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Re-visiting the renewable energy-economic growth nexus: Empirical evidence from African OPEC countries

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Empirical evidence from African OPEC countries

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Abstract

Purpose – This paper aims to investigate the dynamic relationship between renewable energy and economic growth in African OPEC member countries (Angola, Algeria and Nigeria).

Design/methodology/approach – The fully modified ordinary least squares technique for heterogeneous cointegrated panels (Pedroni, 2000) is used to estimate the parameters of the model.

Findings – The study revealed four main findings. First, there is a bidirectional causality between renewable energy and economic growth in the long and the short run. Second, a bidirectional causality exists between non-renewable energy and economic growth in the short and long run. Third, a bidirectional causality exists between CO_2 emissions and economic growth. Fourth, a unidirectional causality was also found between CO_2 emissions and non-renewable energy consumption with the direction of causality stemming from the consumption of non-renewable energy to CO_2 emissions.

Practical implications – Because renewable consumption enhances growth, OPEC-member Africa countries should encourage investment in modern renewable sources that has high conversion efficiency such as solar, wind and hydro to strengthen their response to mitigating the impacts of climate change.

Originality/value – This study applies multiple methods to analyze the relationship between renewable energy and economic growth in African OPEC countries.

Keywords Africa, Energy sector, Renewable energies, Granger causality, Energy demand, Co-integration, Fully modified ordinary least squares, OPEC countries

Paper type Research paper

1. Introduction

The intergovernmental panel on climate change third assessment report (IPCC, 2001) and the United Nations (UN) facts sheet on climate change (UN, 2006) declare African economies as the most vulnerable and at risk to the impacts of climate change. These impacts are estimated to be driven by increasing energy demand and changing temperatures across African regions, which have the potential to ultimately threaten sustainable development (UN, 2006). Since the establishment of the United Nations Framework Convention on

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Climate Change (UNFCCC) in 1994, there have been various mechanisms, actions and strategies to support developing countries, in particular Africa countries, in mitigating and adapting to climate change. The Kyoto protocol enforced in 2005 sets a legal obligation of reduction in emission of developed countries at 5.2 per cent from 1990 levels for the period 2008-2012. Whilst developing countries faced no restriction on emission, however, they were required to adopt policies and mechanisms that promote greener growth (UNFCCC, 1998). In addition to this, the Kyoto protocol also made provision for developing countries to receive financial and technological support from developed countries to counter the impacts of climate change (UN).

Subsequently, in December 2015, after more than two decades of negotiations, the annual Conference of Parties COP21, also known as the 2015 Paris Climate Conference, saw a unified international political response to global climate change challenges. The negotiations aimed at achieving a legally binding and universal agreement on climate change, with the goal of keeping global warming below 2°C. As at April 22, 2016 (Earth Day), about 174 countries have signed this agreement, including more than 20 African countries.

The UNFCCC negotiations and agreement of Kyoto and Paris are crucial for Africa, as these provide incentives and support to counter the impacts of climate change. However, there are considerable barriers that stand in the way of mitigating climate change in Africa. For instance, African economies (e.g. Angola, Algeria and Nigeria, etc.) are heavily dependent on energy revenues (such as oil, natural gas) in supporting economic growth. According to the World Bank (2015), oil contributes more than 45 per cent of gross domestic product (GDP) and about 70 per cent of export earnings in oil producing and exporting Africa countries. Since mid-2014, oil prices have dropped drastically, declining to less than \$55 per barrel (Brent). The falling oil prices hits African oil exporting countries the largest, given that global oil prices need to be above \$100 per barrel to balance economic budgets and sufficiently support economic growth (IEA, 2016). Additionally, Africa suffers from lack of a diversified economic and energy base despite the abundance of renewable energy sources. Currently, more than 70 per cent of Africa's total energy consumption comes from renewable sources, but almost all from traditional uses of biomass, leaving a huge gap to include other modern sources (IEA, 2015). Essentially, modern renewable energy sources have not been effectively harnessed to potentially support a clean development mechanism and sustainable energy future across Africa. As a result, African economies remain even more vulnerable to impacts of climate change due to their reliance on fossil fuels and weak integration of renewable energy sources in energy mix. This trend is predicted to worsen, as the amount of untapped fossil fuel reserves has the potential to increase CO_2 beyond any scenario currently estimated (Knopf *et al.*, 2010).

