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RESEARCH ARTICLE

Environmental aspect of energy transition and urbanization in the OPEC member states

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Abstract

More than any other nations, the crude oil–exporting countries and especially the Organization of the Petroleum Exporting Countries (OPEC) are likely to experience a more difficult energy-transitioning regime because of the economies' high dependence on crude oil revenue. By using the Pooled Mean Group (PMG) Autoregressive Distributed Lag Models (ARDL) approach, this study examines the impact of the energy transition albeit from conventional to clean energy on carbon emissions in 11 members of the OPEC. While engaging the aforementioned objective, the study further examined the validity of the Environmental Kuznets Curve (EKC) hypothesis amidst urbanization drive among the countries. The result from the long-run estimates shows that fossil fuel utilization exerts a positively significant on environmental degradation in the selected countries, while the observed negative impact of renewable energy utilization and urbanization on carbon dioxide emission (CO_2) was insignificant in both the short and long run. The implication is that the current energy transition policy of the OPEC states is not sufficient at driving the states' environmental sustainability agenda. In addition, the EKC was not valid in the panel of the OPEC countries for the period of study, rather a U-shaped relation is established between income level and environmental degradation. Thus, this further posits that there is a setback in the push for environmental quality especially when there is an improvement in economic well-being through income growth in the OPEC states. Moreover, findings from the panel causality test show that there is no causality running from both fossil fuel and renewable energy consumption to the income level among the countries. On the contrary, a uni-directional causality was obtained from income level to renewable energy consumption, while urbanization strongly Granger causes fossil fuel use and CO_2 emissions among the countries. As such, it is concluded that energy conservation policies can be implemented to reduce extreme dependence on fossil fuel use with little or no detrimental consequences, thus positioning the countries for economic prosperity in a sustainable environment.

Keywords Environmental sustainability · Renewable energy · Non-renewable energy · EKC · OPEC · PMG/ARDL

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Introduction

Environmental degradation and its attendant effects constitute a major part of the challenges posing significant threats on not only the existence of life but also on the quality of life on our planet as more evidence is being revealed in recent times (Hopke 2009; Perera 2017; Hill 2020). Human activities that are often premised on the realization of economic growth agenda have been closely linked to the growing trends in the global environmental carbon emissions over the years especially in the periods of industrial revolutions as experienced in many nations when energy demand was mainly met by the burning of coal in powering industrial plants (Clark and Jacks

2007; Fernihough and O'Rourke 2014; Finkelman and Tian 2018).

Although coal dominated the primary source of energy in the 1780s, however, the global energy market saw an era of change from huge dependence on coal to oil and gas with the aid of refining technology as more nations discover fossil fuels deposits in commercial quantity, thus making oil and gas to account for over 50% of global energy mix since mid-1960s (Hughes and Rudolph 2011; Zou et al. 2016). Thus, the global attention in the energy markets began to gradually shift to the use of fossil fuels, and many countries that are endowed with vast deposit became enriched from factors like increased foreign direct investments through the energy industry, larger volume of trade, and occasional windfalls in periods of booms and fluctuations (Moshiri 2015; Smith 2019). Following this development, the share of global greenhouse gas (GHG) emissions from the burning of fossil fuels have grown with gases like carbon dioxide (CO_2) and methane (CH_4) accounting for a substantial amount of the total global greenhouse effect in recent times (Ağbulut et al. 2019).

Since its inception in 1960, the Organization of Petroleum Exporting Countries (OPEC) has been one of the world's biggest energy cartels with 7 African countries out of the total of 13 member countries as of the last quarter of 2020. Member countries include Algeria, Angola, Congo, Equatorial Guinea, Gabon, the Islamic Republic of Iran, Iraq, Kuwait, Libya, Nigeria, Saudi Arabia, the United Arab Emirates, and Venezuela. In the last quarter of 2019, OPEC member countries accounted for about 79.11% of the total 1,551 billion barrels (bn b) of globally proven oil reverse and about 35.47% of the total estimated 206.2 trillion standard cubic meters (tr s cu m) of globally proven natural gas reserves (OPEC 2020).

