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Dynamic Effects of Energy Consumption and Economic Growth on CO2 Emission: Testing EKC Hypothesis in Africa

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Abstract

This paper focuses on using time series data on real GDP, energy consumption, and CO2 emission to examine the effect of economic growth and energy consumption on CO2 emission for a panel of 23 African countries within the period 1980–2019. The study used Pedroni (1999) approach of panel cointegration analysis to test for existence of long-run cointegration relationship between the variables. Fixed effect model was used to test for the Environmental Kutznets Hypothesis, and income squared was included as an additional explanatory variable. The estimated empirical results for the panel of 23 African countries from fixed effect model indicates the evidence of EKC hypothesis. At the level of individual countries, there is large divergence. 13 countries show evidence of EKC, implying that CO2 emission has fallen over the long run. As income increases, the levels of environmental damage decreases in those countries. 10 countries show opposite relationship among the variables. Based on the estimated results, it is recommended that countries should pursue economic growth policies that are not highly carbon intensive. Policy makers in these countries should adopt strategies that uses

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environmentally friendly technologies to decrease CO2 emission. Countries should also implement strong regulatory and market-based policies in highly energy-intensive sectors to reduce their current level of emissions and attain sustainable, environment-friendly economic growth.

Keyword: EKC Hypothesis, Panel cointegration, African countries

1.0 Introduction

In the economics of African energy markets, three crucial trends have policy implications for economic growth, energy use, and environmental policy formulations. First, Africa has the fastest-growing population and some of the fastest-growing economies globally. Africa also produces and consumes a large fraction of the world's fossil fuels. Therefore, the economic growth of many African economies could lead to a significant increase in demand for energy and carbon emissions.

Secondly, the share of fossil fuels in the total energy mix of Africa has been rising, and this induces rising carbon emissions. Most of these economies cannot carry out their economic activities without burning fossil fuels because they greatly depend on them. In addition, the populace feel entitled to access fossil fuels at an affordable price, especially for oil producing countries.

Thirdly, many developing countries including Africa see global warming as an issue of little or no importance. This is caused by industrialized nations and therefore should be solved by them. According to Bartsch and Mueller, (2000), some even argue that it is a conspiracy by the industrialized nations to impede their development. 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 Africa. In addition, African developing economies should follow separate growth routes that are viable and less destructive to the environment. Gill et al. (2018) argues that since energy is a crucial contributing factor to pollution, policymakers should formulate distinct policies for renewables by imposing taxes on fossil fuels and subsidizing the renewables.

However, the seeming contradiction between the desire to promote rapid/high levels of economic growth, over-reliance on fossils, 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 expensive, low-carbon energy system without compromising the fundamental objective of achieving a high

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level of economic growth in African countries? Secondly, how can the huge potential in less carbon emitting renewable energy technologies be incorporated in the operation and development of a sustainable energy system that is environmentally friendly in these countries? Finally, in what ways can market-based policies (such as proper pricing policies)[1] and demand management policies (that may require a rise in energy prices) be used to change individual behavior in those countries to ultimately follow price signals?

Answers to these questions could lead to energy efficiency as well as a substantial reduction in the consumption of energy and emission of carbon. The key basis for concern is whether the energy and environmental policy makers 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. The findings of this research will help in understanding the importance of having a global environmental agenda as well as how to formulate environmental policies in Africa that are consistent with global best practices.

The objective of this paper is to contribute to the existing literature on the Environment Kuznets Hypothesis, specifically focusing on African countries. Firstly, it improves on previous studies by estimating the data in the panel structure while showing country-specific results. Secondly, this study also accounts for the heterogeneity of selected countries in terms of their incomes, energy consumption, and CO_2 emissions by calculating the trends in economic growth, energy consumption , and CO_2 emission in each country. The study is structured as follows. Section two reviewed some stylized facts on the annual growth trends in energy consumption, GDP, and CO_2 emission in 23 African economies. Section three presents empirical literature review, while Section four presents the econometric methods and data. Section five presents the empirical results and discussions. Section six outlines the conclusion and policy recommendation of the findings of the study.