Furthermore, there are significant questions that remain unanswered in the context of production and consumption of cleaner and sustainable sources of energy/fuel in Africa. One of these renewable energy sources can sustain economic growth, given increasing energy demand and population size of most African countries. These indications call for a re-evaluation of policy, initiatives and incentive to responding to climate change issues in Africa. In this study, the fully modified ordinary least squares (FMOLS) technique for heterogeneous cointegrated panels (Pedroni, 2001) is used to revisit the relationship between renewable energy, non-renewable, carbon emission and economic growth in OPEC African member countries. The objective of this study is to provide evidence of the nature of the relationship between economic growth, environmental impacts and cleaner and sustainable energy sources to support policy and response to climate change impacts.

The remainder of the paper is structured as follows. In Section 2, we briefly review literature that have examined the relationship between energy consumption, carbon emissions and economic growth. Section 3 details the data and the methods used to investigate the links between renewable energy, carbon emissions and economic growth. The empirical results are discussed and presented in Section 4. The final section gives a summary and conclusion of the study.

2. Literature

The empirical literature on the relationship between energy consumption, economic growth and carbon emissions is a well-studied area in energy economic literature and can be grouped into three:

(1) the nexus of energy consumption and economic growth;
(2) the nexus of economic growth and carbon emissions; and
(3) the nexus of energy consumption, carbon emissions and economic growth.

2.1 Economic growth and energy consumption nexus

The study of the relationship between energy consumption and economic growth has a long history, dating back to the pioneer study by Kraft and Kraft (1978) who found unidirectional causality between energy consumption and economic growth for USA for 1947-1974. Subsequently, studies examine the nature or direction of causality between energy consumption (non-renewables and or renewables) and economic growth based on of four possible theoretical hypotheses. These are growth hypothesis, conversation hypothesis, feedback hypothesis and neutrality hypothesis (Ozturk, 2010; Payne, 2009). First, growth hypothesis infers a one-directional causality running from energy consumption to economic growth. This implies that energy consumption stimulates economic growth; hence, policy should focus on the expansion of the energy mix to harness a stronger economic contribution from diverse energy sources (Akinlo, 2009; Mahadevan and Asafu-Adjaye, 2007; Odhiambo, 2010; Payne, 2009; Squalli, 2007; Wolde-Rufael, 2005a, 2005b). Second, conversation hypothesis asserts causality running from economic growth to energy consumption. This implies that as the economy grows, there will be increase energy consumption, as such policies should aim at increasing energy efficiency (Chang *et al.*, 2009; Mehrara, 2007; Zachariadis, 2007). Third, if causality runs in both directions between energy consumption and economic growth, then this suggests a feedback hypothesis. In this case, energy and economic policies should be explored simultaneously due to complementary nature of energy consumption and economic growth (Apergis and Payne, 2010; Ebohon, 1996; Sadorsky, 2009). Lastly, neutrality hypothesis suggests no causality between energy consumption and economic growth. Therefore, policy need to focus on other factors (e.g. human capital and investment in infrastructure, etc.) to facilitate energy consumption and economic growth (Bowden and Payne, 2010; Menegaki, 2011; Yildirim and Aslan, 2012). Ozturk (2010) and Payne (2009) provide a comprehensive of studies that examine the relationship between energy consumption and economic.

2.2 Economic growth and environmental impacts nexus

The relationships between economic growth and environmental impacts is another widely studied area in energy economics literature. Studies in this strand use the environmental Kuznets curve (EKC) hypothesis to examine the relationship between energy consumption and economic growth. EKC is derived from Kuznets (1955) hypothesis; it postulates that at early stages of economic growth, environmental impacts increase as economic growth increases, up until a threshold is reached, after which environmental impacts begin to decline as economic growth increases. This trend is interpreted as an inverted U-shaped relationship between economic growth and environmental impacts. EKC is widely used a tool for describing the relationship between measured levels of environmental quality indicators such as CO_2, SO_2, etc. and economic growth (Apergis and Ozturk, 2015). Some examples of studies that found evidence to support EKC hypothesis include Hettige *et al.* (1992), Cropper and Griffiths (1994), Selden and Song (1994), Grossman and Krueger (1995), Heil and Selden (1999), Martnez-Zarzoso and Bengochea-Morancho (2004) and Dinda and Coondoo (2006). However, several authors have found results that reject the hypothesis of higher economic growth leading to decline in environmental impacts such as Akbostancı *et al.* (2009), Holtz-Eakin and Selden (1995), Ozturk and Acaravci (2010) and Shafik (1994). For a further survey of literature using EKC hypothesis, refer to Coondoo and Dinda (2002), Dinda (2004) and Stern (2004).

