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**Article**

## Carbon emissions and economic growth in Africa: Are they related?

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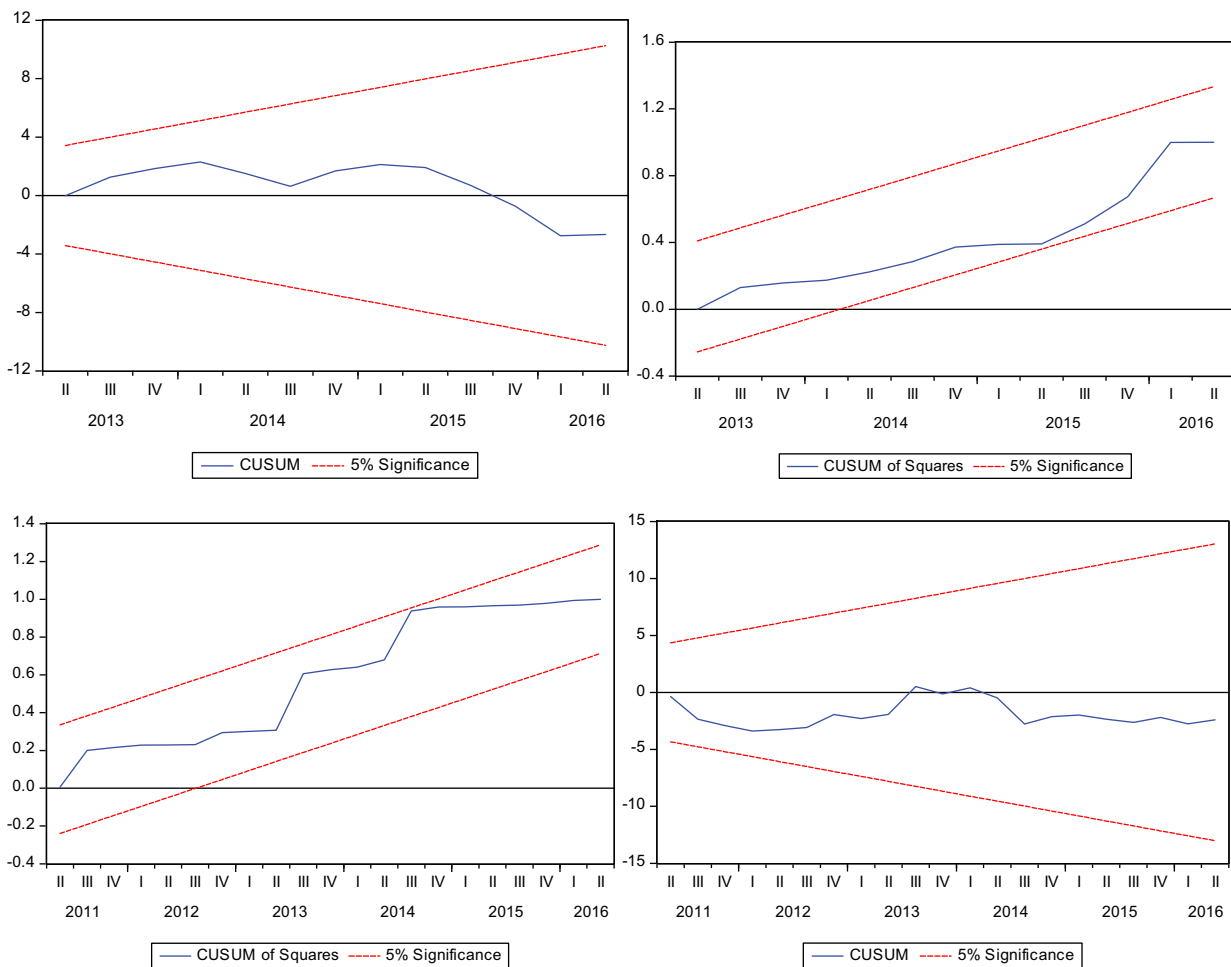
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## GENERAL & APPLIED ECONOMICS | RESEARCH ARTICLE

# CARBON EMISSIONS AND ECONOMIC GROWTH IN AFRICA: ARE THEY RELATED?

Olusanya Elisa Olubusoye<sup>1</sup> and Dasauki Musa<sup>2\*</sup>

**Abstract:** The study the ARDL model, Mean Group (MG), and the Pooled Mean Group (PMG) model to examine the Environmental Kuznets Curve (EKC) hypothesis in 43 African countries pooled into 3 income groups from 1980–2016. The EKC hypothesis is accepted in only 21% of the sample but rejected in 79% of the countries in the total sample. This result shows that carbon emissions increase as economic growth increases in 79% of the countries while economic growth will lead to lower carbon emissions in only a few countries (21%). The study concludes that an increase in economic growth will induce higher emissions in most countries in Africa. These countries should take all possible policy actions such as the massive deployment of renewable energy, carbon tax policy, and the carbon emissions trading scheme to curtail growth in carbon emission.

**Subjects:** Sustainable Development; Environment & the Developing World; Economics; Environmental Economics

**Keywords:** EKC hypothesis; renewable energy; carbon tax; climate change; PMG

## 1. Introduction

Since the industrial revolution, intensive industrial activities have led to a significant increase in emissions of atmospheric greenhouse gases (GHGs). These have caused changes to climate, and as



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## PUBLIC INTEREST STATEMENT

The study tested the Environmental Kuznets curve (EKC) hypothesis in 42 Countries in Africa. The countries were pooled into 3 income groups: low-income countries (LIC); Middle-Lower Income Countries (MLIC), and Middle-Upper Income countries (MUIC). The EKC hypothesis posits an inverted-U relationship between carbon emissions and economic growth, which differs from the view of a monotonically increasing or decreasing relationship. Annual time-series data gathered from the World Bank development indicators from 1980–2016 was applied and estimated using a recently developed technique called the income elasticity approach. The EKC hypothesis is rejected in most African countries. The long-run income elasticity is positive in more than 79% of the sample. These countries have not reached a turning point in carbon emissions as economic growth increases. This indicates that economic growth will drive future emissions in Africa if adequate mitigation measures are not put in place.

a result, pose a major challenge confronting humans in the 21<sup>st</sup> century (Atanassov & Atanassov, 2012; Cohen & Waddell, 2009; Edwards et al., 2008; Mosnier et al., 2014; Parsons, 2010). In 2015, the World witnessed its hottest year since 1900. Between 1998 and 2015, sixteen (16) warmest years were recorded as documented in Jos et al. (2016). The Intergovernmental Panel of Climate Change (IPCC) fifth assessment report indicated an increase in the land surface temperature of 0.5°C or more at least in the last 50–100 years and a rise in global mean sea level by at least 19 cm between 1900 and 2010 in most African countries. The report warned that, maintaining the current carbon trend could lead to an increase of 2.6–4.8°C in the global temperature by 2100.

Carbon dioxide (CO<sub>2</sub>) is identified as the most dominant GHG in the atmosphere (Bond et al., 2004; Choi et al., 2009; Olivier, et al, 2013; Solomon et al., 2007). The combustion of fossil fuel and cement manufacturing is responsible for over 60% of GHGs in the atmosphere. Although Carbon is an important building block of life, the excessive release of carbon has some negative implications on the quality of the environment (Arrigoni et al., 2017; Iddon & Firth, 2013; Khanna et al., 2008; G. Q. Chen et al., 2011; Zehnder & Svensson, 1986; Zhang & Wang, 2015). The GHGs naturally exist in the atmosphere. They trap heat and keep the earth warm enough to sustain life (Chilingar et al., 2009; Haines et al., 2006; Kweku et al., 2018). However, when these GHGs accumulate and exceed the threshold that is naturally needed, the earth's climate becomes warmer than its normal temperature. Climate Change has brought about rising sea-level leading to flooding, a decline in rainfall, and other disasters that negatively impact food security, Animal production, and has increased poverty. Climate change impact is more severe in Africa, especially where Agriculture is the main source of economic livelihood (IPCC (Intergovernmental Panel on Climate Change), Stocker, et al, 2013).