Crude oil plays an important role in the global economy, and it is the backbone of most of the OPEC member countries across the globe. For instance, the Middle East accounts for 48.3% of the total proven oil reserve in the world out of which OPEC member countries of the region like Saudi Arabia, Iran, Iraq, Kuwait, and UAE account for about 17.2%, 9.0%, 8.5%, 5.9%, and 5.7% of the global proven oil reserves, respectively (BP 2019). Besides, at the end of 2019, about 8.15% of the world's total proven oil reserves are in Africa out of which OPEC member countries like Libya, Nigeria, Algeria, and Angola account for up to 84.77% of the continent' entire proven oil reserves (OPEC 2020). At the end of 2018, Venezuela, another OPEC member, holds about 17.5% of the total 18.8% of the globally proven oil reserves in the South and Central America region (BP 2019).

The vast majority of the member countries in the OPEC economic block still have a huge economic dependence on fossil fuels. In these countries, crude oil energy largely remained the major driver of the economy through foreign exchange earnings and as the primary source of energy for growing energy demand. Hence, in the quest to address the challenge of maintaining the balance between economic growth agenda and environmental sustainability among these countries, this study provides insight into the energy transition drive in the panel of 11 (Algeria, Angola, Congo, Gabon, the Islamic Republic of Iran, Iraq, Libya, Nigeria, Saudi Arabia, the United Arab Emirates, and Venezuela) OPEC members. In recent years, except for Gabon, there has been an upward trend of carbon emissions in the examined countries (see Fig. 1 in Appendix), thus suggesting potential challenges in the environmental sustainability agenda of the member states. To establish the challenges to the environmental sustainability agenda, as an objective, the role of conventional and renewable energy utilization in addition to income and urbanization on carbon emission was explored. By providing an insight into the role of urban population growth, in addition to the energy transition drive, this study is designed to contribute a significant perspective to the existing Environmental Kuznets Curve (EKC) literature.

The study consists of 4 major parts starting with the introduction in the first part. The second part provides a brief review of related studies on the subject matter of the nexus between environmental pollution, energy utilization types, urbanization, and economic growth. The third part presents a full detail of the adopted method of empirical analysis, while part four concludes the study with relevant notes on policy directions.

Literature review

Economic literature has witnessed substantial growth in energy-related researches in this decade, and this is partly due to the level of urgency required to tackle the growing concerns on the dangers of increasing carbon emissions. Several factors have been associated with the rise in the level of global GHG emissions, thus leading to the attraction of numerous studies on the adoption of potential strategies for mitigating global GHGs emissions over a target period of time (Randers 2012). For instance, and especially in urban growth, energy demand often rises as nations struggle to lift their citizens from poverty, unemployment, and other socioeconomic challenges through economic growth agenda that are often predicated on manufacturing and industrial expansion (Wu et al. 2019; Ogbeide-Osaretin 2020). Importantly, the role of urbanization in environmental sustainability has been examined for different cases in the literature (Al-Mulali and Ozturk 2015; Farhani and Ozturk 2015; Shahbaz et al. 2017). For instance, Shahbaz et al. (2017) identified that urbanization is responsible for the increase in energy demand in Pakistan.

However, there could be an environmental cost associated with increased demand for the use of unclean energy as demonstrated by the negative relationship between fossil fuel energy consumption and carbon emission in many studies. Dogan and Ozturk (2017) observed that an increase in CO_2 emissions in the USA is enhanced by a rise in non-renewable energy consumption. Similar results have also been confirmed in other countries and economic zones across the globe. The study of Haseeb et al. (2017) from a panel analysis on the BRICS countries revealed that energy consumption Granger causes the emission of CO_2 in the cases of China, India, and Brazil. The study of Al-Mulali et al. (2013) also confirmed the existence of a two-way causal relationship between CO_2 emission and energy consumption among a group of the Middle East and North African (MENA) countries on both the short-run and the long-run basis. Bekun et al. (2019) observed that energy consumption through fossil fuels creates destructive impacts on the sustainability of the environment among 16 European Union (EU) countries. The study of Sarkodie and Strezov (2019) also concluded that CO_2 emissions are strongly positively impacted by energy consumption among five developing countries including Iran, Indonesia, India, South Africa, and China. On the other hand, the utilization of cleaner energy sources and technologies is one of the generally acceptable environmental sustainability policies that has been expressed in extant studies (Alola et al. 2019; Usman et al. 2020a).