2.3 Energy consumption, environmental impacts and economic growth nexus

More recent attention has focused on investigating the relationship between energy consumption, environmental impacts and economic growth. For example, Ang (2007) use vector error correction model (VECM) technique to examine the causal relationship between energy consumption, emissions and economic growth for France for period 1960-2000.The results provide evidence of causality from economic growth to energy consumption and carbon emission in the long run, whereas energy consumption causes economic growth in the short run. Apergis and Payne (2009) examines the relationship between energy-CO_2-economic growth for six Central American countries from 1971 to 2004 using a panel VECM approach. The study provides evidence of unidirectional causality from energy consumption to economic growth and from energy consumption to carbon emissions, whereas a bidirectional relationship was found between economic growth and energy consumption. Pao and Tsai (2011) use cointegration and granger causality VECM to estimate the relationship between energy-environment-economic growth for countries such as Brazil, Russia, India and China. The results suggest a bidirectional relationship between CO_2 and economic growth and energy consumption and CO_2.

Turning attention to studies that have considered the relationship between energy consumption, environmental impacts and economic growth for emerging and developing African countries, the evidence/results are limited. Menyah and Wolde-Rufael (2010) apply granger causality test and found unidirectional causality running from CO_2 to economic growth, energy consumption to economic growth and energy consumption to CO_2 in South Africa for the period 1965-2006. In an investigation into the relationship between energy consumption and economic growth in MENA countries, Al-mulali (2011) found bidirectional causality relationship between energy consumption, CO_2 and economic growth using autoregressive distributed lag model (ARDL) approach from 1980 to 2009. Arouri *et al.* (2012), on the other hand, found unidirectional causality running from economic growth to CO_2 in MENA countries using Bootstrap panel and cointegration approach. Kivyiro and Arminen (2014) analyze the causal relationship between energy consumption, CO_2 and economic growth in six Sub Saharan African countries from 1971 to 2009. Their findings suggest that economic growth granger causes environmental impacts, and energy consumption granger causes CO_2.

Recent studies by Asongu *et al.* (2016) test the relationship between energy, CO_2 and economic growth for 24 African countries using a panel ARDL approach. The result suggests that in the short run, there is no causality between economic growth and energy consumption. However, in the long-run relationship, causality runs from economic growth to CO_2 and energy consumption. Esso and Keho (2016) applied cointegration and the granger causality test to examine the long-run and causal relationships between energy consumption, CO_2 emissions and economic growth of 12 Sub-Sahara African countries. Empirical findings show evidence of unidirectional causality running from economic growth to CO_2 emissions in Benin, Democratic Republic of Congo, Ghana, Nigeria and Senegal. However, CO_2 granger causes economic growth for Gabon, Nigeria and Togo.

A comprehensive survey of the three main strands of the relationship between energy consumption environmental impacts and economic growth is given by Ozturk (2010), Payne (2010), Omri (2014), Tiba and Omri (2016) and Adewuyi and Awodumi (2016). In reviewing the literature, a general observation is that most studies focus on developed countries and very limited literature on emerging and developing countries. However, there is a consensus among previous studies that suggest that these country groups suffer from major energy deficiencies (e.g. energy shortages, poor energy grid/network and poor access to energy) and fluctuating levels of economic growth (Ebohon, 1996; Amaewhule, 2002; Wolde-Rufael, 2005a, 2005b; Akinlo, 2008; Ackah *et al.*, 2016). Moreover, most of these countries (e.g. Algeria, Angola and Nigeria) are heavy dependent on energy revenues (e.g. oil) to support economic growth although there are other factors that determine energy consumption across these countries (Ackah and Kizys, 2015). Furthermore, several factors such as population size, poverty, socio-political and terrorism-related upheavals can potentially create instability and distort economic growth in these countries (Carmignani and Kler, 2016) (Tables I and II).