2.0 Trends in Energy Consumption, GDP, and Carbon (CO_2) Emission

The comparison of annual average growth rates of energy use, economic growth, and CO_2 emission in 23 economies in Africa indicates that there are some 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 selected countries. Between 1980 and 1990, the yearly

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

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average growth of energy utilization ranged from -2.6% to 0.08% in the case of low-income countries of the Democratic Republic of Congo and Gabon, and to 8.2% and 5.6% in oil-producing middle-income countries of Algeria and Kenya. 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 at 5.2% and 5.0% respectively from their previous decade. Subsequently, these are higher than the African 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, between 2000 to 2016, most African countries recorded an appreciable increase in energy consumption. Angola and Algeria recorded an annual average rise in energy consumption from 2.4% and 1.9% annually to 6.4% and 5.6% annually between 1990 to 2019. Similarly, for the whole of Africa, the annual average consumption of energy has increased appreciably. Table 1 shows statistics of average growth rate of GDP, carbon emission, and energy consumption in the selected countries.

Table 1. Annual Average Growth Rates of GDP, CO_2 Emission, and Energy Consumption

Country	1980-2016			1980-1990			1991-2000			2001-2019		
Algeria	.1	.7	.8	.2	.8	.2	.9	.7	.1	.6	.7	.0
Angola	.8	.7	.0	.9	.5	.8	.4	.8	.2	.4	2.0	.4
Benin	.4	.8	.1	.0	.7	0	.5	.8	0.8	.8	.0	.1
Cameroon	.8	.7	.3	.2	.3	.8	.3	.4	0.2	.7	.6	.6
Congo	2.7	.6	.5	1.6	.8	.7	.3	.4	5.6	.9	.9	.8
CDR	3.4	.2	0.7	2.6	.9	.7	4.2	5.6	2.9	4.7	.8	.1
Cote'dvour	.8	.2	.0	1.5	.7	.5	4.0	.3	.7	2.4	.08	1.6
Gabon	.8	.0	0.2	.08	.8	.8	.2	.0	1.1	.7	.3	1.1
Ghana	.7	.4	.6	.4	.2	.1	.5	.4	.8	.1	.8	.5
Ethiopia	.8	.1	.5	.2	.9	.9	.6	.8	.4	.8	.4	.4
Egypt	.6	.8	.3	.0	.5	.5	.4	.2	.2	.0	.9	.8
Kenya	.1	.4	.6	.6	.1	.1	.3	.9	.8	.3	.1	.5
Libya	.4	3. 6	.4	.3	.3	.7	.2	.2	0.2	.4	.0	.2
Morroco												

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	.1	.0	.2	.5	.9	.3	.0	.4	.8	.6	.9	.3
Nigeria	.6	.5	.3	.4	.1	.1	.8	.9	0.2	.5	.4	0.9
Senegal	.6	.2	.4	.3	.6	.3	.0	.1	.6	.6	.1	.0
South Africa	.6	.3	.2	.6	.5	.0	.2	.7	.3	.3	.9	1
[2]Sudan	.9	.0	.9	.7	.5	.0	.2	.8	.3	.4	.0	.5
Tanzania	.1	.5	.4	.1	.3	.9	.2	.4	0.3	.8	.6	.9
Togo	.5	.0	.0	.6	.1	.03	.3	.2	.2	.6	.2	.1
Tunisia	.6	.0	.9	.1	.6	.4	.3	.7	.2	.7	.4	0.3
Zambia	.0	.5	1.3	.8	.4	2.8	.5	.7	3.4	.2	.1	.5
Zimbabwe	.4	.6	0.01	.4	.4	.5	.7	.0	0.9	0.4	4.8	3.9

Source: compiled from varied database sources

3.0 Theoritical Framework and Literature Review

The EKC hypothesis predicts that anytime an environmentally toxic indicator is plotted against income per capita, it will behave like an inverted-U-shaped. This relationship was suggested and first used by Grossman and Krueger (1991, 1995) and Panayotou (1994), thus describing the association between the quality of the environment and economic development as shown in Figure 1. In energy literature, the Environmental Kuznets Curve (EKC) hypothesized the relationship between various indicators of environmental degradation and per capita income. In the early stages of economic growth, pollution emission increases and environmental quality declines. However, beyond some level of per capita income (which will vary for different indicators), the trend reverses so that at high income levels, economic growth leads to environmental improvement.