A consensus has been reached among most scholars that human activities are responsible for most of the GHGs in the atmosphere since the industrial revolution (Hallegatte et al., 2016; Niang et al., 2015; Stocker et al., 2013). Human activities often require the combustion of fossil fuels that degrades the environment through the release of harmful Greenhouse Gases (GHGs) (Minx et al., 2013; Pearson et al., 2017). Although carbon emission in Africa is significantly low compared to China, Russia, India, and Japan, the total emissions in Africa have significantly increased by more than twelve-fold since the 1950s (Boden et al., 2009), and this level is projected to increase further. Africa has disproportionately suffered the impact of climate change in addition to being among the most vulnerable regions to climate change (IEA & Special, 2019). In 2015, carbon emissions declined as a result of a 7% reduction in the Gross Domestic Product (GDP) growth rate in China. Projections show that carbon emissions will increase by 2% in 2017 after 3 years of relative stability in carbon emissions).

The United Nations Framework Convention on Climate Change (UNFCCC) was set up to stabilize the concentration of GHGs in the atmosphere and all countries including Africa are parties to the UNFCCC. The UNFCCC parties have reached a consensus to limit climate change to 2 degrees Celsius (3.6 f) relative to the pre-industrial level. However, the current trajectory in GHG emissions suggests some inconsistencies may compromise the efforts directed towards limiting global warming below 1.5 degrees or 2 degrees. This objective will be jeopardized if GHGs fail to fall by 7.6% per year between 2020 and 2030 (United Nations Department of Economic and Social Affairs Population Division, 2019). This means Africa can play an important role as part of global efforts to mitigate carbon emissions and future climate change impact. There are growing global efforts to combat climate change by minimizing carbon emissions.

The Environmental Kuznets Curve hypothesis (EKC) is the theoretical framework that links environmental degradation to economic growth. The EKC hypothesis emphasized an inverted-U relationship between economic growth and environmental degradation. It implies that, as economic growth increases, the level of environmental degradation increases but when a certain level of economic growth is reached, the level of degradation of the environment will decline. According to Grossman and Krueger (1991), during the early stage of economic growth, the economy relies

on poor technology that degrades the environment. A less industrialized economy then gradually grows into an industrialized economy. As higher income is realized and the economy becomes more industrialized, the level of pollution reaches its peak. When a high-income level is reached, the economy can afford new and improved technology. At this stage, Environmental protection laws emerge and a cleaner environment becomes important. As the economy transits from an industry-driven to a service sector-driven economy, the level of degradation of the environment declines. It is through all these stages that the inverted-U path of the EKC hypothesis is derived. Thus, testing the validity of this hypothesis is important to aid the development of appropriate policies to combat climate change, particularly in Africa.

Two main streams of literature have examined carbon emissions and economic growth relationship. One stream of literature examined the direction of the causal relationship (See Ahmad et al., 2017; Alam et al., 2011; Apergis et al., 2010; Y. Y. Chen et al., 2019; Ezzo & Kehoe, 2016; Gao & Zhang, 2014; Jahangir Alam et al., 2012; Kaplan et al., 2011; Lee & Yoo, 2016; Onishi et al., 2012; Pao & Tsai, 2011; Salahuddin et al., 2015). There is significant evidence supporting bidirectional causal relationships against one way causality often implied by most multivariate and bi-variate approach, while one-way causality is confirmed in some cases.

The second stream of literature consists of studies that primarily examined the presence of an inverted-U relationship between carbon emission and economic growth based on the EKC hypothesis (see Bekun et al., 2019; Bertinelli & Strobl, 2005; Dijkgraaf & Vollebergh, 2005; Narayan & Narayan, 2008; Narayan et al., 2016; Perman & Stern, 2003; Suri & Chapman, 1998), among others. Grossman and Krueger (1991) noted that testing the EKC hypothesis has been applied to both individual-specific countries as well as a panel of countries. Significant literature investigated the EKC hypothesis in developed economies, emerging and developing countries (see Al-mulali & Binti Che, 2012; Apergis & Payne, 2010a; Arouri et al., 2012; Narayan & Narayan, 2010a; Pao & Tsai, 2011; Perman & Stern, 2003; Wang et al., 2011).

A majority of extant literature examining the EKC hypothesis applied the polynomial regression models where GDP level, GDP squared, and GDP cubed are incorporated as explanatory variables to capture linear, quadratic, and cubic relationship, respectively (see Alege et al., 2016; Gao & Zhang, 2014; Mudakkar et al., 2013; Nwodo et al., 2017; Saboori et al., 2012; Superior et al., 2016). This approach has been identified to accommodate high multicollinearity among the variables, which makes the estimates unreliable and misleading (Jaunky, 2011; Narayan & Narayan, 2010b; Narayan et al., 2016; Olubusoye & Dasauki, 2018).

The present study fills the gap, by testing the validity of the EKC hypothesis in 42 African countries by using recently developed econometric techniques. The study also adds to existing literature, new empirical evidence of the relationship between carbon emissions and economic growth in the case of Africa. This methodology employed has been applied to the Middle East and North Africa (MENA) countries in Arouri (2012); 42 high-income countries are considered in Jaunky (2011) and, 42 developing countries are considered in Narayan and Narayan (2010) out of which only 12 countries are from Africa, while few other studies examined the EKC hypothesis in Sub-Saharan Africa (SSA) region [see Abid (2016) for 25 SSA Countries; Awad and Warsame (2017) for 54 Countries in Africa; Bah et al. (2020), Shahbaz et al. (2016)], however, these studies were based on the polynomial regression approach.

Our study differs from Narayan and Narayan (2010) in terms of scope. Narayan and Narayan (2010) examined the EKC hypothesis from the year 1980 to 2004. However, much economic transformation must have transpired between 2004 and 2016. African countries have grown significantly in the last decade and this will have implications on the quality of the environment. Thus, we extend Narayan and Narayan (2010) to cover the years 1980 to 2016. We further apply the income elasticity approach to 31 additional countries that were not covered in Narayan and Narayan (2010). To the best of our knowledge, as at the time of writing this paper, our study is the first applying the income elasticity

approach in the spirit of Narayan and Narayan (2010) to the case of Africa. The result we obtained from the implementation of the income elasticity approach indicates positive long-run income elasticity in 79% of the sample. Thus, the EKC hypothesis is rejected in 79% of the sample while the EKC hypothesis is accepted in only 21% of the countries in the study.

The rest of this paper is organized as follows. In section 2, we give a brief review of the literature, In Section 3, the methodology for the study is discussed. Section 4 presents the results obtained while section 5 renders the conclusion and recommendations.

## 2. Literature Review

There are quite high number of literature that have examined EKC hypothesis in many countries and regions of the world. Perman and Stern (2003) examined the EKC hypothesis in 74 countries and the evidence did not support the EKC hypothesis. Narayan and Narayan (2010) applied the income elasticity approach to examine the EKC hypothesis in 43 developing countries from 1980–2004. The EKC hypothesis is true in 35% of the sample. The panel result also shows evidence supporting the EKC hypothesis in the Middle Eastern and South-Asian panel. The identified countries are to expect lower future carbon emission and higher economic growth is attained. Pao and Tsai (2010) applied the causality test and found evidence of feedback causal relationships from energy consumption to carbon emissions and from carbon emissions to energy consumption. There is a one-way short-run causality from carbons to energy consumption in BRICK countries. The study found evidence consistent with the EKC hypothesis in Bricks. Wang et al. (2011) applied panel VECM to examine the direction of causality from 1995 to 2007 in 28 Chinese provinces. The study found evidence of feedback causality from emissions to energy consumption and from energy consumption to carbon emission. There is also a feedback causality from energy consumption to economic growth and from economic growth to carbon emissions.