In this paper, we contribute to the literature by investigating the dynamic relationship between renewable energy and economic growth in oil-producing and exporting African OPEC countries (Angola, Algeria and Nigeria). The paper examines if the abundance of non-renewable energy sources such as oil among other sources affects direction of causality between energy consumption, carbon emissions and economic growth. In addition, the study investigates how the consumption of renewable energy sources like solar, hydro and wind influences economic growth and carbon emissions.

3. Method

3.1 Data

The study examined the dynamic causality between energy consumption (renewable and non-renewable), CO_2 emissions and economic growth in OPEC member African countries (Nigeria, Angola and Algeria). The study used annual data spanning from 1971 to 2011. Data on renewable energy, non-renewable energy and CO_2 emissions were sourced from International Energy Agency. Data on GDP was collected for each country from the World Bank data bank. GDP per capita (Y) is expressed in real 2005 US Dollars. Renewable (REN) and non-renewable energy consumptions are measured in kilogram per capita of oil equivalent. CO_2 emissions (C) are expressed in tons per capita.

Most macroeconomic time series according to Asteriou and Hall (2007) are trended and, as a result, happen to be non-stationary on several occasions. Thus, it is very imperative to conduct pre-tests such as unit root and cointegration to circumvent the problem of spurious regression. These specific tests are described in the sections that follows.

3.2 Unit root test

To ascertain the order of integration of the variables, the panel unit root rest was conducted using three main tests. These are the Levin, Lin and Chu (LLC), Im, Pesaran and Shin (IPS)

Table I.
Summary of literature on the relationship between energy consumption and economic growth

Author(s)	Country/countries	Years	Method	Conclusion
Akinlo (2009)	Nigeria	1980-2006	Cointegration and VECM	Growth hypothesis
Al-mulali (2011)	MENA	1980-2009	ARDL	Feedback hypothesis
Ang (2007)	France	1960-2000	VECM	Conversation hypothesis
Apergis and Ozturk (2015)	14 Asian countries	1990-2011	Multivariate framework	Evidence of EKC
Apergis and Payne (2009)	Central America	1971-2004	Panel cointegration technique	Conversation hypothesis
Arouri *et al.* (2012)	12 MENA	1981-2005	Bootstrap panel cointegration	Evidence of EKC
Asongu et al. (2016)	24 African	1971-2011	ARDL	Conservation hypothesis
Bowden and Payne (2010)	US	1949-2006	Toda-Yamanto	Neutrality hypothesis
Chang *et al.* (2009)	G7 countries	1997-2006	Threshold estimation	Conservation hypothesis
Ebohon (1996)	Nigeria and Tanzania	1960-1994	Granger causality test	Feedback hypothesis
Esso and Keho (2016)	12 SSA countries	1971-2010	Granger causality test	All four hypothesis
Jumbo (2004)	Malawi	1970-1999	Granger causality test	Evidence of EKC
Kivyiro and Arminen (2014)	6 SSA countries	1971-2011	Granger causality test	Conversation hypothesis
Kraft and Kraft (1978)	US	1947-1974	Toda-Yamamto	Growth hypothesis
Mehrara (2007)	11 oil exporting countries	1971-2002	Toda Yamamoto	Growth hypothesis
Menegaki (2011)	27 European countries	1997-2007	Cointegration and VECM	Growth hypothesis
Menyah and Wolde-Rufael (2010)	South Africa	1965-2006	Granger causality test	Growth hypothesis
Odhiambo (2010)	South Africa	1971-2006	simultaneous-equations	feedback hypothesis
Omri (2014)	14 MENA	1990-2011	Toda-Yamamto	All four hypothesis
Pao and Tsai (2011)	BRIC countries	1971-2011	Bound test approach	Conversation hypothesis
Payne (2009)	US	1946-2006	Panel cointegration technique	Conversation hypothesis
Sadorsky (2009)	18 emerging countries	1994–2003	Random effect model	Neutrality
Solarin and Shabhaz (2013)	Angola	1971-2009	Ordinary least squares (OLS)	Feedback hypothesis
Squalli (2007)	11 OPEC countries	1980-2003	ARDL,Tado-Yamamto	Conversation hypothesis
Tamba *et al.* (2012)	Cameroon	1975-2008	Bootstrap causality test	Neutrality hypothesis
Tiwari *et al.* (2015)	12 SSA countries	1971-2011	Conintegration	Conversation hypothesis
Wolde-Rufael (2005a, 2005b)	19 African countries	1971-2001	Error correction	Feedback hypothesis
Yildirim and Aslan (2012)	17 OECD countries	1970-2009	Error correction	Feedback hypothesis
Zachariadis (2007)	G7	1960-2004	ARDL	Feedback hypothesis