[2] Including South Sudan

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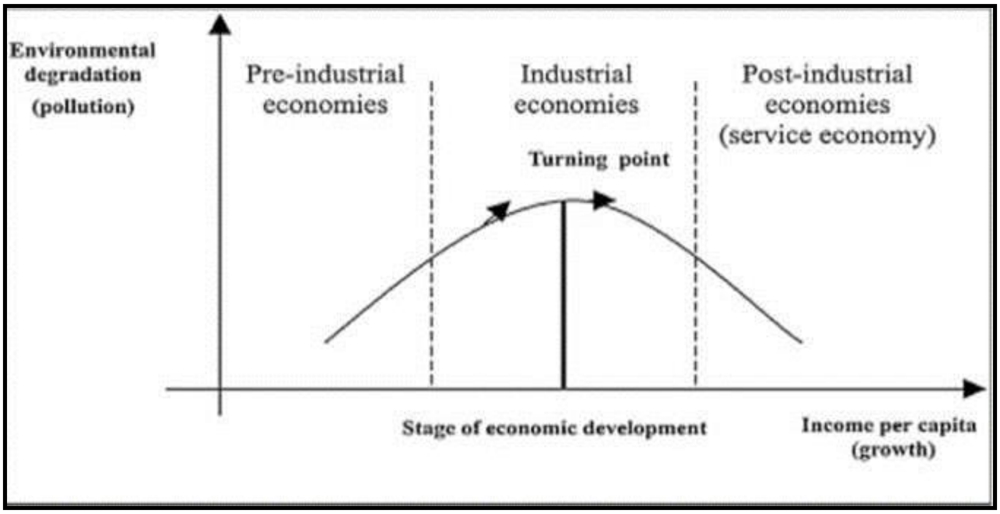

Source: (Panayotou, 1994)

Figure 1. Development Process and Pollution: The Environmental Kuznets Curve

The EKC is named for Simon Kuznets, who hypothesized that income inequality first rises and then falls as economic development proceeds. Emissions of various pollutants, such as carbon dioxide, sulfur, and nitrogen oxides are tightly coupled to the use of energy. Hence, the EKC is a model of the relationship among energy use, economic growth, and the environment.

A plethora of research exists in energy economics, specifically on economic growth, energy utilization, and pollution relationship. However, Kraft and Kraft (1978) is considered to be the earliest study in the relationships. 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 attempts to ascertain 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). 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.

The empirical findings from those studies revealed mixed results. These could be attributed largely to the econometric methodology (Nguyen-Van, 2010) and to some extent, the scope of coverage of the variables used as well as the data set employed by these researchers (Sa'ad, 2010). Table 2 presents a summary of some of the existing studies on the relationship between CO_2 emissions, income, and energy utilization in developing economies.

Specifically, 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 panel data in 74 countries. The

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study regressed per capita Sulphur dioxide alongside per capita income and its square. Evidence from their study suggests that an inverted U-shaped EKC hypothesis exists among the countries. Nguyen-Van (2010) used a semi parametric panel data analysis to assess the connection between per capita energy consumption and per capita income. The study found minute indication of the existence of EKC for energy consumption. Menyah and Wolde-Rufael (2010) used the Bound test cointegration approach to investigate the connection between CO_2, 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 CO_2, from energy consumption to GDP, and from energy utilization to CO_2. Panel data was employed for 43 developing countries by Narayan and Narayan (2010) to test for EKC hypothesis using CO_2 emission, 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 CO_2 has fallen over the long run. Nonetheless, as income increases, the levels of environmental damage decreases 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 was not rejected.

Furthermore, Saboori et al. (2012) 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-shaped curve. Using the vector error correction, Bloch et al. (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, from income to coal utilization, and from coal utilization to pollutants. Hamit-Haggar (2012) used a panel cointegration approach to study the Kuznets hypothesis in Canada while utilizing the industrial sector as a case study for the period 1990 to 2007. The empirical evidence from the result revealed a long-run association between the series. However, the results of the causality disclose a uni-directional causality among energy consumption, $CO_{2,}$ and economies, with energy utilization causing CO_2, and there is no evidence of the EKC hypothesis.

Furthermore, Omri (2013) assessed the connections between CO_2, 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 CO_2 emission in the region. Furthermore, there is no substantiation to the EKC hypothesis from the reported result.

