy consumption and per capita income, and for the international data set, the study found minute indication of the existence of EKC for energy consumption. Kojo, et.al (2010), used the Bound test cointegration approach to investigate the connection between CO2, Energy utilization, and GDP in South Africa for the period 1965 to 2000. The result of his analysis revealed a long-run relationship amongst the three variables, however, the outcome of the causality effect shows a causal linkage running from GDP to CO2, from energy consumption to GDP, and also from energy utilization to CO2. The literature did not test for the EKC hypothesis. Panel data was employed for 43 developing countries by Narayan and Narayan (2010) to test for EKC hypothesis using CO2 emission as well as GDP and GDP squared as variables for estimation. The study tested for both individual and country groupings. The empirical evidence based on specific countries revealed that about 35 percent of the countries do not reject the EKC hypothesis, implying that CO2 has fallen over the long run, as income increases the levels of environmental damage have fallen in those countries. Similarly, the study also examines the Kuznet hypothesis on the panel of countries based on groupings. The result revealed that it is only in the Middle East and South Asian panels that the EKC hypothesis will not be rejected.

Similarly, Saboori et al (2011), used Malaysian data for the period 1980 to 2009, to test for the Kuznets hypothesis. Both the long-run and short-run substantiate the inverted U shape curve. After using the vector error correction, Bloch (2012), examined the cointegration and causal relationships amongst Coal utilization, output, Income, and pollutant emission in China. Their result shows a causality running from coal consumption to output, also from income to coal utilization, and from coal utilization to pollutants. Mahamat, (2012), used a panel cointegration approach to study the Kuznets hypothesis in Canada utilizing the industrial sector as a case study, the period spanned from 1990 to 2007. The empirical evidence from the result revealed a long-run association between the series. But the results of the causality disclose a uni-directional causality among energy consumption and CO2 and economies, with energy utilization causing CO2, and there is no evidence of the EKC hypothesis.

Furthermore, Omri, (2013), assessed the connectedness between CO2, energy utilization, and economic growth by employing a simultaneous equation model with panel data of 14 economies from MENA for the period: 1990 to 2011. The result of the study suggests a bi-directional connection between economic growth and CO2 emission in the region. Further, there is no substantiation to the EKC hypothesis from the reported result.

Between 2016 and 2017, the interest of researchers in this area increased significantly, and this attracted so many empirical studies, including, Shaojian et.al (2016), who used Chinese data for the period 1990-2012 to look at the cointegrating, temporal dynamic, and casual linkages that exist connecting economic development, energy use, and CO_2 emissions. The findings of cointegration tests imply that the variables have a long-term cointegrating relationship but with short dynamic adjustment mechanisms. Similarly, Granger causal relationships were discovered connecting economic growth, energy utilization, and CO_2 emissions; specifically, a two-way causal connection that connects economic growth and energy utilization was discovered, as well as a uni-directional causal relationship connecting energy utilization and CO_2 emissions.

One of the studies that investigated the EKC in Africa is the work of Boqiang (2016), the study assesses the hypothesis authenticity and the driving components of CO_2 toxicity in five African economies by adopting the panel cointegration and fully adjusted ordinary least squares. In the study, economics is segregated into agriculture and industrial economics. The findings revealed no proof of the authenticity of the Kuznets hypothesis in Africa, irrespective of if development is determined by agriculture or massive production in the economy. The two main forces that determine CO_2 toxicity in Africa are energy intensity and energy structure. The growth in population and urban development has a negative impact on CO_2 toxicity. As of the results, the Kuznet curve is not a firm foundation for an environmental course of action in Africa; rather, the environmental course of action in Africa, specifically for CO_2 emissions palliation, should concentrate on fostering energy efficiency, boosting the use of clean energy, and incorporating the effects of the growth of population and exploiting the positive impacts of urban development.

Selin and Ozlem (2017) used data between 1980 and 2010 in panel data estimation techniques to investigate the relationship between CO_2 emissions and the level of income in the context of the (EKC) in 26 OECD and 52 emerging economies. The results of both N and inverted N-shape models reveal the relationship for cubic functional form. Consequently, the results are not in compliance with the EKC hypothesis, meaning that economic growth cannot solve environmental degradation automatically.