Table II. Summary of causal studies in Africa

Author(s)	Country/countries	Period	Method	Conclusion
Akinlo (2009)	Nigeria	1980-2006	Cointegration	Growth hypothesis
Asongu *et al.* (2016)	24 African	1971-2011	ARDL	Conservation hypothesis
Ebohon (1996)	Nigeria &Tanzania	1960-1994	Granger causality	Feedback hypothesis
Esso and Keho (2016)	12 SSA countries	1971-2010	Granger causality	All four hypothesis
Jumbo (2004)	Malawi	1970-1999	Granger causality	Evidence of EKC
Kivyiro and Arminen (2014)	6 SSA countries	1971-2006	Granger causality	Conversation hypothesis
Menyah and Wolde-Rufael (2010)	South Africa	1965-2006	Granger causality	Growth hypothesis
Odhiambo (2010)	Tanzania	1971-2006	ARDL	Feedback hypothesis
Solarin and Shabhaz (2013)	Angola	1971-2009	OLS	Feedback hypothesis
Tamba *et al.* (2012)	Cameroon	1975-2008	Bootstrap causality	Neutrality hypothesis
Tiwari *et al.* (2015)	12 SSA countries	1971-2011	Conintegration	Conversation hypothesis
Wolde-Rufael (2005a, 2005b)	19 African countries	1971-2001	Error correction	Feedback hypothesis

and Phillips and Perron (PP) tests. Among these tests, LLC is based on the assumption of a common unit root process that the autocorrelation coefficients of the tested variables across cross-sections are identical. However, the IPS and PP rely on the individual unit root process assumption that the autocorrelation coefficients vary across cross-sections. In the LLC, IPS and PP tests, cross-sectional means are subtracted to minimize problems arising from cross-sectional dependence. The Akaike information criterion was used to determine the country-specific lag length for the ADF regressions, with a maximum lag of three regarding the LLC and the IPS tests. Further, the Bartlett kernel was used to estimate the long-run variance in the LLC test, with the maximum lags determined by the Newey–West bandwidth selection algorithm.

3.3 Panel test for cointegration

The study makes use of Kao test for cointegration to test for the existence of long-run relationship among the variables because it was established that the variables are integrated of order one. Kao (1999) describes two tests under the null hypothesis of no cointegration for panel data. One is a Dickey–Fuller type test and another is an Augmented Dickey–Fuller type test:

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

where:

$$y_{it} = y_{it-1} + \mu_{it}$$

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

α_i are the fixed effect varying across the cross-section observations, β is the slope parameter, y_{it} and x_{it} are independent random walks for all i. The residual series e_{it} should be I(1) series. The Dickey–Fuller test can be applied to the estimated residual using:

$$\hat{e}_{it} = \rho \hat{e}_{it-1} + v_{it}$$

The null and alternative hypothesis is, therefore, written as *H0:* $\rho = 1$.

H0: $\rho < 1$.

3.4 Long-run model

The long-run relationship between CO_2 emissions, renewable and non-renewable energy consumption and economic growth is specified as:

$$\mathrm{In}\, C_{\mathrm{it}} = \beta_0 + \beta_1 \,\mathrm{In}\, NRENC_{it} + \beta_2 \,\mathrm{In}\; RENC + \beta_3 \,\mathrm{InIn}\, Y_{it} + \mu_{it} \tag{2}$$

The FMOLS technique for heterogeneous cointegrated panels is estimated (Pedroni, 2001) is used to estimate the parameters of the model. FMOLS can be used to estimate the asymptotically efficient consistent in panel series, where the method takes in to consideration non-exogeneity, serial correlation and heterogeneity (Pedroni, 1996). The parameters estimated represents the long-run elasticities because the model is specified in log form.