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Between 2016 and 2017, the interest of researchers in this area increased significantly. This attracted so many empirical studies, including Wang et al. (2016) who used Chinese data for the period 1990-2012 to study the cointegrating, temporal dynamic, and casual linkages that exist, thereby 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 Lin et al. (2016). The study assessed the authenticity of the hypothesis 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, economies of these countries are segregated into agriculture and industrial economics. The findings revealed no proof of the existence of the Kuznets hypothesis in Africa, irrespective of whether 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. The authors suggest that the Kuznet curve is not a firm foundation for an environmental course of action in Africa. Therefore, 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, incorporating the effects of the growth of population, and exploiting the positive impacts of urban development.

Özokcu and Özdemir (2017) used data between 1980 and 2010 in panel data estimation techniques to investigate the relationship between CO2 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. This implies that economic growth cannot solve environmental degradation automatically.

Similarly, Mirza and Kanwal (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 the long and short-term periods.

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Furthermore, Ali et al. (2017) reinvestigated the existence of EKC in Malaysia for the period of 1971-2012. The study empirically investigated 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. Conversely, the other variables uni-directionally causes CO_2 emissions. In the short run, there is absence of bidirectional causality between the variables. The uni-directional causalities run from trade openness and FDI to economic growth, financial development, and CO_2 emissions. Subsequently, the uni-directional causality from other variables towards CO_2 emissions backs the EKC hypothesis.

Atasoy (2017) tested 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 prove that the Augmented Mean Group estimator strongly backs the EKC hypothesis. This affirms that the EKC holds in 30 of the 50 states, and the turning points for income per capita lies between \$1292 and \$48597. Conversely, 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. Gill et al. (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 resource intensive and has an immense environmental cost that the earth may not be able to take up in the future.

Lean and Smyth (2010) assessed the causal connection between CO_2 emissions, consumption of electricity, and economic growth in five ASEAN countries from 1980-2006 using Panel Vector Error Correction Models. The result indicates evidence of a positive connection between the consumption of electricity and emissions in the long run. In addition, the relationship connecting CO_2 emissions and real output is nonlinear, which is out of the EKC. The results further revealed a one-way causal effect between electricity consumption and CO_2 emission to economic growth. Nonetheless, in the short run, there is evidence of one-way causality from CO_2 emissions to electricity consumption. Similarly, Tan et al. (2014) analyzed CO_2 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 CO_2 emissions as GDP rose over the years, indicating a trade-off between environment and

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growth in the short run. Furthermore, the results of causal analysis indicate that CO_2 emissions caused a decline in economic growth in Singapore. Solarin and Lean (2016) examined how CO_2 emission in China and India respond to natural gas consumption, urbanization, and output for the period 1965-2013 using the cointegration technique. Based on the result, long-run relationship exists among the variables. Also, the existence of positive long-run impact of real GDP, natural gas, and urbanization on CO_2 emission in the two countries shows no evidence of EKC. Omaye et al. (2022) explored this relationship in African countries whithin the framework of energy transition. The study recommends adoption of both techonology and market-based policy to promote environmental sustainability in Africa.

Table 2. The Summary of Empirical Results for Developing Countries

Study	Methodology	Period	Country	Remark
Perman & Stern (2003)	Panel Co-integration		74 countries	Inverted U shaped both in the long and short run.
Menyah & Wolde-Rufael (2010)	Bound test approach to Co-integration	1965–2006	South Africa	$CO_2 \rightarrow$ GDP Energy Consumption → GDP Energy consumption → CO_2
Narayan & Narayan (2010)	Panel Co-integration	1980-2004	43 Developing countries	Mix results
Sa'ad (2010)	Co-integration and Vector Error Correction Models	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. (2016)	Panel Co-integration	1995-2007	China	Bi-directional CO_2 →Energy, Energy → GDP, Energy, GDP jointly → CO_2
Saboori et al. (2012)	Co-integration	1980-209	Malaysia	Inverted U both in long and short run.
Hamit-Haggar (2012)	Panel Co-integration analysis	1990-2007	Canadian industrial Sector	Energy consumption → greenhouse gas emissions; Economic growth →greenhouse gas emissions
Omri A.,(2013)	Simultaneous equations models	1990-2011	14 MENA Countries	Energy consumption↔ GDP Energy consumption → CO_2