Although increasing demand for unclean energy consumption to stimulate growth has been closely linked to the lower environmental quality vis-à-vis the rising level of GHG emissions in many countries, however, it has also been proven that the adverse effect of carbon emission on environmental quality could be taken care of at certain levels of income as an economy experience growth over time according to the popular Environmental Kuznets Curve (EKC) (Kuznets 1955). The validity of the EKC has been tested in many countries, and there is no consensus on its validity as the curve is influenced by diverse factors in different economies. The theoretical background that underpinned the EKC hypothesis with regard to the tradeoff between environmental sustainability and nations' economic performances vis-à-vis income levels has been discussed in contemporary studies (Udemba 2020a; Udemba 2020b).

Ben Jebli et al. (2015) conducted a panel analysis of a group of 24 sub-Saharan African countries, and their results suggested that the EKC does not hold in the case of these countries. The study of Shahbaz et al. (2019) through the application of the Generalized Method of Moments (GMM) confirms the validity of the EKC for MENA countries. The study of Dogan and Inglesi-Lotz (2020) shows that the inverted U shape for carbon emission as demonstrated by EKC is only valid when overall economic growth is used as a proxy for economic structure in the case of EU countries, but on the other hand, the EKC becomes invalid when the economic structure is captured by industrial share. Moreover, the role of renewable energy and urbanization in environmental pollution has been examined in the context of the EKC hypothesis (Shahbaz et al. 2014; Apergis and Ozturk 2015; Alam et al. 2016; Al-Mulali et al. 2016a, 2016b).

In the light of the foregoing, this study provides a joint analysis of the panel of data collected on related issues from these countries using robust econometric techniques while also paying adequate attention to the individual differences among the represented member countries in the study.

Data and methodology

Data

Data were obtained from the World Bank development indicator (WDI 2019) and British Petroleum Statistical Review of World Energy (BP 2019) for the eleven (11) OPEC member countries between 1990 and 2014. The countries included in the study are Algeria, Angola, Congo, Gabon, the Islamic Republic of Iran, Iraq, Libya, Nigeria, Saudi Arabia, the United Arab Emirates, and Venezuela. The scope of the study concerning the data span and the decision to exclude two other member countries, namely, Equatorial Guinea and Kuwait, is mainly prompted by data availability. In addition, we provided the country-specific statistical properties of the examined variables in logarithmic terms (Table 1). A panel data analysis was conducted under the framework of the Autoregressive Distributed Lag Modeling (ARDL) as developed by Pesaran et al. (1999) in line with the application in contemporary literature (Shahbaz et al. 2016; Da Silva et al. 2018; Mert et al. 2019).

Method

The simple multivariate form of interactions among the variables in the study was captured in Eq. (1) as follows:

$$Ln(CO_{2it}) = \beta_0 + \beta_1 LnFOF_{it} + \beta_2 LnRWE_{it} + \beta_3 LnY_{it} + \beta_4 LnY^2{}_{it} + \beta_5 LnURN_{it} + \omega_{it} \quad (1)$$

In Eq. (1), the amount of carbon dioxide emitted in metric tons per capita was used as a proxy for carbon emission such that CO_{2it} denoted the amount of carbon emitted in a country i at time t. FOF and RWE represent the amount of fossil fuel energy consumption and renewable energy consumption as a percent of the total final energy consumption in each country respectively. Y denotes the real per capita income for each country measured at constant 2010 US$.