3.5 Granger causality test

The dynamic causality between renewable energy consumption, non-renewable energy consumption, CO_2 and economic growth were estimated using panel VECM based on the two-step Engle and Granger (1987) procedure. This was done by first estimating the long-run relationship and saving the residuals. The lagged residuals then serve as the error correction term for the VECM as follows:

$$\Delta Y_{it} = \psi_{1i} + \sum_{k=1}^{n} \psi_{11ik}\Delta Y_{it-k} + \sum_{k=1}^{n} \psi_{12ik}\Delta NREC_{it-k} + \sum_{k=1}^{n} \psi_{13ik}\Delta REC_{it-k} + \sum_{k=1}^{n} \psi_{14ik}\Delta C_{it-k} + \eta_{1it}ECT_{it-1} + \mu_{1it} \tag{3}$$

$$\Delta NREC_{it} = \psi_{2i} + \sum_{k=1}^{n} \psi_{21ik}\Delta NREC_{it-k} + \sum_{k=1}^{n} \psi_{22ik}\Delta Y_{it-k} + \sum_{k=1}^{n} \psi_{23ik}\Delta REC_{it-k} + \sum_{k=1}^{n} \psi_{24ik}\Delta C_{it-k} + \eta_{2it}ECT_{it-1} + \mu_{2it} \tag{4}$$

$$\Delta REC_{it} = \psi_{3i} + \sum_{k=1}^{n} \psi_{31ik}\Delta REC_{it-k} + \sum_{k=1}^{n} \psi_{32ik}\Delta Y_{it-k} + \sum_{k=1}^{n} \psi_{33ik}\Delta NREC_{it-k} + \sum_{k=1}^{n} \psi_{34ik}\Delta C_{it-k} + \eta_{3it}ECT_{it-1} + \mu_{3it} \tag{5}$$

$$\Delta C_{it} = \psi_{4i} + \sum_{k=1}^{n} \psi_{41ik}\Delta C_{it-k} + \sum_{k=1}^{n} \psi_{42ik}\Delta Y_{it-k} + \sum_{k=1}^{n} \psi_{43ik}\Delta NREC_{it-k} + \sum_{k=1}^{n} \psi_{44ik}\Delta REC_{it-k} + \eta_{4it}ECT_{it-1} + \mu_{4it} \tag{6}$$

Where Δ is the first-difference operator; k (k = 1,…, n) is the optimal lag length selected based on Schwarz Information Criterion (SIC), μ the serially uncorrelated error term and $ECT_{it\text{-}1}$ is the estimated lagged error correction term derived from the long-run cointegrating relationship. The causality in the short run is determined by the statistical significance of the partial *F*-statistics connected with the right-hand variables On the other hand, the causal relation in the long run is revealed by the statistical significance of the *t*-statistic of the respective error correction terms.

4. Results and discussions

Table III summarizes descriptive statistics of the variables used in our study. All variables are expressed in real per capita terms. GDP per capita (Y) is expressed in real 2005 US Dollars (USD). Renewable (REN) and non-renewable energy consumptions are measured in kilogram per capita of oil equivalent. CO_2 emissions (C) are expressed in tons per capita. Over the sample period and across countries, the mean of real GDP is 1,465 real USD per capita. Real GDP per capita varies between 153 and 5,482.432 USD per capita. The degree of

Table III.
Summary statistics of variables

Variables	Observation	Mean	Median	Maximum	Minimum	SD	Skew	Kurt	JB	Probability
Y	112	1,464.8	923.90	5,482.43	1,53.076	1,333.63	1.361	4.1581	40.841	0.000
C	123	0.260	0.089	1.103	0.022	0.317	1.365	3.417	39.089	0.000
NREN	126	0.219	0.118	0.794	0.031	0.185	1.330	3.640	39.337	0.000
REN	126	0.286	0.305	0.588	0.0003	0.222	0.211	1.495	2.832	0.0016

variability is also witnessed by the standard deviation. Real GDP deviates from its mean on average by 1,333.625 USD per capita. The data for this variable are positively skewed (with the value of the skewness standing at 1.361) and leptokurtic (with the value of kurtosis of 4.1581). The latter suggests that the distribution of real GDP across countries and over time features heavy tails, whereas the former suggests that positive deviations from the mean tend to be more dispersed than negative deviations.