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Mirza & Kanwal (2017)	Vector Error Correction Models	1971-2009	Pakistan	bidirectional causalities between energy consumption, economic growth and the CO_2 emissions
Özokcu & Özdemir (2017)	Panel data estimation techniques	1980 – 2010	26 OECD&52emerging economies	
Ali et al. (2017)	ARDL	1971-2012	Malaysia	Unidirectional causality from other variables towards CO_2 supports the evidence of EKC
Atasoy (2017)	Panel data estimators	1960-2010	50 US States	EKC holds in 30 of the 50 states
Gill et al. (2017)				
Solarin & Lean (2016)				
Lean & Smyth (2010)	Panel Vector Error Correction Models	1980-2006	ASEAN	CO_2 → Economic growth, energy consumption → economic growth. Consistent with EKC
Tan et al. (2014)	Co-integration and Causality Techniques	1975–2011	Singapore	CO_2 → Economic growth
Solarin & Lean (2016)	Co-integration Techniques	1965-2013	China and India	No evidence for EKC

Source: Author's computation

4.0. Methodology

4.1 Research Design

This study investigates the dynamic relationships between four variables, namely: energy, carbon emission, real GDP, and real GDP squared. The variables are constructed as follows: Per capita GDP are real GDP in billions of US dollars and is divided by the population of each country. Per capita energy consumption is the total energy consumed by end user sectors for each country in tons of oil equivalents (toe) and is divided by population. Per capita CO_2 emission and the CO_2 emission in tons is divided by the population of each country. The description of the variables are provided in Table 3.

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Table 3. Definitions and Descriptions of the Variables

Variable	Symbol	Description	Data Source
Natural logarithms of GDP as a measurement of economic growth	lnY	Real GDP in billions of US dollars 2010 prices	Worldbank development indicators (*WDI - Home*, n.d.)
Natural logarithms of energy consumption	lnE	Total energy consumed in each country in tons of oil equiverlents	Internatioinal Energy Agency
Natural logarithms of carbon emission	$\ln CO_2$	Carbon dyodide emission in tons by various sectors diveded by population	Amerian Energy Information Administration
Natural logarithms of GDP^2 as a measurement of turning point for environmental quality	$\ln Y^2$	Turning point in which the quality of environment is expected to improve	

Source: Author's computation

4.2 Panel Unit Root Test

Panel data analysis is a known analysis among social scientists, and it includes the *N* cross-sectional (countries, households, firms) and *T* time series data (yearly, quarterly, monthly). The combination of cross-section and time series data in a single unit increases the number of observation by adding up developments overtime and the variation amongst the series. This significantly reduces the amount of noises emerging from a single time series and addresses the problem of heteroscedasticity in residuals. In order to investigate the dymamic long-run relationship between economic growth, energy consumption, and carbon emission among 23 African countries, a balanced panel data is built (i.e., the same time periods are available for all cross-section units). When a panel data is unbalanced, it will be difficult to handle when running it.

The empirical analysis centered on the subject and the data analysis gives significant merits upon the cross-sectional research. The most relevant feature of panel data studies reveal that change is openly incorporated into the design. As a result, individual changes in a set of variables are directly assessed to examine whether the variables have a panel unit root. However, a number of panel unit root tests have been developed by Breitung (2000), Hadri (2000), IPS (2003), Choi (2006), Levin et al. (2002), and Lluís Carrion-i-Silvestre et al. (2005), among others. This study adopted the panel unit root tests proposed by Levin et al. (2002), IPS (2003), and Breitung (2000). Both tests are first generation test and allowed for individual time series to cross-sectionally and independently be distributed in the panel.

The study started by running a panel unit root. This was folllowed by a panel cointegration test based on Pedroni (2004) methods and the long run

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estimates of elasticities based on panel and individual country OLS. Theoretically, a positive relationship is expected between CO_2, economic growth, and energy consumption. However, economic growth squared is expected to have an inverse relationship with CO_2 emission. *A priori*, a negative relationship is expected between CO_2 and economic growth squared, thus suggesting the existance of EKC relationship. In the absence of *a priori* expectation in a country, a low level of development is witnessed. As a result, real incomes and energy use are highly polluted. By implication, there is a need for market-based policy and adoption of new technology to improve the quality of the environment.