Esteve and Tamarit (2012) applied a linear cointegration model with multiple structural changes based on the stability test proposed by Kejriwal and Perron to examine the EKC hypothesis in Spain from 1957–2007. The result did not comply with the EKC hypothesis; however, carbon emission is expected to decline in the future. Saboori et al. (2012) examined the EKC hypothesis using time-series data from 1980–2009 in Malaysia. The ARDL result supports the EKC hypothesis of an inverted-U relationship. The VECM causality test indicates there is no evidence of short-run causality however, a unidirectional long-run causality flows to carbon from economic growth. Al-mulali and Binti Che (2012) examined how carbon emission responds to increases energy consumption using a panel data approach in 30 Sub-Saharan countries from 1980 to 2008. The study concluded with strong evidence that energy consumption is a key predictor of GDP and that financial development in Sub-Saharan Africa has implications on the degradation of the environment. Gao and Zhang (2014) found evidence supporting the EKC hypothesis in 14 Sub-Sahara African Countries. The study also found evidence of unidirectional causality in the short-run to carbon emissions from economic growth while feedback causality is found in the long-run.

Farhani et al. (2014) examined the EKC hypothesis in 10 the Middle East and North African (MENA) countries from 1990–2010. The study found evidence of an inverted-U relationship between environmental sustainability and human development. Kiviyiro and Arminen (2014) examined the EKC hypothesis in 6 SSA countries. The result is consistent with the EKC hypothesis in the Democratic Republic of Congo (Congo DR), Kenya, and Zimbabwe only. Shahbaz et al. (2015) applied VECM cointegration to examine the EKC hypothesis in countries of Sub-Saharan Africa (SSA). The study found evidence in support of the EKC in SSA. The study found evidence of bidirectional causality from economic growth to carbon emission. Ben Jebli et al. (2015) applied a panel OLS and FMOLS cointegration approach to examine the validity of the EKC hypothesis in 24 SSA countries over 1980–2010. The long-run result did not support the EKC hypothesis of an inverted U relationship. Export and import have and positive and negative impact on carbon emissions respectively in SSA. Abid (2016) Applied the GMM model to examine the EKC hypothesis within the relationship between economic, financial, institutional developments, and carbon



emissions for 25 SSA countries. The study found no evidence of EKC (inverted-U relationship), rather strong evidence of a monotonically increasing relationship is found.

Lin et al. (2016) tested the validity of the EKC hypothesis in 5 African Countries. The evidence from the study did not agree with the EKC hypothesis. Shahbaz et al. (2016) included globalization and energy intensity to the EKC model to investigate the validity of the EKC hypothesis in 19 African countries. The results indicated the positive effect of energy intensity on CO<sub>2</sub> emissions in Africa, Algeria, Angola, Cameroon, Congo Republic, Ghana, Kenya, Libya, Morocco, Nigeria, South Africa, Sudan, Togo, and Tunisia while energy intensity declines CO<sub>2</sub> emissions in the case of Zambia and Zimbabwe. The study found evidence supporting the EKC hypothesis in Africa, Algeria, Cameroon, Congo DR, Morocco, Tunisia, and Zambia but the U-shaped relationship is found between economic growth and CO<sub>2</sub> emissions in Sudan and Tanzania. Sirag et al. (2017) applied a dynamic panel threshold approach to examine the EKC hypothesis in developing countries. Evidence of statistically significant positive impact on carbon emissions is found in Low income and middle-income countries. Awad and Warsame (2017) applied a semiparametric panel fixed effect regression to test the EKC hypothesis in the context of carbon emissions and economic growth relationship in 54 African Countries. The study did not find evidence in support of the EKC hypothesis.

Twerefou, Danso-Mensah, & Bokpin, (2017) in a panel study, examined the impact of economic growth and globalization on carbon emission in 36 SSA countries from 1990–2013, using a system GMM model. The evidence supports the EKC hypothesis, while globalization is found to worsen the quality of the environment by increasing the level of carbon emissions.

Charfeddine and Mrabet (2017) examined the EKC hypothesis in 15 oil-exporting and oil-importing countries in MENA from 1975 to 2007. The EKC hypothesis is accepted in oil-exporting countries but rejected in the panel of oil-importing countries. Zerbo (2017) applied the ARDL cointegration model to examine the relationship between energy consumption, income growth, trade openness, and carbon emission. The long-run result contradicts the EKC hypothesis. The result also shows a monotonically increasing impact of income growth and energy consumption on carbon emissions in both the long-run and short-run in most countries. Sarkodie (2018) applied the ECM and Panel cointegration approach to investigate the determinants of pollution and degradation of the environment from 1971 to 2013 in 17 African countries. The EKC hypothesis was accepted by the study. Hundie (2018) applied the ARDL model with a polynomial specification and found evidence that carbon emission in Ethiopia is largely impacted by energy consumption, population, trade openness, and economic growth in the long run. The evidence from the squared of GDP in the study supports the EKC hypothesis. The short-run result shows that urbanization and energy consumption increases the degradation of the environment. Based on Toda-Yamamoto shows evidence of feedback causality among energy consumption and carbon emissions, carbon emissions, and urbanization.

Adzawla et al. (2019) applied the ordinary least squares (OLS) approach to test the EKC hypothesis in the relationship between GHGs and economic growth in SSA from 1970–2012. The study did not find any evidence that there is a turning point as posited by the EKC hypothesis. The OLS and VAR indicate an Inverted N-shaped relationship and an inverted N-shaped relationship respectively. The study concludes generally that of a monotonically decreasing relationship between environmental quality (NH<sub>4</sub> emissions as proxy) and economic growth in the long run. Acheampong et al. (2019) applied the fixed and random effect models to examine the impact of globalization and renewable energy on carbon emissions in 46 SSA countries from 1980–2015. The evidence supports the EKC hypothesis. The result also shows that FDI and the population reduce carbon emissions while trade openness increases environmental degradation. Demissew Beyene and Kotosz (2019) Applied the Pooled Mean Group (PMG) approach to test the EKC hypothesis in 23 East African Countries from 1990–2013. The EKC hypothesis is rejected in the long-run but accepted in the short-run estimation. Bah et al. (2020) applied a panel cointegration approach to examine the EKC hypothesis in 10 Middle-Income countries in SSA from 1971–2012. The



evidence from the study is consistent with the EKC hypothesis. On country-specific analysis, the EKC hypothesis is validated only in Cote d'Ivoire, Kenya, and Nigeria for countries in the middle-lower income group, while in the middle upper-income countries group, the EKC hypothesis is validated for Mauritius, South Africa, and Botswana.

### 3. Data and Methodology

The study tests the EKC hypothesis for 42 African countries. The countries are pooled into 3 panels of 23 Low-income countries; 14 Middle-Lower, and 5 Middle-Upper-income countries. Annual data are obtained from the World Bank Development Indicators from 1980–2016. To reduce skewness, all the variables are transformed into their natural logarithmic form. The estimated model is of the form:

$$\Delta \text{ICO2}_{it} = \beta_0 + \beta_1 \text{ICO2}_{it-1} + \beta_2 \text{GDP}_{it} + \beta_3 \text{EC}_{it-1} + \sum_{i=1}^p \alpha_1 \Delta \text{ICO2}_{it-1} + \sum_{i=0}^q \alpha_2 \Delta \text{GDP}_{t-1} + \sum_{i=0}^s \alpha_3 \Delta \text{EC}_{it-1} + \mu_t \quad (1)$$

where  $\Delta \text{ICO2}$  is the first difference of carbon emissions, and GDP and EC are economic growth and energy consumption variables, respectively. Lags  $p$ ,  $q$ , and  $s$  are maximum lags for the variables in the short run, while optimal lags are based on information criteria. The parameters  $\beta_1$ ,  $\beta_2$  and  $\beta_3$  are the long-run impact of Carbon emission of the previous period, Economic growth (GDP), and energy consumption, respectively, while  $\alpha_1$ ,  $\alpha_2$  and  $\alpha_3$  are respectively the short-run impacts of these variables. Energy consumption is a control variable. The long-run and short-run coefficients can also be interpreted as income elasticity.  $\mu_t$  is the stochastic random error term.  $\text{ICO2}$  is carbon emissions in natural logarithm form, while  $\text{IGDP}$  is the real per capita GDP in natural logarithm.  $\beta_0$  is the constant term. According to Narayan and Narayan (2010), the Carbon emission and Economic growth relationship are consistent with the EKC hypothesis if the long-run income elasticity of GDP is negative while the short-run income elasticity is positive (Narayan & Narayan, 2010b). Alternatively, if the Long-run income elasticity is smaller than the Short-run income elasticity then an inverted-U relationship between Carbon emissions and Economic growth exists (Narayan & Narayan, 2010b). If this condition holds, and then the EKC hypothesis is accepted and an inverted-U relationship exists.