Table 1 Statistical properties of the variables

	Carbon emission	Income	Urbanization	Fossil energy	Renewable energy
Algeria					
Mean	0.4947	1.5123	1.7863	1.9991	− 0.4796
Maximum	0.5724	2.2553	1.8465	1.9999	− 0.2330
Minimum	0.4278	1.1696	1.7167	1.9983	− 1.1634
Std. Dev.	0.0385	0.2870	0.0402	0.0004	0.2202
Angola					
Mean	0.2129	3.2380	1.7072	1.4834	1.8173
Maximum	0.2213	10.5988	1.6840	1.8855	1.8855
Minimum	− 0.5404	0.6370	1.3449	1.7049	1.7049
Std. Dev.	− 0.1243	3.3356	0.0692	0.1141	0.0615
Congo					
Mean	− 0.2904	1.0610	1.7748	1.4722	1.8207
Maximum	− 0.0877	1.4600	1.6237	1.9039	1.9039
Minimum	− 0.7597	0.7565	1.1993	1.7415	1.7415
Std. Dev.	0.1911	0.2367	0.0243	0.1244	0.0443
Gabon					
Mean	0.5560	2.0006	1.9008	1.4247	1.8936
Maximum	0.6919	2.3893	1.9428	1.5656	1.9450
Minimum	0.4332	1.6744	1.8397	1.2165	1.8430
Std. Dev.	0.0874	0.2441	0.0305	0.1165	0.0350
Iran					
Mean	0.7647	2.4315	1.8124	1.9965	− 0.0321
Maximum	0.9254	3.5115	1.8623	1.9985	0.1842
Minimum	0.5722	1.5244	1.7507	1.9942	− 0.3581
Std. Dev.	0.1196	0.5799	0.0348	0.0013	0.1408
Iraq					
Mean	0.5493	2.1938	1.8386	1.9941	− 0.1522
Maximum	0.6985	4.6984	1.8444	1.9992	0.4072
Minimum	0.3477	1.5029	1.8350	1.9822	− 0.4895
Std. Dev.	0.0833	0.8630	0.0027	0.0055	0.3157
Libya					
Mean	0.9411	1.8453	1.8860	1.9960	0.3196
Maximum	0.9999	2.1097	1.8977	1.9969	0.4954
Minimum	0.8031	1.3730	1.8792	1.9951	0.1954
Std. Dev.	0.0362	0.2036	0.0057	0.0004	0.0771
Nigeria					
Mean	− 0.2662	1.7586	1.5674	1.2849	1.9359
Maximum	− 0.0921	2.8222	1.6719	1.3588	1.9486
Minimum	− 0.5058	1.2864	1.4725	1.2002	1.9188
Std. Dev.	0.1468	0.4637	0.0628	0.0390	0.0075
Saudi Arabia					
Mean	1.1865	2.4968	1.9041	1.9997	− 1.9663
Maximum	1.2887	2.7179	1.9189	2.0000	− 1.4204
Minimum	1.0211	2.2426	1.8841	1.9965	− 2.2212
Std. Dev.	0.0793	0.1716	0.0097	0.0009	0.2462
United Arab Emirate					
Mean	1.4173	2.9250	1.9100	1.9927	− 1.3220
Maximum	1.5553	3.2322	1.9313	2.0000	− 0.7250
Minimum	1.2684	2.4858	1.8939	1.9351	− 5.0000

Table 1 (continued)

	Carbon emission	Income	Urbanization	Fossil energy	Renewable energy
Std. Dev.	0.0696	0.2737	0.0128	0.0173	1.1132
Venezuela					
Mean	0.7998	1.7329	1.9401	1.9478	1.1301
Maximum	0.8866	3.2434	1.9452	1.9566	1.2180
Minimum	0.7122	0.4421	1.9257	1.9367	1.0583
Std. Dev.	0.0418	0.8504	0.0063	0.0050	0.0339
Number of observations	275	275	275	275	275

Std. Dev is the standard deviation

Theoretical framework

Theoretically, the implied model used in the current study is based on the augmentation of the STIRPAT (Stochastic Impact by Regression on Population, Affluence and Technology) from the IPAT (Integrated Population, Affluence and Technology) model. In the extant literature, the STIRPAT model has been augmented to accommodate urban population expansion, economic development, energy consumption, and in the framework of the EKC hypothesis (Shahbaz et al. 2017; Akadiri et al. 2020; Alola and Joshua 2020; Usman et al. 2020b).

In this current case, we used Y^2 to capture what happens in the scenario of an increased income level among countries such that β_4 is expected to be negative in value when β_3 assumes a positive value for the EKC hypothesis to be valid among the countries (Shahbaz et al. 2016; Dogan and Ozturk 2017; Shahbaz et al. 2019). Also, URN represents the urban population measured as a percentage of the total population in each country. This variable was factored into the model to check for the possible effects of urbanization within the interaction among the variables for the study as obtainable in contemporary studies (Farhani and Ozturk 2015; Haseeb et al. 2017; Zhao et al. 2019; Asongu et al. 2020). To ensure interpretations of coefficients as elasticities in the model, all the data have been converted into natural logarithms. Firstly, the integration order of the panel of variables is investigated before checking for the existence of cointegration relationships among variables. Then, we estimate the long-run coefficients before reporting the direction of causality between the variables.