Similarly, Faisal and Afra (2017) used data from 1971 to 2009 to examine the connection between energy consumption, growth, and CO_2 in Pakistan via a causality test. Also, the long-run bi-variate relationship amongst the variables is captured. The result revealed that the variables have a bi-directional causality running from energy consumption to CO_2 and from economic growth to CO_2 in both the long and short-term periods.

Furthermore, Wajahat et.al (2017), reinvestigated the existence of EKC in Malaysia for the period of 1971-2012. The literature empirically investigate the effect of financial development, real GDP, trade openness, foreign direct investments, and energy consumption on CO_2 emissions around the bands of EKC structure. The study utilized the ARDL bound test to assess the long-run relationship among the variables, and the causality test to examine the relationships. The empirical result revealed that the EKC hypothesis prevails in Malaysia. The causality test uncovered that energy consumption and carbon emissions have a bidirectional relationship, meanwhile, the other variables uni-directionally causes CO2 emissions. Whereas, in the short-run, there is absence of bidirectional causality between the variables while the uni-directional causalities run from trade openness and FDI to economic growth, financial development, and CO2 emissions. The unidirectional causality from other variables towards CO2 emissions backs the EKC hypothesis.

Additionally, Burak, (2017), tested the cogency of the EKC Hypothesis for 50 U.S. States during the 1960-2010 period using topical panel data that take account of cross-sectional dependence and heterogeneity. The findings prve that, the Augmented Mean Group estimator strongly backs the EKC hypothesis affirming that the EKC holds in 30 of the 50 states with turning points for income per capita lie between $1292 and $48597. Contrariwise, Common Correlated Effects Mean Group Estimator disapproves the EKC hypothesis, and the EKC holds only in 10 states with a defining moment between $2457 and $14603.

More so, Abid (2017), evaluated the relevance of the Environment Kuznets Curve (EKC) hypothesis to the environmental problem of the world. To accomplish this objective, different aspects of the EKC have been critically analyzed in the study. The study concludes that EKC‘s growth strategy “grow now clean later” is too resource intensive and has an immense environmental cost that the earth may not be able to take up in the future.

Hooi and Russell (2010) assessed the causal connection between CO_2 emissions, consumption of electricity, and economic growth in five ASEAN countries from 1980-2006 using Panel VECM. The result indicates evidence of a positive connection between the consumption of electricity and emissions in the long run, and the relationship connecting CO_2 emissions and real output is nonlinear, which is even out of the EKC. The results further revealed a one-way causal effect between electricity consumption and CO_2 emission to economic growth. But in the short-run there is evidence of one-way causality from CO2 emissions to electricity consumption. Similarly, Tan, Hooi & Khan, (2014), analyzed CO2 emissions, energy consumption (measured by two proxies) and per capita GDP for Singapore over the period 1975–2011 by utilizing the cointegration and causality techniques. However, the results reveal a significant rise in CO2 emissions as GDP rose over the years indicating a trade-off between environment and growth in the short-run. Meanwhile, the results of causal analysis indicate that CO2 emissions caused a decline in economic growth in Singapore. Moreover, Solarin and Lean (2016) examined how CO2 emission in China and India respond to natural gas consumption, urbanization and output for the period, 1965-2013 using the cointegration technique. From the result, there revealed the presence of long-run relationship among the variables; also, the presence of positive long-run impact of real GDP, natural gas, and urbanization on CO2 emission in the two countries. Further the countries shows no evidence of EKC.

Table 2. The Summary of Empirical Results for Developing Countries

Study	Methodology	Period	Country	Remark
Perman and Stern(2003),	Panel contrgration		74 countries	Inverted U shaped both in the long and short run.
Kojo Menyah, Yemane Wolde-Rufael(2010)	Bound test approach to cointegration	1965–2006	South Africa	CO2→GDP Energy consumption→GDP Energy consumption → CO2
Narayan and Narayan(2010)	Panel cointegration	1980-2004	43 Developing countries	Mix results
Sa'ad S(2010)	Cointegrastion and VEC	1971–2006	Nigeria	One-way causality-running from GDP to energy
Nguyen-Van(2010)				No evidence of the existence of EKC for energy consumption.
Wang et al, (2011)	Panel Cointegration	1995-2007	China	Bi-dirctional CO2 →Energy, Energy → GDP, Energy, GDP jointly → CO2
Saboori,et al (2012),	Cointegration	1980-209	Malaysia	Invertyed U both in long and short run.
MahamaHamit-Haggar(2012)	panel cointegration analysis	1990-2007	Canadian industrial Sector	Energy consumption → greenhouse gas emissions; Economic growth →greenhouse gas emissions
Anis Omri(2013)	Simultaneous equations models	1990-2011	14 MENA Countries	Energyconsumption↔ GDP Energy consumption → CO2