Overall, positive skewness and kurtosis collectively result in a non-normal distribution, as indicated by the Jarque–Bera test statistic and the associated probability value. CO_2 emissions per capita are on average are estimated at 0.260 *t* per capita across countries and over time. The data vary between 0.022 and 1.103 *t* per capita. The range of variation causes the data to deviate from the sample mean by 0.317 *t* per capita. Again, we observe positive skewness (with the asymmetry coefficient standing at 1.365) and kurtosis (with the value of kurtosis standing at 3.417). Subsequently, the Jarque–Bera test statistic provides strong evidence of non-normality in the data. The consumption of non-renewable energy averages 0.219 kg of oil equivalent per capita. The values range between 0.031 and 0.794 kg of oil equivalent per capita with a standard deviation estimated at 0. 185 kg of oil equivalent per capita. It is positively skewed (1.330) and leptokurtic (3.640). Therefore, the Jarque–Bera test statistic unambiguously rejects the null of normality in the data. Lastly, the consumption of renewable energy on the other hand averages 0.286 kg of oil equivalent per capita. The values range from 0.0003 and 0.588 kg per capita, with the standard deviation estimated at 0.222 kg per capita. It is positively skewed (0.21) and leptokurtic (1.495). The Jarque–Bera test statistic, therefore, unambiguously rejects the null of normality in the data.

The Pearson coefficients of unconditional correlation among the variables under investigation are reported in Table IV. The results show that non-renewable energy consumption is highly negatively correlated (−0.8095) with the consumption of renewable energy. CO_2 emissions per capita is also negatively correlated (−0.7622) with renewable energy consumption per capita. GDP per capita was found to be positively correlated (0.5416) with per capita renewable energy consumption. Non-renewable energy consumption per capita was also found to be correlated positively with CO_2 emissions per capita (0.9793) and GDP per capita (0.7288). GDP per capita also revealed a high positive correlation with capital per capita (0.6405).

Each unit root test is summarized in two columns. The first column assumes the presence of a constant in the test equation, whereas the second column assumes the presence of both a constant and a linear trend in the test equation. The null hypothesis assumes the presence of a unit root in the variable. If the null is rejected then the variable is deemed to be stationary. In general, the results of the three unit root tests show that all the variables under consideration are not stationary and, hence, possess unit roots. The LLC and IPS tests show that all the variables are not stationary. The PP test with no trend indicates that renewable energy consumption per capita is stationary at the 10 per cent level All the other variables are not stationary according to the PP test. The results, therefore, show that the

Variables	REN	NREN	C	Y
REN	1			
NREN	−0.8095	1		
C	−0.7622	0.9793	1	
Y	0.5416	0.7288	0.6405	1

Table IV.
Pearson correlation matrix

variables contain unit roots. The study further first differenced the variables and applied the three unit roots again. The results are reported in the second panel of Table V. It can be seen that all the three tests provide an overwhelming evidence of stationarity when the variables are first difference. It is, therefore, concluded that all the variables are integrated or order one, i.e. I (1).

To avoid the problem of spurious regression, we tested if the variables are cointegrated, that is, to ascertain if the variables share a common stochastic trend. To this end, we used the Kao test for cointegration. The null hypothesis of no cointegration is rejected. We, thus, conclude that the variables share a common stochastic trend (Table VI).

We estimated the long-run relationship in log levels using the panel FMOLS. Because the equations were estimated in log levels, the coefficient represents the long-run elasticities. A 1 per cent increase in non-renewable energy consumption per capita decreases CO_2 emissions per capita by 1.20 per cent, whereas a 1 per cent increase in per capita renewable energy increases CO_2 emissions per capita by 0.24 per cent. The result also indicates that a 1 per cent increase in GDP per capita increases CO_2 emissions per capita by 0.83 per cent. The result implies that non-renewable energy consumption in these countries contribute more to CO_2 emissions than GDP per capita in the long run (Table VII).