Estimation and results

Unit root test

Unit root tests (see Table 2) are often conducted to clearly understand the statistical properties of variables before proceeding on testing for cointegration among variables in time series analysis (Bekun et al. 2019; Onifade et al. 2020a; Onifade et al. 2020b). This study utilizes a combination of different unit root test procedures to maximize the strengths of each procedure before arriving at a conclusion on the order of integration of the variables. The null hypothesis that there is a presence of unit root was tested against the alternative of no unit root among the cross sections of variables in the model. The combined panel unit root tests that were conducted summarize the output of the test from the Fisher Augmented Dickey and Fuller (1979), Phillips and Perron (1988), Breitung (2000), Levin et al. (2002), and Im et al. (2003). While the test of Levin et al. (2002) assumes homogeneity in autoregressive coefficients among country samples, thus requiring a bias correction terms to take care of heterogeneous variance among sample observations across countries, the Breitung (2000) on the other hand applies a variable transformation approach to cater for variance heterogeneity across observations. Each of the approaches has its strengths and weaknesses, but a decision arrived at from the combination of all is useful for making valid conclusions regarding the order of integration of the variables.

The unit root test was reported for the model with both intercept and trend. The superscripts p, q, and r denote estimates significance at 10%, 5%, and 1% significance level, respectively. CO_2 represents the amount of carbon emission and Y and Y^2 denote per capita income and square value of income level, respectively. URN represents the level of urbanization, while FOF and RWE denote fossil energy and renewable energy, respectively. Variables are in natural log form

Based on the unit root test result from all the techniques, there is sufficient evidence to reject the null hypothesis of unit root presence in all variables at the level except in the cases of fossil fuel proxy (FOF) and real per capita income (Y) where there is no evidence and little evidence to reject the null hypothesis, respectively. The test at first difference shows that all the variables are integrated of order one I(1). Hence, the cointegration test was carried out.

Table 2 Unit root test results

Variables	Levels CO_2	FOF	RWE	Y	Y^2	URN
LLC	− 1.55269 ^{p}	0.37634	− 25.5229 ^{r}	− 3.32440 ^{r}	− 6.57704 ^{r}	− 3.63887 ^{r}
Breitung	− 2.91434 ^{r}	0.47732	2.16039	2.07644	1.88240	2.13167
IPS	− 1.13675	0.32177	− 12.4452 ^{r}	− 1.27734	− 3.15188 ^{r}	− 2.36827 ^{r}
Fisher-ADF	29.9940	18.6200	284.944 ^{r}	26.9839	48.8034 ^{r}	67.1567 ^{r}
Fisher-PP	53.7794 ^{r}	24.6250	92.1587 ^{r}	99.4184 ^{r}	550.062 ^{r}	294.079 ^{r}
	First difference					
LLC	− 8.17937 ^{r}	− 5.96244 ^{r}	− 43.9377 ^{r}	− 4.43811 ^{r}	− 2.03185 ^{q}	− 74.3521 ^{r}
Bg	− 8.37316 ^{r}	− 4.88139 ^{r}	− 3.14270 ^{r}	− 3.66103 ^{r}	− 3.99319 ^{r}	0.08250
IPS	− 8.60489 ^{r}	− 6.71977 ^{r}	− 20.0536 ^{r}	− 4.69915 ^{r}	− 3.70186 ^{r}	− 32.6707 ^{r}
Fisher-ADF	105.281^r	83.0277 ^{r}	342.259 ^{r}	62.0048 ^{r}	52.6063 ^{r}	289.125 ^{r}
Fisher-PP	706.701 ^{r}	384.686 ^{r}	244.162 ^{r}	166.162 ^{r}	199.495 ^{r}	107.758 ^{r}