Faisal,M and Afra,K(2017),	VECM framework	1971-2009	Pakistan	bidirectional causalities between energy consumption, economic growth and the CO2 emissions
Selin, O. & Ozlem O (2017),	panel data estimation techniques	1980 - 2010	26 OECD&52emerging economies	
Wajahat,A.,et.al (2017),	ARDL	1971-2012	Malaysia	unidirectional causality from other variables towards CO2 supports the evidence of EKC
Burak, S. (2017),	panel data estimators	1960-2010	50 US States	EKC holds in 30 of the 50 states
Abid, R G(2017),				
Sakiru, A S, et.al(2017),				
Hooi Hooi Lean and Russell Smyth (2010)	Panel VECM	1980-2006	ASEAN	CO2 → Economic growth, energy consumption → economic growth. Consistent with EKC
Tan, Francis & Lean, Hooi Hooi & Khan, Habibullah. (2014)	Cointegration and Causality Techniques	1975–2011	Singapore	CO2 → Economic growth
Solarin SA, and Lean HH., (2016)	Cointegration Techniques	1965-2013	China and India	No evidence for EKC

Methodology and Empirical Result

4.1. Panel unit root test

The empirical analysis centered on the subject in which the data analysis gives significant merits upon the cross-sectional research. The most relevant feature of panel data studies is that change is openly incorporated into the design so that individual changes in a set of variables are directly assassed. At the beginning, examining whether the variables gets a panel unit root, while a number of panel unit root tests have been developed by Breitung (2000),, Hendri (2000), Im et al (2003), Choi (2006), Levin et al. (2002),, and Carrion-i-Silvestre et al.(2005),among others. This study adopted the panel unit root tests proposed by the test developed by Levin et al (2002) and Breitung (2000).

$$y_{it} = \eta_{it} + \sum_{k=1}^{p+1} \beta_{ik} x_{i,t-k} + \varepsilon_t \tag{1}$$

The test statistic assesses the H_0 that the process is differenced stationary :

$$H_0 : \sum_{k=1}^{p+1} \beta_{ik} - 1 = 0 \tag{2}$$

The other option is that the panel series is stationary; that is $\sum_{k=1}^{p+1} \beta_{ik} - 1 < 0$ for all i. The Breitung (2000) uses the following transformed vectors to build the test statistic:

$$Y_i^* = AY_i = [y_{i,1,}^* y_{i2,}^*, \ldots., y_{i,T}^*] \tag{3}$$

$$X_i^* = AX_i = [x_{i,1,}^* x_{i2,}^*, \ldots., x_{i,T}^*]', \tag{4}$$

indicating the following test statisti

$$\lambda_B = \frac{\sum_{i=1}^{N} \sigma_1^{-2} Y_i^{*'} X_i^{*'}}{\sqrt{\sum_{i=1}^{N} \sigma_1^{-2} X_i^{*'} A'^{AX_i^*}}} \tag{5}$$

which shows a standard normal distribution.

4.2. The panel cointegration tests

Pedroni (2004) measured the following the panel regression

$$Y_{it} = \propto_{it} + \delta_{it} t + X_i \beta_i + e_{it} \tag{6}$$

where Y_{it} and X_{it} are the apparent variables with dimension of (N * T) x 1 and (N* T) x m, respectively, α_{it} and δ_{it} are fixed effects for every country and deterministic trend, e_{it} is the stochastic error term. Pedroni (1999) creates asymptotic and determinate-sample properties of testing statistics to assess the H_0 of no-cointegration in the panel. The tests permit for heterogeneity among every single member of the panel, including heterogeneity in both the long-run cointegrating vectors and in the dynamics, since there is no evidence to accept that all parameters are alike across countries.