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

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

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

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

$$Y_i^* = AY_i = [y_{i,1,}^* y_{i2,}^*, \ldots, y_{i,T}^*] \quad (3)$$

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

indicating the following test statistic

$$\lambda_B = \frac{\sum_{i=1}^{N} \sigma_1^{-2} Y_i^{*'} X_i^{*'}}{\sqrt{\sum_{i=1}^{N} \sigma_1^{-2} X_i^{*'} A'^{AX_I^*}}} \quad (5)$$

which shows a standard normal distribution.

4.3 The Panel Cointegration Tests

Pedroni (2004) is employed and it incorporates the trend coefficient and heterogeneity across the cross-sections in the panel. However, it measured the following panel regression:

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$$Y_{it} = \propto_{it} + \delta_{it} t + X_i \beta_i + e_{it} \quad (6)$$

where Y_{it} and X_{it} are the apparent variables, including per capita GDP, per capita energy consumption, per capita CO_2 emission, and per capita income squared 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 is a 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 the long-run cointegrating vectors and in the dynamics. This is because there is no evidence to accept that all parameters are alike across countries.

Pedroni suggested two types of hypothesis testings: (i) the within-dimension approach, which includes four statistics: 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 individual coefficients for each member. Following Pedroni (1999), the heterogeneous group mean panel and heterogeneous panel cointegration statistics are calculated as follows:

Panel v-statistic

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

Panel ρ-statistic

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

Panel PP-statistic:

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

Panel ADF-statistic

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

Group ρ-statistic

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

Group PP-statistic

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

Group ADF-statistic

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

5.0 Empirical Results and Discussions

5.1 Empirical Result

The panel unit root result is presented in Table 4 based on three tests (Breitung, IPS and LLC). The result confirms that all the three variables have unit roots. Therefore, this suggests that the series shared the same integrational properties of I (1). Based on the result, the test for cointegration is carried out

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in order to determine the posssibility of a long-run relationship between CO_2, energy and income, and income squared.

Table 4. Results of Panel Unit Root Tests

Variables	Breitung test		IPS test		LLC test	
	Level	First difference	Level	First difference	Level	First difference
E	1.40 (0.920)	-8.57 (0.00)	8.29 (1.00)	-13.7 (0.00)	2.30 (0.98)	-11.28 (0.00)
Y	2.48 (0.99)	-2.96 (0.00)	9.42 (1.00)	-9.43 (0.00)	4.38 (1.00)	-5.14 (0.00)
Y^2	-0.31 (0.37)	-1.64 (0.04)	11.45 (1.00)	-7.24 (0.00)	6.98 (1.00)	-3.34 (0.00)
CO_2	-1.62 (0.05)	-9.91 (0.00)	2.85 (0.99)	-14.86 (0.00)	-0.22 (0.40)	-12.08 (0.00)

Note: probability values in parenthesis

Table 5. 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 5 and it consist of both the within and between group dimension. For all the tests rejected, the H_0 accepted panel rho and group rho which failed to reject the H_0. However, the rho statistics recorded a power less than the PP statistics. For 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.

$$lnCO_2 = -5.423 + 0.376lnE + 1.804lnY - 0.142lnY^2 \quad (17)$$

(-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 that the estimated coefficients of

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explanatory variables are all statistically significant with correct expected signs. The coefficients of energy and income have a positive relationship with the dependent variable. This denotes that increase in energy consumption and per capita income will, *ceteris paribus*, lead to increase in damage to the environment. However, as income increases further, the quality of environment tends to improve. This is shown by the negative sign on the coefficient of Y^2. Accordingly, this result substantiates the EKC hypothesis . The adjusted R^2 of 0.98 and the JB normality test indicates that the data fits into the model quite well, regardless of the problem of non-normality. Nonetheless, in panel analysis, the post estimation test do not count as much because it is not necessary.

Table 6. OLS Estimates (ln CO_2 as dependent variable)