We will estimate the model in (1) using an Autoregressive Distributed Lags (ARDL) model for individual countries while the PMG and MG model will be applied for the Panel analysis. The MG model is designed to estimates each country with its model through a simple arithmetic average. It computes the average value of the coefficients. The PMG combines both pooling and averaging of the coefficients. The PMG also allows the varying of the short-run coefficients including the speed of adjustment and regression intercept while imposing long-run coefficients. In comparing MG and PMG models, the null hypothesis for such a test is that PMG is the preferred model.

The PMG remains consistent even when cross-sectional dependence (CD) exists. Also, the PMG is applicable regardless of the order of integration of the variables (Salahuddin et al., 2016). The study applies the Pesaran CD test to investigate the presence of cross-sectional dependence in the variables. In addition to the conventional unit and the study also applies a nonconventional unit root test (PCDADF) which accounts for cross-sectional dependence. This is important because the presence of Cross-sectional Dependence may cause size distortions and low power to reject the null hypothesis of non-stationarity (Salahuddin et al., 2016).

### 4. Result

The results of IPS and Breitung unit root tests are presented in Panel A of Table 1, while the results of the Pasaran CDADF unit root test are given in Panel B. Pedroni cointegration test results are reported in Panel C of the reporting table. The IPS unit root test results indicate that the variables employed in the study are  $I(1)$ , that is they are stationary at first difference. Similarly, the Breitung unit root test indicates the variables are stationary at first difference except for  $\text{CO}_2$  emissions in the panel of

**Table 1. Panel results**

<b>Panel A: Unit root</b>	<b>IPS</b>			<b>Breitung t-test</b>		
	<b>IGDP</b>	<b>IECONS</b>	<b>LCO<sub>2</sub></b>	<b>IGDP</b>	<b>IECONS</b>	<b>LCO<sub>2</sub></b>
LIC	−8.10 **	−5.91***	−6.33***	−9.29***	−5.047***	−2.10**
MLIC	−5.88***	−5.76***	−5.88***	−5.01***	−1.74**	−5.01***
MUIC	−5.73***	−6.42***	−4.88***	−2.42***	−4.57***	−1.03
<i>Panel B: Pasaran CADF Unit root test</i>						
	<b>Level</b>			<b>First Difference</b>		
	<b>LGDP</b>	<b>ICO2</b>	<b>LECONS</b>	<b>D(LGDP)</b>	<b>D(ICO2)</b>	<b>D(LECONS)</b>
LIC	1.44	−1.71	−1.89	−3.55***	−3.49***	−3.55***
MLIC	−1.48	−1.45	−1.70	−3.04***	−3.28***	−3.23***
MUIC	−2.13	0.79	−1.88	−3.06***	−3.30***	−3.33***
<b>Panel C: Pedroni</b>						<b>cointegration</b>
Panel PP	Panel ADF	Group PP	Group ADF			
LIC	−1.85*	−1.95**	−1.81**	−2.64***		
MLIC	−1.70**	−1.77**	−0.74	−0.67		
MUIC	−3.87***	−4.02***	−4.03***	−3.98***		

Where \*, \*\*, \*\*\* represents statistical significance at 10%, 5% and 1% respectively. Low-income countries (LIC); Middle-lower income countries (MLIC), and Middle-Upper Income countries (MUIC)

Middle-Upper Income (MUIC). However, the Pesaran Cross-Sectional Dependence ADF (PCDADF) Unit root test suggests the rejection of the null hypothesis of a unit root. This result is reported in Panel B of Table 1. The Pedroni cointegration test result reported in Panel C of Table 1 shows that carbon emissions, energy consumption, and GDP are cointegrated, and long-run relationships exist.

#### 4.1. Discussion of result for individual countries

The short-run and long-run income elasticity for individual countries are reported in Table 2, 3, and 4 for LIC, MLIC, and MUIC. We begin with the result for the Low-Income Countries (LIC) reported in Table 2. This result shows that the long-run income elasticity ranges from 0.041 in the Central African Federation (CAF) and 12.7 in (Uganda). We also found a positive and statistically significant long-run impact of economic growth on carbon emissions in Chad, Ethiopia, Liberia, and Niger. This result means that an increase in economic growth (GDP or income) will increase carbon emissions by 0.83, 1.76, 6.53, 6.52, and 2.12 in Chad, Congo DR, Ethiopia, Liberia, and Niger, respectively. In Congo DR, Ethiopia Liberia, and Niger, income elasticities are greater than 1, which implies that carbon emissions will increase by a proportion that is higher than the initial increase in economic growth. Since the long-run income elasticity is positive and significant in Chad, Congo DR, Ethiopia, Liberia, and Niger, they are not consistent with the EKC hypothesis. Although the impact of economic growth on carbon emissions is positive, it is not statistically significant in the following LIC countries: Benin, Burkina-Faso, Equatorial Guinea, Gambia, Malawi, Mali, Mozambique, Malawi, Rwanda, Senegal, Sierra-Leone, Uganda, and Zimbabwe. The short-run income elasticity is positive and statistically significant, implying that a 1% increase in economic growth will bring about a statistically significant increase in Burkina-Faso (0.56), Congo DR. (3.71), Ethiopia (0.92), Liberia (0.92), Mozambique (1.39), Niger (0.57), Rwanda (0.57), and Sierra-leone (0.44). Other countries with a positive but not statistically significant impact of economic growth on Carbon emissions are Benin (0.93), Burkina Faso (0.56), Chad (0.08), Equatorial Guinea (0.82), Gabon (0.82), Guinea Bissau (0.02), Madagascar (1.02), Senegal (1.44), Uganda (0.97), and Zimbabwe (2.11) while the impact of economic growth on Carbon emission is negative but statistically insignificant in CAF (−0.025), Tanzania (−0.67), and Togo (0.6).