Table V. Results of the panel unit root tests

Variables	LLC Cons	Trend	IPS Cons	Trend	PP Cons	Trend
level						
REN	−0.1941	0.8004	1.6896	3.2029	12.0675*	0.7871
NREN	1.1403	0.1953	2.2855	1.1728	3.6969	1.9502
C	0.7734	0.1161	2.7090	1.4295	1.8246	3.8623
Y	−0.2305	−1.5310	−0.2947	−1.0216	4.4418	2.6929
First difference						
REN	−2.6514***	−4.2216***	−3.061***	−5.0284***	−3.9183***	−5.1287***
NREN	−9.7251***	−8.7085***	−9.697***	−9.8528***	−9.517***	−9.2287***
C	−10.285***	−9.0364***	−10.740***	−10.955***	−11.176***	−10.966***
Y	−3.9751***	−3.1331***	−3.8858***	−3.1372***	−8.5793***	−8.0301***

Note: *, *** shows rejection of the null hypothesis at the 10% and 1% significance level, respectively

Table VI. Results of test for cointegration

Method	Test	Statistic	Probability
Kao (1999)	ADF	−4.013812	0.0000

Table VII. FMOLS estimates of the long-run relationship

Variables	Coefficient	Standard error	*T* statistic
NRENC	1.204***	0.109	10.956
RENC	−0.239***	0.0219	10.906
Y	0.833***	0.0922	11.960

Note: *** means significant at the 1% significance level

Next, we estimated the dynamic causality between renewable energy consumption, non-renewable energy consumption, CO_2 and economic growth in a panel VECM based on the two-step Engle and Granger (1987) procedure. A maximum lag length was selected based on SIC. The study revealed a bidirectional causality between renewable energy and economic growth in the long and short run, a bidirectional causality between non-renewable energy and economic growth in the short and long run, as well as a bidirectional causality between CO_2 emissions and economic growth. This result is consistent with the findings of Apergis and Payne (2010).

A unidirectional causality was also found between CO_2 emissions and non-renewable energy consumption with the direction of causality stemming from the consumption of non-renewable energy to CO_2 emissions (Table VIII).

5. Conclusion

This paper investigates the dynamic relationship between renewable energy and economic growth in OPEC member oil-producing African countries. The FMOLS technique for heterogeneous cointegrated panels is estimated (Pedroni, 2001) and used to estimate the parameters of the model. The study revealed a bidirectional causality between renewable energy and economic growth in the long and short run. There is also evidence of bidirectional causality between non-renewable energy and economic growth in the short and long run. A bidirectional causality was also found between CO_2 emissions and economic growth. Additionally, there is a unidirectional causality between CO_2 emissions and non-renewable energy consumption with the direction of causality stemming from the consumption of non-renewable energy to CO_2 emissions.

These results are consistent with the fact that for many years, the economic structure of the African OPEC countries studied has first and foremost focused on the petroleum industry, as this is their primary source of economic growth and energy/fuel. Their heavy reliance on oil revenues has prevented these economies from devoting both capital and substantial investment to the development of less carbon-intensive energy sources. Hence, many of the OPEC economies have failed to effectively mitigate the current impacts of climate change and make have weak response to future climate change impacts. Therefore, we recommend that the energy mix in these countries should integrate more renewable energy sources such as solar, wind and hydro because it has the potential to stimulate economic growth. Moreover, because of bidirectional relationship between non-renewable energy consumption and economic growth, policy should target higher investments in renewable energy sources to minimize the consumption of non-renewable energy and to support reduction in carbon emissions. Again, to curb carbon emissions, effort should also be directed an energy efficiency education and effective demand side management to reduce non-renewable energy consumption.

	Direction of causality				
	Short run				Long run
Dependent variable	ΔY	ΔREN	ΔNREN	ΔC	ECM_{t-1}
ΔY	–	22.09***	180.05***	97.70***	−5.69***
ΔREN	60.04***	–	14.5		−3.26***
ΔNREN	160.27***	2.97	–	4.10	−8.99***
ΔC	97.71***	2.25	35.6***	–	−11.48***

Note: *** means significant at the 1% significance level

Table VIII. Results of the panel causality test

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