Panel cointegration test

The linear combination of non-stationary variables is known to be capable of generating a stationary process in time series analysis (Nwaka and Onifade 2015; Haseeb et al. 2017; Taiwo et al. 2020; Çoban et al. 2020). Thus, the Pedroni (1999, 2004) cointegration approach that allows for heterogeneity across sample observation was applied to ascertain the existence of a cointegration relationship between the underlying variables in the model. The technique consists of two categories of test statistics, namely, the panel cointegration statistics and the group mean panel cointegration statistics. Under these two categories are the seven test statistics upon which inference is made regarding the presence of cointegration among variables. The seven statistics include the panel v-statistics, the rho statistics, the PP-statistics, the ADF-statistics, the group rho statistics, the group PP-statistics, and the group ADF-statistics. The test follows the model specification as shown in Eq. (2).

$$X_{it} = \gamma_i + \varphi_i t + \sum_{p=i}^{p} \delta_{qi} Z_{qit} + \mu_{it} \quad (2)$$

From Eq. (2), the cointegrating vectors are expected to be heterogeneous across observations such that i denotes the individual country represented in the panel over the observed period of time t. The μ_{it} is the residual estimate for the unit root test with the null hypothesis that there is no long-run equilibrium against the alternative of cointegration among variables. The cointegration results are provided in Table 3.

The superscripts p, q, and r denote estimates significance at 10%, 5%, and 1% significance level, respectively

From the results, there is enough evidence to reject the hypothesis of no cointegration among the variables given the statistical significance of a combination of the various test statistics. As such, there is an existence of a long-run relationship among the variables, and the cointegrating long-run coefficient can be obtained.

Panel ARDL

The Autoregressive Distributed Lag Model (ARDL) Pooled Mean Group (PMG) method as proposed by Pesaran et al. (1999) was applied to obtain the cointegrating long-run coefficients among the interacting variables in Eq. (1) following a generalized ARDL model as express in Eq. (3).

$$Y_{it} = \sum_{j=i}^{p} \delta_i Y_{it-j} + \sum_{j=0}^{q} \beta_{ij} X_{it-j} + \varphi_i + \varepsilon_{it} \quad (3)$$

From Eq. (3), Y_{it} is the dependent variable, while X_{it} exits as a vector with the possibility of a mixed order of integration among variables [I(0) or I(1)]. δ_i and β_{ij} are the slope of the lagged explained variables and the slopes of the vectors, respectively. φ_i captures the unit-specific fixed effects such that i and t ranges from 1 to N^{th} numbers of countries and 1 to the T^{th} period of time. p and q are the optimum lags as selected by the information criterion, and ε_{it} denotes the error term. The error correction model follows the specifications in Eq. (4).

$$\Delta Y_{it} = \vartheta_i \left\{ Y_{i(t-1)} - \phi_i X_{it} \right\} + \sum_{j=1}^{p-1} \pi_{ij} \Delta Y_{i(t-j)} + \sum_{j=0}^{q-1} \beta_{ij} \Delta X_{i(t-j)} + \varphi_i + \varepsilon_{it} \quad (4)$$

From Eq. (4), the vector of the long-run relationship is denoted by ϕ_i, while the error correction term (ECT) is captured by $\{Y_{i(t-1)} - \phi_i X_{it}\}$. The coefficient ϑ_i represents the group-specific speed of adjustment which is expected to be

Table 3 Panel cointegration test results

Alternative hypothesis: common AR coeffs. (within-dimension)				
	Statistic	Prob.	Weighted statistic	Prob.
Panel v-statistic	− 1.050574	0.8533	− 3.830932	0.9999
Panel rho-statistic	1.258230	0.8958	2.518684	0.9941
Panel PP-statistic	− 7.143438	0.0000 ^{r}	− 7.648205	0.0000 ^{r}
Panel ADF-statistic	− 3.308578	0.0005 ^{r}	− 6.223536	0.0000 ^{r}
Alternative hypothesis: individual AR coeffs. (between-dimension)				
	Statistic	Prob.		
Group rho-statistic	3.071025	0.9989		
Group PP-statistic	− 10.44611	0.0000 ^{r}		
Group ADF-statistic	− 4.170604	0.0000 ^{r}		

less than 0, such that $\vartheta_i = -(1-\delta_i)$. π_{ij} and β_{ij} capture the short-run coefficients. The PMG applies both pooling and averaging, thus generating consistent estimates of the mean of short-run coefficients. The estimated coefficients are provided in Table 4.