**Table 2. Short-run and long-run income elasticity for low-income countries**

	Long-run		Short-run		
COUNTRY	GDP	ECONS	D(GDP)	D(ECONS)	ECM
Panel A: Low-Income Countries					
Benin	3.02 (0.91)	76.5 *** (5.42)	0.93 (0.91)	23.7**(3.02)	-0.31** (-3.13)
Burkina Faso	2.17 (1.62)	13.2 (0.46)	0.56 ** (2.82)	32.92 *** (4.22)	-0.26 ** (-2.007)
CAF	-0.041 (-0.88)	0.16*** (5.77)	-0.025 (-0.84)	-0.019 (-0.55)	-0.59 *** (-4.63)
Chad	0.83 ** (1.95)	0.44 (0.826)	0.08 (1.16)	0.043 (1.124)	-0.10 (-0.99)
DR- Congo	1.76 *** (4.73)	5.95 *** (4.93)	3.71*** (3.65)	2.23 *** (4.64)	-0.37** (-3.63)
Equatorial Guinea	1.34 (0.87)	0.29 (0.22)	0.82 (1.43)	0.66** (2.61)	-0.28* (-1.72)
Ethiopia	6.53 ** (1.74)	5.05** (2.67)	0.92 ** (1.98)	0.71 ** (2.12)	-0.14 (-1.61)
Gambia	1.34 (0.87)	0.29 (0.22)	0.82 (1.43)	0.66 ** (2.60)	-0.29** (-1.71)
Guinea Bissau	-0.38 (-0.89)	0.08 (1.35)	0.02 (0.53)	0.04 ** (1.88)	-0.11 (-1.07)
Liberia	6.52** (1.73)	5.06 ** (2.68)	0.92 *(1.98)	-0.71** (2.12)	-0.14 (-1.61)
Madagascar	-2.34 (-0.93)	1.58** (3.17)	1.02 (1.17)	0.337 (0.16)	-0.23** (-1.87)
Malawi	0.63 (1.51)	0.57** (2.97)	0.16 (1.28)	0.32** (2.61)	-0.26 ** (-2.04)
Mali	1.03 (1.22)	0.36 (0.11)	0.24 (1.16)	-0.14 (0.25)	-0.23 (-1.50)
Mozambique	-26.5 (-0.58)	5.55 (0.59)	1.39 ** (2.19)	-0.29 (-1.06)	0.05 (0.63)
Niger	2.13 ** (3.11)	1.43 *** (5.74)	0.57 ** (3.21)	0.38 *** (4.82)	-0.27** (-3.32)
Rwanda	1.19 (1.05)	-0.12 (-0.24)	0.11** (3.22)	-0.01 (-0.29)	-0.09 (-0.89)
Senegal	6.47 (0.72)	4.08 (1.63)	1.44 (0.64)	2.86** (2.08)	-0.22 ** (-1.79)
Sierra Leon	0.70 (0.39)	-1.64 (-0.49)	0.44 ** (2.05)	0.08 (0.87)	0.06 (0.55)
Tanzania	-11.40 (-0.68)	30.8 (0.88)	-0.57 (-1.49)	1.55*** (2.83)	-0.01 (-0.73)
Togo	-0.07 (-0.17)	1.22 *** (15.8)	-0.6 (-0.17)	1.02 *** (7.14)	-0.83*** (-6.95)
Uganda	12.7 (0.85)	-0.31 (-0.07)	0.97 (0.88)	0.75** (-2.36)	-0.06 (-0.94)
Zimbabwe	8.37 (1.61)	12.8** (1.73)	2.11 (1.33)	10.7 ** (3.15)	-0.25 ** (-2.12)

where: () t-statistics; \*, \*\*, \*\*\* represents P-value statistical significance at 10%, 5% and 1% respectively.

**Table 3. Middle-lower-income countries**

	Long-run Income Elasticity		Short-run Income Elasticity		ECM
	GDP	ECONS	D(GDP)	D(ECONS)	
Cameroon	3.14 (1.57)	3.02 ** (2.85)	14.5 ** (2.51)	2.44 ** (2.43)	-0.81*** (-4.42)
Cape Verde	0.25 *** (3.68)	0.06 (1.47)	-0.34 ** (-3.06)	0.02 (1.14)	-0.33 ** (-3.06)
Comoros	-0.19 (0.64)	0.13 ** (2.12)	-0.03 (-0.70)	0.04*** (4.02)	-0.17 (-1.29)
Congo	-0.30 (-0.14)	4.74 ** (3.60)	-0.11 (-0.14)	0.46 (0.57)	-0.37 ** (-2.65)
Cote di voire	2.96 (1.53)	3.98 ** (3.49)	15.0 ** (2.71)	2.77 ** (2.71)	-0.69 *** (-4.59)
Egypt	82.7 (0.50)	78.95 (0.83)	183.5** (2.22)	27.5 (0.84)	-0.35 ** (-2.88)
Ghana	4.21 (0.80)	7.83** (2.13)	1.03 (0.71)	-1.07 (-0.93)	-0.24** (-2.34)
Kenya	28.17 (1.00)	3.29 (1.27)	5.81 (1.03)	0.59 (0.75)	-0.18 (-1.24)
Lesotho	1.01*** (9.46)	0.07 (1.63)	0.37 ** (3.24)	0.03 (1.23)	-0.36 *** (-4.07)
Mauritania	4.41 ** (2.30)	-0.22** (-3.28)	2.02 ** (2.09)	0.35 (1.13)	-0.46 ** (-3.28)
Mauritius	-0.27 (-0.13)	2.25 (1.61)	-0.05 (-0.14)	0.42** (2.63)	-0.19 ** (-2.36)
Nigeria	41.8 (0.57)	8.43 (0.14)	56.6 (1.37)	26.3 ** (1.77)	-0.17 (-1.49)
Sudan	7.60 ** (3.62)	4.91*** (4.48)	-4.74* (-1.84)	2.37 *** (-3.92)	-0.48*** (-4.30)
Zambia	0.52 (0.16)	6.59 ** (2.02)	0.09 (0.17)	2.97 *** (3.86)	-0.17 (-1.33)

**Table 4. Middle-upper income countries**

<b>Botswana</b>	<b>12.12 (1.68)</b>	<b>-4.26 (-0.95)</b>	<b>2.68 ** (2.65)</b>	<b>1.36 (1.62)</b>	<b>-0.22 ** (-1.82)</b>
Gabon	1.47 (2.26)	0.32 (0.31)	3.23** (2.29)	0.15 (0.30)	-0.47 ** (-3.37)
Libya	-16.0 (-0.54)	145 (0.80)	9.02* (1.87)	33.65 ** (3.01)	-0.17 (-0.52)
Namibia	4.19 *** (7.26)	0.18 (0.60)	-2.72 (-1.07)	-4.67 (-1.67)	-1.15 *** (-5.19)
South Africa	159.2** (3.59)	291.7*** (9.65)	110** (2.53)	169.6 (1.35)	-0.69 *** (4.21)

where: () t-statistics; \*, \*\*, \*\*\* represents P-value statistical significance at 10%, 5% and 1% respectively.

#### 4.2. Discussion of individual-country specific result

An alternative approach is to test the validity of the EKC hypothesis by comparing the long-run and short-run income elasticity. When the short-run income elasticity is higher than the long-run income elasticity, then carbon emissions have increased and declined over time, and the EKC hypothesis is accepted (Narayan and Narayan 2010; Olubusoye & Dasauki, 2018). The EKC hypothesis implies a negative relationship is reached after a certain level of income is reached. Based on this criterion, the EKC hypothesis is accepted in Guinea-Bissau, Madagascar, and Mozambique. To conclude that there is a turning point or EKC hypothesis is true, the long-run income elasticity must be negative (Narayan and Narayan 2010; Jaunky, 2011). This result represents 13% of the LIC sample. In Mozambique, only the short-run coefficient is statistically significant while Mozambique and Guinea-Bissau are not statistically significant in both the long-run and short-run. On the other hand, the EKC hypothesis is rejected in 20 of 23 countries (representing 87%) of the low-income countries (CAF, Chad, Equatorial-Guinea, Ethiopia, DR Congo, Gambia, Liberia, Malawi, Mali, Niger, Rwanda, Senegal, Sierra-Leone, Tanzania, Togo, Uganda, and Zimbabwe). These countries have not reached a turning point in carbon emissions relative to economic growth. The result shows that only DR Congo and Liberia are statistically significant. Although not consistent with the EKC hypothesis, the CAF, Tanzania, and Togo have negative income elasticity in both the short-run and long-run. Madagascar, Guinea-Bissau, Mozambique are identified with a negative income elasticity only in the long-run. In sum, the study found evidence that 6 low-income countries have reduced carbon emissions as higher income is attained. This result represents 21% of the low-income countries.