Pedroni suggested two types of set: (i) the within- dimension approach, which includes four statistics. They are panel v-statistic, panel ρ-statistic, panel PP-statistic, and panel ADF-statistic. These statistics merge the autoregressive coefficients across different members for the panel stationarity tests on the estimated residuals. (ii) the between-dimension approach consist of three statistics, which are: group q-statistic, group PP-statistic, and group ADF-statistic. These statistics accounts on estimators that simply average the individually coefficients for each member. Following Pedroni (1999), the heterogeneous group mean panel and heterogeneous panel cointegration statistics are calculated as follows:

Panel v-statistic

$$Z_v = \left(\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{it-1}^{2}\right)^{-1} \tag{7}$$

Panel ρ-statistic

$$Z_\rho = \left(\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\hat{e}_{it-1}^{2}\right)^{-1}\sum_{i=1}^{N}\sum_{t=1}^{T}\hat{L}_{11i}^{-2}\left(\hat{e}_{it-1}\Delta\hat{e}_{it} - \hat{\lambda}_i\right) \tag{8}$$

Panel PP statistic:

$$Z_t = \left(\hat{\sigma}^2\sum_{i=1}^{N}\sum_{t=1}^{T}L_{11i}^{-2}\hat{e}_{it-1}^{2}\right)^{-\frac{1}{2}}\sum_{i=1}^{N}\sum_{t=1}^{T}L_{11i}^{-2}\left(\hat{e}_{it-1}\Delta\hat{e}_{it} - \hat{\lambda}_i\right) \tag{9}$$

Panel ADF

$$Z_t^* = \left(\hat{s}^{*2} \sum_{i=1}^{N} \sum_{t=1}^{T} L_{11i}^{-2} \hat{e}_{it-1}^{*2} \right)^{-\frac{1}{2}} \sum_{i=1}^{N} \sum_{t=1}^{T} L_{11i}^{-2} \hat{e}_{it-1}^{*} \Delta \hat{e}_{it}^{*} \tag{10}$$

Group ρ-statistic:

$$\tilde{Z}_\rho = \sum_{i=1}^{N} \left(\sum_{i=1}^{T} \hat{e}_{it-1}^{2} \right)^{-1} \sum_{t=1}^{T} \left(\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i \right) \tag{11}$$

Group PP-statistic

$$\tilde{Z}_t = \sum_{i=1}^{N} \left(\hat{\sigma}^2 \sum_{i=1}^{T} \hat{e}_{it-1}^{2} \right)^{-\frac{1}{2}} \sum_{t=1}^{T} \left(\hat{e}_{it-1} \Delta \hat{e}_{it} - \hat{\lambda}_i \right) \tag{12}$$

Group ADF

$$\tilde{Z}_t^* = \sum_{i=1}^{N} \left(\sum_{i=1}^{T} \hat{s}_i^2 \hat{e}_{it-1}^{*2} \right)^{-\frac{1}{2}} \sum_{t=1}^{T} \left(\hat{e}_{it-1}^{*} \Delta \hat{e}_{it}^{*} \right) \tag{13}$$

5.0 Discussion

Data

In order to investigate the cointegration relationship and causality effects in growth, energy consumption, and carbon emission among 23 African countries, a balanced panel of time series data is built (i.e. the same time periods are available for all cross-section units). Energy consumption, GDP and carbon are obtained from annual data for non-OECD member countries of the International Energy Agency (2020) (beyond 2020, 2022 edition), the data on CO2 emmission were sourced from American Energy Information Administration (2022) GDP are in billions of US dollars 2010 prices, Energy consumption are expressed in thousands tons of oil equiverlents and CO2 emmision from energy consumption are expressed in thousands of metric tons. All the data sets are converted to per capita and are from 1980 to 2019.

Table 3. Results of panel unit root tests

Variables	Breitung test		IPS test		LLC test	
	Level	First ifference	Level	First difference	Level	First difference
E	1.40	-8.57	8.29	-13.7	2.30	-11.28
	(0.920)	(0.00)	(1.00)	(0.00)	(0.98)	(0.00)
Y	2.48	-2.96	9.42	-9.43	4.38	-5.14
	(0.99)	(0.00)	(1.00)	(0.00)	(1.00)	(0.00)
Y^2	-0.31	-1.64	11.45	-7.24	6.98	-3.34
	(0.37)	(0.04)	(1.00)	(0.00)	(1.00)	(0.00)
CO2	-1.62	-9.91	2.85	-14.86	-0.22	-12.08
	(0.05)	(0.00)	(0.99)	(0.00)	(0.40)	(0.00)

Note: probability values in parenthesis

The panel unit root result is presented in Table 3 at both levels and first difference are based on three tests (Breitung, IPS and LLC). The result confirms that all the three variables have unit roots; this therefore, suggests that the series shared the same integrational properties of I(1). Based on the result, we therefore, go ahead and test for cointegration in order to determine whether there exists a long run relationship between CO2, energy and income.