The subscripts ***, **, and * represent the significance of estimates at 1%, 5%, and 10% levels, respectively. Y and Y^2 denote per capita income and square value of income level, respectively. URN represents the level of urbanization, while FOF and RWE denote fossil energy and renewable energy, respectively. ECT is the error correction term. Variables are in natural log form

Table 4 PMG/ARDL results

Long-run estimates		
Variables	Coefficients	P-value
LnFOF	0.2462	0.0029 ^{r}
LnRWE	− 0.0058	0.7101
LnY	− 0.1118	0.0001^r
LnY^2	0.0091	0.0000 ^{r}
LnURN	− 2.7069	0.0000 ^{r}
Short-run estimates		
ECT	− 0.4863	0.0000 ^{r}
DLnFOF	7.2612	0.2695
DLnRWE	0.1072	0.7522
DLnY	0.2566	0.7443
DLnY^2	− 0.1204	0.5488
DLnURN	− 51.0500	0.1314
C	2.7978	0.0000 ^{r}

The superscript r denotes estimates significance at a 1% significance level, respectively. Y and Y^2 denote per capita income and square value of income level, respectively. URN represents the level of urbanization, while FOF and RWE denote fossil energy and renewable energy, respectively. ECT is the error correction term. Variables are in natural log form

From Table 4, fossil fuel use is significant and positively impacts the amount of CO_2 emitted into the environment for the group of countries in the study, while urbanization mitigates environmental degradation in the panel countries, especially in the long run. To be precise, urbanization exerts the biggest impact on the rate of environmental degradation by carbon emission among the countries as a percentage rise in the rate of urbanization is expected to trigger a reduction in the rate of carbon dioxide emission up to about 2.71%, while a 1% rise in fossil fuel consumption is expected to also trigger carbon emission by about 0.25%. This finding is in line with the established nexus among these variables in the literature (Dogan and Ozturk 2017; Mert et al. 2019; Bekun et al. 2019; Udemba and Agha 2020). In contrast, an increase in renewable energy consumption is expected to help in curbing carbon dioxide emissions, but the impact is not statistically significant in the long run. However, the result projects a tendency of achieving a desirable energy-transitioning goal in the panel of OPEC economies, especially if the right policy is in place. This result follows the expected negative nexus between renewable energy consumption and CO_2 emission in the literature (Haseeb et al. 2017; Mert et al. 2019). The potential negative impact further implies that the current level of renewable energy use among these countries is still grossly inadequate to create a significant cushioning effect on carbon emission among these nations. A close look at the energy consumption statistics for the study shows that most of the countries have increasingly become fossil fuel-dependent over the years with renewable energy consumption notably constituting less than 1% of the total final energy consumption on the average in some countries including Saudi Arabi, Algeria, Iran, Iraq, and the UAE.

Furthermore, in the long run, there was insufficient evidence to support the validity of the Environmental Kuznets Curve (EKC) among the countries with regard to the expected cushioning effect of rising income on environmental degradation. Based on the finding, even when income level doubles