The result for Middle-Lower-Income (MLI) Countries reported in Table 3 shows a statistically significant error correction terms at least at a 10% significance level or better for all the Middle-lower income countries except Comoros, Kenya, Nigeria, and Zambia. A significant ECT indicates the presence of long-run cointegration. The result shows that economic growth has a statistically insignificant short-run effect on carbon emissions in Comoros, Congo, Ghana, Kenya, Mauritius, Nigeria, and Zambia. On the other hand, economic growth has a statistically significant short-run impact on carbon emissions in Cameroon, Cape-Verde, Cotedivoure, Egypt Lesotho, Mauritius, and Sudan only. The result also shows that economic growth impacts on carbon emissions in Cape Verde, Lesotho, Mauritania, and Sudan in both long-run and short-run while the income elasticity ranges from 0.03 in Comoros to 183.5 in Egypt.

Generally, the result shows a positive short-run impact of economic growth on carbon emissions in Cameroon, Cape-Verde, Cote d'Ivoire, Egypt, Ghana, Kenya, Lesotho, Mauritania, Nigeria, Sudan, and Zambia with coefficients of 3.14, 0.25, 2.96, 82.7, 42.1, 28.17, 1.01, 4.41, 4.18, 7.60, and 0.52 respectively. On the other hand, the long-run result shows a negative relationship in Comoros (-0.19), Congo (-0.30), and Mauritius (-0.27). Similar to this result, Shahbaz et al. (2016); Adzawla et al. (2019) in SSA Countries; and Zerbo (2017) found a positive impact of GDP on carbon emissions in Ghana, Libya, Nigeria, Sudan, Kenya, Tanzania, and Togo.

Based on the criteria for the presence of an inverted-U relationship propounded by Narayan and Narayan (2016),<sup>1</sup> We have observed that the long-run income elasticity is not smaller than the short-run

income elasticity, consequently, the EKC hypothesis is rejected in 10 out of 14 MLIC countries. This is composed of Cape-Verde, Ghana, Kenya, Lesotho, Mauritania, Sudan, Comoros, Congo, Mauritius, and Zambia (See [Table 3](#)). Representing 71% of the Middle-lower income countries. There are 3 countries (21%) namely Comoros, Congo, and Mauritius have a negative income elasticity in both the long-run and short-run.

The result also indicates that only 4 countries (approximately 10% of the total sample of 42 countries) representing 29% of the MLIC panel are consistent with the EKC hypothesis. In the MLIC panel, the EKC hypothesis is accepted in Cameroon, Cote d'Ivoire, Egypt, and Nigeria. This result is similar to for Cameroon, and, Shahbaz et al. (2016); Kiviyiro and Arminen (2014) in the Democratic Republic of Congo.

In the Middle-Upper income countries, the result in [Table 4](#) shows that the error correction terms are statistically significant at least at 5% significance level or better in all the countries except in Libya. The income elasticity ranges from 1.47 in Gabon to 159.2 in South Africa. All Middle-Upper income countries have income elasticity greater than 1. We found a positive long-run (LR) impact of economic growth on carbon emissions in Botswana (12.12), South Africa (159.2), Namibia (4.19), and Gabon (1.47) but the relationship is Negative in the case of Libya (−16.0). Only Namibia and South Africa are statistically significant at a 1% significance level. An increase in economic growth will induce an increase of 4.19% and 159.2 in Carbon emissions in Namibia and South Africa respectively.

The short-run (SR) income elasticity is statistically significant except for Namibia. The long-run income elasticity is smaller than the short-run income elasticity in only Gabon (LR: 1.47, SR: 3.23) and Libya (LR: −16.0, SR: 9.02), representing 40% of Middle-Upper income countries (MLIC) in Africa. This evidence supports an inverted U-relationship between carbon emissions and economic growth in 2 out of 5 Middle Upper-income countries. The long-run (LR) income elasticity is not lower than the short-run income elasticity and thus, the EKC hypothesis is rejected in Botswana (LR: 12.12; SR: 2.68), Namibia (LR: 4.19; SR: −2.72), and South-Africa (LR: 159; SR: 110) representing 60% of Middle-Upper-Income countries. The result for the Middle Upper-Income countries (MUIC) in [Table 4](#) suggests that carbon emissions in the future (long-run) will increase as economic growth or income increases.

In summary, the country-specific result from all three panels (LIC, MLIC, and MUIC), indicates that the EKC Hypothesis is valid in only 9 out of 42 African countries, representing 21% of the total sample for the study. The EKC hypothesis is on the other hand rejected in 33 of 42 countries, (representing 79%) of the sample. There are similar studies that also confirmed or refuted the EKC hypothesis in some African countries. For instance, The EKC hypothesis is rejected in the study by Adzawla et al. (2019)—SSA; Ben Jebli et al. (2015) in 24 SSA countries; Zerbo (2017)—SSA; Lin, et al., (2016) —5 African countries; Perman and Stern (2003) in 74 countries; Charfeddine and Mrabet (2017) for oil-exporting countries; Hundie (2018) Ethiopia; Abid (2016); Bah et al. (2020)—South Africa, Nigeria, Mauritius, and Botswana; Kiviyiro et al. (2014) Congo DR, Kenya, Zimbabwe; Shahbaz et al. (2016) in Africa, Cameroon, Congo, Ghana, Kenya, Libya, Nigeria, and Southern Sudan. On the other hand, the EKC hypothesis is accepted by other studies like (Acheampong et al., 2019)—46 African Countries; Bah et al. (2020)—Cote d'Ivoire, and Nigeria; and Farhani et al. (2014); Charfeddine and Mrabet (2017) in oil-importing countries; Shabaz (2016) Cameroon, Congo DR, Zambia, Tunisia.

#### 4.3. Discussion of panel result

The PMG and MG technique are applied to estimate the Panel long-run and Short-run results. The Hausman test chose the MG as the best model for LIC and MLIC while the PMG is chosen as the appropriate model for the panel of MUIC. The panel long-run and short-run income elasticity are reported in [Table 5](#), [6](#), and [7](#) for individual Low-income (LIC), Middle- Lower Income countries (MLIC), and Middle-Upper income countries (MUIC) respectively. The MG result in [Table 5](#) shows a statistically significant error correction term (ECT) at a 1% significance level.

**Table 5. Panel result from income elasticity approach for low-income countries (LIC)**

	PMG (D.ICO <sub>2</sub> )	MG (D.ICO <sub>2</sub> )
<b>ECT</b>		
lgdp	2.131*** (7.12)	0.13 (0.57)
lecons	0.751*** (16.80)	0.716*** (8.98)
<b>SR</b>		
ECT	0.294 *** (8.67)	0.347*** (9.60)
lgdp	0.542*** (7.51)	-0.110* (-1.97)
D.lecons	0.396*** (5.62)	0.406*** (-0.16)
Cons	-0.292 (0.80)	-0.0597 (-0.16)
Hausman	-126.48	
Pesaran (CD) Test		
ICO <sub>2</sub>	51.081***	
lgdp	16.979***	
Lecons	52.766***	

t statistics in parentheses ()

\* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

**Table 6. Panel result for middle-lower-income countries (MLIC)**

	pmg (D.ICO <sub>2</sub> )	mg (D.ICO <sub>2</sub> )
<b>ECT</b>		
lgdp	-1.98*** (-6.48)	0.542 (1.60)
lecons	0.619*** (9.00)	0.747 (3.39)
<b>SR</b>		
ECT	0.381*** (5.62)	0.487 *** (7.98)
lgdp	-75.66*** (-5.61)	-0.287* (-2.03)
D.lecons	0.226*	0.297*** (2.72)
Cons	0.223 (0.44)	0.158 (0.13)
Hausman	-42.1	
Pesarn (CD) Test		
ICO <sub>2</sub>	30.282***	
lgdp	22.012***	
lecons	42.497***	

t statistics in parentheses ()

\* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

The income elasticity for the LIC Panel is less than 1, which indicates that an increase (decrease) in economic growth by 1% will lead to a less than 1% increase (decrease) in carbon emissions. The statistically significant ECT indicates the presence of a significant long-run relationship. The result also shows a positive but statistically insignificant long-run income elasticity of 0.13%, and a statistically significant negative short-run income elasticity of -0.11%. This result indicates that carbon emission has increased as economic growth increases in the long run, and thus the EKC hypothesis is rejected in LIC Panel. The result indicates that in the short-run, an increase (decrease) in economic growth will bring about a decrease (increase) in carbon emissions of the Low-Income countries by 0.11%, while a 1% increase (decrease) in economic growth will bring about an increase (decrease) in carbon emission by 0.13% in the long run.