Country	nY	-Stat	ln Y^2	-Stat	nE	-Stat	Remarks
Algeria	.85	.75	-0.002	4.98	.004	.42	EKC Accepted
Angola	.62	.80	-0.005	4.90	.002	.02	EKC Accepted
Benin	0.62	5.80	0.004	.90	.002	.02	EKC Rejected
Cameroon	.02	.08	0.003	.70	.0017	.97	EKC Rejected
Congo	.05	.87	-0.99	2.79	0.0007	0.25	EKC Accepted
CDR	.23	.84	-0.004	2.01	0.0004	5.47	EKC Accepted
Côte d'Ivoire	.17	.43	0.0003	.14	.97	.17	EKC Rejected
Gabon	.11	9.71	-0.024	11.78	0.003	7.03	EKC Accepted
Ghana	.34	.71	-0.55	12.92	.0003	6.03	EKC Accepted
Ethiopia	.07	.88	-4.96	0.083	6.83	0.18	EKC Accepted
Egypt	.53	.25	-0.0003	1.201	.0008	.90	EKC Rejected
Kenya	0.02	0.20	0.002	.709	0.0002	0.36	EKC Accepted
Libya	.003	.42	-0.29	2.827	.001	.91	EKC Accepted
Morocco	0.293	1.91	0.003	.428	0.001	1.91	EKC Rejected
Nigeria	.34	.50	-0.002	2.976	.003	.38	EKC Accepted
Senegal	.16	.23	0.003	.188	.0008	.24	EKC Rejected
South Africa	.84	.10	-0.0004	1.494	0.001	0.71	EKC Accepted

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Sudan	0.12	0.69	0.002	.73	.0012	.40	EKC Rejected
Tanzania	.22	.92	-0.001	1.91	.0004	.56	EKC Accepted
Togo	0.21	1.11	0.026	.53	.0023	.93	EKC Rejected
Tunisia	.42	.25	-0.004	2.15	.004	.44	EKC Rejected
Zambia	.56	.68	-0.016	6.15	.0008	.93	EKC Accepted
Zimbabwe	0.55	0.12	0.31	.71	.002	.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 findings of each country and the panel OLS estimates are stated in Table 6 above. From the result of the panel estimates, with and without time dummies presented at the bottom of the table shows that Y and Y^2 coefficients are significant at 5% levels. However, E is statistically insignificant. According to the result, income appears to have more influence on CO_2 than energy in these countries during the estimation period. However, in the panel without time dummies, all explanatory variables are statistically significant. Y^2 has a negative sign, which implies an inverse relationship between CO_2 and Y^2. Nevertheless, the two models substantiates the EKC hypothesis in the long run. The elasticity of Y, with respect to CO_2, is greater than 1. Notwithstanding, the coefficients of E and Y^2 are less than 1. The result therefore suggests that income appears to have more influence on the quality of environment than energy.

5.2 Discussion

Based on 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% levels. The result of 13 countries shows that income and energy have a positive and significant connection with CO_2. However, income squared has a significant negative influence on CO_2, implying that CO_2 has fallen over the long run. As income increases, the levels of environmental damage decreases in those countries. The countries that support 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

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in Algeria. Furthermore, estimates for Benin, Cameroon, Zimbabwe, Togo, Sudan, Kenya, and Ethiopia are either not statistically significant or have 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 inhouse political crisis over a long time. However, there is no evidence to support the EKC in 10 countries. Based on the estimation period of those countries, a significant rise in real incomes did not have postitive and significant effects on the quality of environment.

Conclusion and Policy Implications

Recently, the international community has expressed great concern over the role of energy and economic activities in environmental quality. Similarly, there have been growing literature in both OECD and non-OECD countries that investigate the effect of energy consumption and economic growth on the quality of environment (mostly represented by CO_2 emission), known as the EKC hypothesis.

This study contributes to the growing literature by examining the possibility of any long-run asociation between energy consumption, economic growth, and economic growth squared on CO_2 emission for the selected 23 African countries. The empirical findings suggest that there is an evidence of cointegration between energy consumption, GDP, GDP squared, and CO_2 emission at panel level.

However, specific result suggest that energy consumption related activities increased carbon emission in most of the countries. Also, a negative and significant impact of income squared and CO_2 emission exists. This indicates that in nearly 60 percent of the countries, CO_2 emission decreases as income increases, which substantiates the EKC hypothesis.

The policy implications for the result indicates that most of the countries should pursue economic growth policies that are not highly carbon intensive, and projects that promote energy efficiency should be increased. In addition, renewable energy technologies that 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 implemented with market-based incentive to regulate highly energy-intensive and polluting sectors in order to achieve sustainable environmental friendly growth.

Finally, it must be emphasized that for all the countries, market-based incentives such as soft loans and tax holidays, aimed at increasing the consumption of renewable energy and less carbon-intensive activities, can boost economic growth to reach the turning point. As a result, the association between energy consumption and growth will improve the environment.

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