Table 4. Panel cointegration result

Panel(within dimension)			(between dimension)		
Statistics	Value	probability	Statistics	value	probability
Panel v-stat	3.68**	0.0001			
Panel rho-stat	-0.68	0.2453	Group rho-stat	0.18	0.5736
Panel PP-stat	-2.99**	0.0014	Group PP-stat	-3.51**	0.0002
Panel ADF-stat	-0.27**	0.0928	Group ADP-stat	-2.03**	0.0214

Note:deterministic intercept and trend are included in the estimation. **suggest rejection of null hypothesis at 5%

The panel cointegration result is presented in Table 4 and it consist of both the within and between group dimension. For all the tests rejected the H_0 accept panel rho and group rho which failed to reject the H_0. even though the rho statistics recorded a power less than the PP statistics the other statistics that rejected the H_0, it may be rational to assent to the existence of the long-run cointegration among the series. From the result, the coitegrating equation can be taken by estimating fixe or random effect model as stated in the equation below‘

$$lnCO2 = -5.423 + 0.376lnE + 1.804lnY - 0.142lnY^2 \quad (17)$$

(-13.003) (6.546) (15.873) (-10.020)

R^2 0.97, Jarque-Bera normality test 15.53(0.000)

The Houseman test favours fixed effect against the random effect model. The long run elasticities from the estimated fixed effect model are reported in equation (17), the result shows the estimated coefficients of explanatory variables are all statistically significant with correct expected signs. The coefficients of energy and income have a positive relationships with the dependent variable, suggesting that increase in energy consumption and percapita income will, *cateris peribus* lead to increase in damage to the environment. However, as income increases further, the quality of environment tends to improve as shown by the negative sign on the coefficient of Y^2; this result substantiates the EKC hypothesis . The adjusted R^2 of 0.98 and the JB normality test indicate that the data fits into the model quite well though there is problem of non-normality but in panel analysis the post estimation test do not count as much because it is not necessary.

Table 5. OLS estimates (lnCO2 as dependent variable)

Country	Income	t-Stat	Income-Squared	t-Stat	Energy	t-Stat	Remarks
Algeria	0.85	6.75	-0.002	-4.98	0.004	3.42	EKC Accepted
Angola	0.62	5.80	-0.005	-4.90	0.002	1.02	EKC Accepted
Benin	-0.62	-5.80	0.004	4.90	0.002	1.02	EKC Rejected
Cameroon	0.02	0.08	0.003	0.70	0.0017	0.97	EKC Rejected
Congo	0.05	8.87	-0.99	-2.79	-0.0007	-0.25	EKC Accepted
CDR	0.23	3.84	-0.004	-2.01	-0.0004	-5.47	EKC Accepted
Côte d'Ivoire	0.17	4.43	0.0003	0.14	8.97	0.17	EKC Rejected
Gabon	1.11	19.71	-0.024	-11.78	-0.003	-7.03	EKC Accepted
Ghana	0.34	2.71	-0.55	-12.92	0.0003	-6.03	EKC Accepted
Ethiopia	0.07	0.88	-4.96	-0.083	-6.83	-0.18	EKC Accepted
Egypt	0.53	2.25	-0.0003	-1.201	0.0008	0.90	EKC Rejected
Kenya	-0.02	-0.20	0.002	4.709	-0.0002	-0.36	EKC Accepted
Libya	0.003	3.42	-0.29	-2.827	0.001	1.91	EKC Accepted