**Table 7. Panel result for middle-upper-income countries (MUIC)**

	PMG (D.ICO <sub>2</sub> )	MG (D.ICO <sub>2</sub> )
ECT		
lgdp	−0.673	0.529 (1.49)
lecons	0.758*** (12.34)	0.569 (1.92)
SR		
ECT	0.351** (2.61)	0.479*** (6.33)
lgdp	−0.342** (−3.22)	−0.171 (−1.79)
D.lecons	0.548* (2.40)	0.540* (2.32)
Cons	−0.536 (−0.81)	−0.539 (−0.36)
Hausman	0.40	
Pesarn (CD) Test		
ICO <sub>2</sub>	−1.980	
lgdp	−2.134	
lecons	−1.476	

t statistics in parentheses ()

\* p < 0.05, \*\* p < 0.01, \*\*\* p < 0.001

The Hausman test rejects the null hypothesis that PMG is the appropriate model in favor of MG. The ECT is statically significant and indicates that long-run cointegration exists. The long-run income elasticity from the MG model is positive (0.54) while short-run income elasticity is negative (−0.29) and thus not consistent with the EKC hypothesis. This result show shows that in the Middle-Lower Income countries, there is a short-run decline in carbon emission by −0.29% as higher income from economic growth is derived. The declining carbon emissions changed its direction and began to increase as higher economic growth is attained.

The Hausman test for the Middle-Upper Income countries (MUIC) did not support the rejection of the null hypothesis that PMG is the most appropriate. The estimates from the PMG model shows a Negative but statistically insignificant long-run income elasticity (−0.67), and a negative, and statistically significant short-run income elasticity (−0.34). Although this result did not comply with the criteria provided by Narayan et al. (2016) for accepting the EKC hypothesis, the result shows that both the long-run and short-run income elasticity of carbon emission responds negatively to an increase in economic growth. This implies that as economic growth increases by 1%, carbon emissions will respectively reduce by 0.67% and 0.34% in the long-run and short-run, and vice versa.

The long-run income elasticity for LIC and MLIC is higher than the short-run income elasticity. The result suggests that higher carbon emissions are expected from the Lower-income countries (LIC) and Middle-Upper Income countries. The MUIC shows declining carbon emissions in both the short-run and long-run which indicates lesser carbon emissions and a cleaner environment despite higher economic growth. The result did not support the EKC hypothesis in over 65% of the 3 Panel in the study. This finding agrees with similar studies that concluded with evidence supporting the EKC hypothesis of an inverted-U relationship between carbon emissions and economic growth does not exist in Africa (see Saboori et al., 2012; Stern, 2004; Soytaş et al. 2007; Perman and Stern (2003); Kiviyiro & Arminen, 2014).

According to Dinda (2004), the evidence of the EKC hypothesis is found mostly in few air quality indicators but the evidence is mixed for other indicators. African countries like most other developing countries are still at the early stage of economic development (Tafirenyika, 2016); consequently, the level of environmental degradation will increase as economic growth increases.



Our result shows that the impact of economic growth (GDP) on carbon emission is positive, but not statistically significant in most cases. The relationship is positive because of the low level of economic growth in Africa, and partly because an increase in GDP or economic growth does not necessarily translate into higher income nor into a higher standard of living for the people (Ogujiuba and Omoju, 2013). For instance, despite the impressive economic growth in Africa in the last 10 years, the region still has a high level of poverty, unemployment, and low development index, and consequently, the observed improvement in economic growth will not reach to poor masses in form of increased income.,

The high dependence on natural resources and commodities is the principal driver of economic growth in Africa. Unlike China, India, the USA, and other emerging and developed countries with a high level of industrialization and manufacturing activities, the industrial sector in Africa remains underdeveloped. Consequently, the regions rely on the extraction of natural resources such as oil, coal, gold, copper, and other commodities for revenue through exportation. This problem is another reason for the failure of most African countries to reach a turning point in their emissions level (Xu and Lin, 2015). When there are high commodity prices, African countries experience higher economic growth but the reverse is the case when commodity prices decline. For instance, commodity prices fell by more than 50% from June 2014 to January 2015; oil prices fell below 40 US dollars per barrel; Copper, and Iron Ore price dropped by about 25% and 40% respectively. This has harmed economic growth and declined carbon emissions in some countries in Africa including Congo, Equatorial Guinea, South Africa, Angola, Cote d'Ivoire, Ethiopia, Mozambique, Rwanda, Tanzania, and Zambia among others. Political tension has also harmed the economic growth of other countries prone to high political instability like Southern Sudan, Burundi. Thus the higher carbon emission in this country is due to a recovery in a rebound in economic activities previously depressed by political instability.

In the developed countries, energy consumption is very high but the converse is the case in Africa due to its high reliance on the less energy-intensive Agricultural sector and the extraction of natural resources. South Africa is the largest emitter of GHGs in Africa and also one of the top global carbon emitters due to its heavy reliance on coal plants (Boden et al., 2009). South Africa accounts for more than half of the emissions in Africa. The Country is still constructing new coal plants for electricity generation. Consequently, the economic growth in South Africa is driven by large energy consumption from coal, which degrades the environment with carbon. Electricity shortage has negatively impacted economic growth in Africa. Low economic growth will imply lower carbon emissions. African countries are net exporters of primary products and are large consumers of fossil fuel despite the global efforts to combat climate change by mitigating carbon emissions. While Nigeria depends on revenue generated from the exportation of oil, South Africa relies on the extraction of Gold, and the consumption of Coal for power generation.

Although South Africa has submitted its Nationally Determined Contribution to the Kyoto protocol, its efforts so far are insufficient to meet its objective. However, future emissions from South Africa may reduce following the recent establishment of new carbon policies including carbon taxes (Alton et al., 2014; South Africa Department of National Treasury, 2010; Winkler & Marquard, 2011). This implies that taxes will be imposed on the future amount of carbon emissions. In Cameroon, the most tangible effort towards reaching the set National set commitment is putting measures to avoid deforestation and forest degradation through Cameroon through The Central African Forest Commission (French: Commission des Forêts d'Afrique Centrale, or COMIFAC).

Most African countries have submitted their Nationally Determined Contributions to join the global efforts to combat climate change by limiting carbon emissions to 1.5 degrees Celsius by 2030. The result of this study shows that carbon emission in Africa is largely driven by economic growth in the region. Economic growth on the other hand is driven by numerous economic activities in Agriculture, Industry, Manufacturing, transportation, etc. which are the major sources of carbon emission. Most African countries dependent on revenue generated from production and exportation of commodities like oil, metals such as gold diamond, copper, etc. these countries are

positively impacted by favorable commodity prices and negatively impacted by declining commodity prices. When commodity prices are high, they generate significant revenue and the economy grows, which brings about higher economic activities, increased supply of output, and this in turn adds to the release of carbon into the atmosphere. Also, low demand for gold, timber, and other commodities from China and other major trading partners of Africa, will decline economic growth in the region and lowers the level of carbon emission.

The short-run income elasticity is negative, implying a negative relationship between economic growth and carbon emissions. Between 1990 and 2014, a large amount of carbon emitted in Africa is absorbed by the rain forest located in Congo DR, Equatorial Guinea, and the Gambia with the largest carbon sink in Gabon, absorbing over 90% of Carbon emissions in Africa. However, this negative short-run impact is temporary due to the high level of deforestation and the exportation of wood-log to generate revenue and raise economic growth.

The International Energy Agency (IEA) reports show that Carbon emissions in Africa are largely driven by the Combustion of fossil fuels in Transportation, Agriculture, and Land Use. One effective carbon emission mitigation strategy is the imposition of a carbon tax on polluting households and firms; Deployment of renewable energy such as solar energy, wind energy, etc. can also play an important role in creating a turning point in countries identified with a positive long-run income elasticity. Recently, South Africa introduced the carbon tax system to ensure that polluters to the environment pay for degrading the environment (IEA, 2019). The carbon tax will add to the cost of business operations for the polluters and will reflect and raise the market price of the produced goods. The implication of this is a decrease in consumption demand and pollution. Countries that are consistent with the EKC hypothesis can further reduce or maintain a low level of carbon emissions by adopting similar policies.

The rise in income and the emergence of the middle class in Africa has made the continent a destination for the Automobile industry (Schiller & Karthi, 2016). Africa has become a dumping ground for used Cars with poor emission standards exported from countries with high environmental laws to Africa and other developing countries with lax environmental law, or weak implementation of already existing laws (Schiller & Karthi, 2016). These vehicles add a significant amount of carbon monoxide which is harmful to human health, with severe implications on the environment.

Globally, there are 1078 projects under the Kyoto protocol such as the Clean Development Mechanism (CDM) focused on addressing climate change; however, only 25 projects are domiciled in Africa as South Africa has 13, Morocco—4, Egypt —3, Tunisia —2, Uganda —1, Nigeria—1, and Tanzania—1 (Millock, 2013; Subbarao & Lloyd, 2011; Sutter & Parreño, 2007). Although South-Africa has the highest number of projects in the region, yet not sufficient as East Africa has only 2 projects and West Africa has only 1 project in Nigeria. Also, East Africa, Ethiopia, and Kenya among others have benefited from some special funds to address climate change, however, these funds are not sufficient in making a meaningful transforming impact on Africa (Millock, 2013).

The World Bank has embarked on carbon reduction projects in Madagascar, Kenya, Ethiopia, and Rwanda in the last 8 years (UN, 2011; United Nations Department of Economic and Social Affairs Population Division, 2019). There is also strong forest-related legislation aimed at combating deforestation in Cameroon, Kenya, Nigeria, and South Africa. This legislation will have a greater impact if adopted by all African countries especially the East African countries.<sup>2</sup> This confirms that the current climate change actions in Africa are not sufficient; hence, the need for more proactive measures to be taken.

Gabon had over 20 million ha of tree cover in 2010 (i.e. 76% of its land area) but has lost over 381,000 ha of trees between 2001 – 2017 with the highest loss in 2013 and 2014 (Amous, 1997; Nunez, 2019; Wood et al., 2004). Currently, Gabon has gained 3900 ha of trees and has become a net carbon sink. Deforestation should be discouraged as more trees should be planted throughout Africa. The advanced economies should continue to take a leadership role in the combat against climate change. More than 9% of carbon emissions in Africa can be absorbed by the rain forest in

Congo and Gabon per annum. Other African countries, especially those identified with higher carbon emissions with relation to economic growth, should discourage deforestation and restore its lost forest areas to naturally remove carbon dioxide already emitted into the atmosphere.

## 5. Conclusion

In this study, we examined if an inverted-U relationship exists between carbon emissions and economic growth in Africa. The income elasticity approach was applied by comparing the short-run and long-run income elasticity for 42 individual countries and the 3 Panels constructed according to income (low-income countries (LIC); middle-lower income countries (MLIC); and Middle-Upper income countries (MUIC)). The ARDL model was applied for the time-series analysis, while Mean Group (MG) and Pooled Mean Group (PMG) models were applied for the Panel study. We contribute to the existing literature by offering new evidence for testing the EKC hypothesis by means of an improved modeling technique in 42 African countries.

The result shows that the estimated income elasticity is not statistically significant in most cases. Over 79% of individual Countries in Africa are not consistent with the EKC hypothesis. Although these countries have low or statistically insignificant income elasticity, income elasticity is positive in most cases. A positive income elasticity implies an increase in carbon emissions over time in over 79% of the countries considered in the study.

An inverted-U relationship or the acceptance of the EKC hypothesis implies that carbon emissions have increased in the short run, but have reduced in the long-run as income increases. Alternatively, the acceptance of the EKC hypothesis implies that a turning point has been reached in carbon emissions as economic growth increases. A negative long-run carbon emission implies fewer carbon emissions as higher growth is attained.

The result from the study indicates that the EKC hypothesis is accepted in Madagascar, Congo DR., Togo, Cameroon, Comoros, Congo, Cote d'Ivoire, and Libya, representing 21% of the countries considered in the study. This result also means that a turning point has been reached in 21% of the LIC. The low, and statistically insignificant income elasticity observed in most African countries is consistent with the results from the African Energy Outlook, and EIA, 2018 reports that the contribution of Africa to Global Carbon emission is very low but positive.

The generated income elasticity results are not statistically significant in most cases as over 79% of countries in Africa are not consistent with the EKC hypothesis. This means that a turning point has not been reached in Benin, CAF, Chad, Congo, Equatorial Guinea, Ethiopia, Gambia, Liberia, Malawi, Mali, Niger, Rwanda, Senegal, Sierra-Leone, Tanzania, Togo, Uganda, and Zimbabwe. Cape-Verde, Ghana, Kenya, Lesotho, Mauritania, Sudan, Zambia, Comoros, Congo, and Mauritius. Botswana, Namibia, and South Africa. It is therefore important for these countries to put in place adequate policies and technology to create a turning point in carbon emissions as economic growth increases. Economic growth is very critical for Africa, however, our evidence has shown that the way Africa grows and meets its energy needs will have implications on the environment and this will increase the future risk of climate change.

There is a need for policies to ensure that all imported vehicles in the continent for private and commercial use meets a globally accepted or nationally determined threshold of emission. This will help the region to reduce carbon emissions induced by road transportation. Importantly, more car emissions testing facilities should be planted in Africa to determine the quality of vehicles, and passing the car emissions test should become a criterion for the issuance of a certificate of roadworthiness of vehicles within the region. Private, commercial vehicles and lorries that emit carbon above the approved threshold should be impounded and heavily fined. The imposition of an effective carbon tax system to improve the quality of cars used on African roads will not only be effective in minimizing carbon emissions from road transportation but will also generate additional revenue for the government.

Renewable energy development in Africa can help develop the region without polluting the environment by combustion of carbon-contained fuels. As a result, Africa will attain economic development without first polluting the environment and then cleaning up in a future time of higher income. African countries should be more committed to meeting their Nationally Determined Contributions (NDCs) and also attract more Carbon reduction projects to the region. Africa should leverage its relationship with China towards achieving increased renewable energy installation and energy security in the region. Chinese investments should be channeled into clean energy and clean technology to harness the rich renewable energy resources in the region. This will enable Africa to leap-frog into a green economy without polluting the environment.

This study was limited by the availability of data for some Africa countries such as Burundi and Libya among others not included in the study. Besides, the lack of actual data on the quality of the environment is a constraint to an adequate examination of the relationship between economic growth and carbon emissions. There is a need for further study and improvements in the modeling technique. Future studies may consider among several other variables that may influence the degradation of the environment such as Foreign Direct Investment (FDI), Trade Openness among others which are not included in this study.

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#### Notes

1. The EKC hypothesis is accepted if the short run income elasticity is greater than the long run income elasticity. Alternatively, if the short run income elasticity is positive and the long run income elasticity is negative then the EKC hypothesis is true. The hypothesis is rejected if otherwise.
2. Comoros, Egypt, Kenya, Madagascar, Malawi, Mauritius, Mozambique, Rwanda, Somalia, South Sudan, Tanzania, Uganda, Zambia, and Zimbabwe

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