Morocco	-0.293	-1.91	0.003	3.428	-0.001	-1.91	EKC Rejected
Nigeria	1.34	2.50	-0.002	-2.976	0.003	1.38	EKC Accepted
Senegal	0.16	1.23	0.003	2.188	0.0008	1.24	EKC Rejected
South Africa	0.84	2.10	-0.0004	-1.494	-0.001	-0.71	EKC Accepted
Sudan	-0.12	-0.69	0.002	1.73	0.0012	1.40	EKC Rejected
Tanzania	0.22	2.92	-0.001	-1.91	0.0004	3.56	EKC Accepted
Togo	-0.21	-1.11	0.026	0.53	0.0023	0.93	EKC Rejected
Tunisia	0.42	1.25	-0.004	-2.15	0.004	4.44	EKC Rejected
Zambiakkk	0.56	5.68	-0.016	-6.15	0.0008	2.93	EKC Accepted
Zimbabwe	-0.55	-0.12	0.31	0.71	0.002	0.88	EKC Rejected
Panel(without time dummies)	1.93	(9.43)	-0.15	(6.18)	0.36	(3.52)	EKC Accepted
Panel(with time dummies)	1.07	(3.9)	-0.09	(-2.6)	0.042	(0.26)	EKC Accepted

Note: the t-statistics is in parenthesis

The finding of each country and the panel OLS estimates are stated in Table 5 above. From the result of the panel estimates with and without time dummies presented at the bottom of the table shows that Y and Y2 coefficients are significant at 5% levels. But E is statistically insignificant. From the result, income appears to have more influence on CO2 than energy. However, in the panel without time dummies, all explanatory variables are statistacally significant, and Y2 have a negative sign, implying an inverse relationships between CO2 and Y2. Nevertheless, both the two models substantiates the EKC hypothesis in the long-run; with the elasticity of income with respect to CO2 is greater than 1. However, the coefficients of E and Y2 are less than 1; the result therefore suggests that income appears to have more influence on the quality of environment than energy.

Looking at the results from specific country basis, most of the estimated coefficient of income and income squared elasticity are statistically significant ranging from 1% to 10% level of significant. The result of the following countries shows that income and energy have a positive and significant connection with CO2, but income squared has a significant negative influence on CO2. The countries that surport EKC hypothesis include, Algeria, Angola, Congo , CDR, Gabon, Ghana, Egypt, Libya, Nigeria, South Africa, Tanzania, Tunisia, and Zambia. however, Congo and CDR have negative energy elasticities. The magnitute of the income elasticities ranges from 0.16 for Senegal to 1.34 for Nigeria. The coefficient of the income squared ranged from -0.99 for Congo to -0.002 in

Algeria. However, estimates for Benin, Cameroon, Zimbabwe, Togo, Sudan, Kenya and Ethiopia are either not statistically significant or have a wrong signs on their coefficients. Arguably, the likely reasons for the poor quality of results for these countries is probably due to the poor quality of the data and some have in political crisis over long time.

Conclusion and Policy Implications

Recently, there has been great concern by international community over the role of energy and economic activities in environmental quality; this led to plethora of studies that investigate the effect of energy consumption and economic growth on the quality of environment (mostly represented by CO2 emission), kwon as the EKC hypothesis. Most of the existing literatures focus on the developed and emerging economies.

The contribution of this study to the growing literature is that it examines if there is any long-run association between energy consumption, economic growth and economic growth squared on CO2 emission for the selected 23 African countries. By employing the Pedroni panel cointegration tests for the 1980-2015 period. The empirical findings suggest that there is an evidence of cointegration between energy consumption, GDP , GDP squared and CO2 emission.

The country's specific result suggest that in most countries, energy consumption related activities increased carbon emission. However, there exist a negative and significant impact of income squared and CO2 emission, suggesting that in more than 60 percent of the countries, CO2 emmission has fallen as income increases; which substantiates the EKC hypothesis.

The policy implications for the result is that most of the countries should pursue economic growth policies that are not highly carbon intensive, increase in projects that can promote energy efficiency and renewable energy technologies that can reduce environmental pollution are highly recommended for policy makers in these countries. For countries where there is no evidence of EKC, strong regulatory policies should be complemented with market based incentive to regulate highly energy intensive and polluting sectors in order to achieve sustainable environment friendly growth.

Finally, it must be emphasized that for all the countries, market based incentives such as soft loans and tax holidays aimed at increased the consumption of renewable energy and less carbon intensive activities can boost economic growth to reach the turning point where the association between energy consumption and growth will become inverse.

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