Table 5 Individual country cross section results

Countries	Coefficients	*P* values
Algeria	ECT = − 0. 896***	0.000
	lnFOF = 8.660	0.99
	lnREW = 0.046***	0.002
	lnY = 0.291	0.325
	lnY^2 = 0.073**	0.030
	lnURN = − 131.11	0.900
Angola	ECT = − 1. 270***	0.000
	lnFOF = − 0.652	0.335
	lnREW = 2.247	0.550
	lnY = − 0.039**	0.013
	lnY^2 = − 0.008***	0.000
	lnURN = − 107.661	0.569
Congo	ECT = − 0. 236***	0.000
	lnFOF = 0.624*	0.060
	lnREW = 1.269	0.354
	lnY = 2.761	0.293
	lnY^2 = − 1.614**	0.036
	lnURN = − 351442	0.987
Gabon	ECT = − 0. 495***	0.000
	lnFOF = − 0.195***	0.001
	lnREW = 0.717	0.018
	lnY = -0.168	0.620
	lnY^2 = 0.050**	0.066
	lnURN = 1.632	0.944
Iran	ECT = − 0. 076***	0.000
	lnFOF = 8.541	0.959
	lnREW = 0.023	0.194
	lnY = − 0.269	0.357
	lnY^2 = 0.053**	0.013
	lnURN = − 5.671	0.957
Iraq	ECT = − 0. 691***	0.002
	lnFOF = − 22.086	0.914
	lnREW = − 0.152***	0.002
	lnY = 0.032	0.433
	lnY^2 = − 0.009***	0.002
	lnURN = − 2.943	0.995
Libya	ECT = − 0. 475***	0.000
	lnFOF = 66.627	0.975
	lnREW = − 0.281	0.162
	lnY = − 0.235	0.644
	lnY^2 = 0.079	0.126
	lnURN = 17.575	0.910
Nigeria	ECT = − 0. 027**	0.019
	lnFOF = 1.074	0.158
	lnREW = − 2.315	0.888
	lnY = − 1.457	0.184
	lnY^2 = 0.365***	0.003
	lnURN = − 16.077	0.938
Saudi Arabia	ECT = − 0. 215***	0.000
	lnFOF = 15.205	0.929
	lnREW = 0.007	0.417
	lnY = − 4.505	0.833
	lnY^2 = 0.881	0.339
	lnURN = 21.724	0.951
United Arab Emirate	ECT = − 0. 663***	0.000
	lnFOF = 0.237	0.722
	lnREW = − 0.004***	0.000
	lnY = 6.189	0.616
	lnY^2 = − 1.022*	0.065
	lnURN = − 1.987	0.976
Venezuela	ECT = − 0. 304***	0.001
	lnFOF = 1.450	0.702
	lnREW = − 0.377***	0.004
	lnY = 0.224**	0.045
	lnY^2 = − 0.027***	0.004
	lnURN = 14.416	0.957

among the countries as in the case of (Y^2), the estimated coefficient posits a positive impact, thus invalidating the inverted U-shape hypothesis of EKC among the countries (rather validating a U-shaped relationship between income and environmental degradation). This finding corroborates some of the empirical studies where the EKC has not been upheld for some countries that are included in the panel of this study (Ben Jebli et al. 2015; Acar et al. 2018), but the result provides contrary evidence to the findings of Shahbaz et al. (2019) on a group of countries which covers some of the countries that are included in this study. This could be as a result of individual-specific differences of other countries that are included in their study and the adopted method of data analysis. The speed of adjustment to equilibrium followed the expected sign, and it is highly significant in the model. It is expected that short-run disequilibrium is adjusted to a long-run equilibrium state at an average speed of about 49% annually.

Besides, the estimation further revealed short-run implications for each specific country (see Table 5). For instance, the EKC hypothesis is valid only in Venezuela, and there is a potential for the validity of the EKC hypothesis in Saudi Arabia, Iraq, Congo, and Algeria. In addition, there is a statistically significant evidence of having a desirable transition from conventional energy to low carbon or renewable energy only in Venezuela, the United Arab Emirates, Iraq, and Algeria.

Panel causality

The direction of causality among the variables was explored to make further consolidation and diagnostics on the results. The result of the panel causality test is detailed in Table 6.

From the Granger causality test, there is no causality observed running from either fossil fuel consumption or renewable energy consumption to the income level among the countries. On the contrary, a uni-directional causality was obtained from income level to renewable energy consumption among the countries. Furthermore, a bi-directional causality was obtained between urbanization and three other variables, namely, fossil fuel consumption, renewable energy consumption, and CO_2 emission. Thus, urbanization can be said to be a central factor in energy-related developments vis-à-vis consumption and environmental pollution among these countries.

Conclusion and policy directions

This study applied the Pooled Mean Group (PMG) estimator under the framework of the Autoregressive Distributed Lag Model (ARDL) to examine the dynamic nexus between energy consumption, carbon emission, and economic growth among OPEC member countries, namely, Algeria, Angola, Congo, Gabon, the Islamic Republic of Iran, Iraq, Libya, Nigeria, Saudi Arabia, the United Arab Emirates, and Venezuela. Fossil fuel and renewable energy were used as a proxy for energy consumption, while real GDP per capita and carbon dioxide emissions were used as a proxy for economic growth and carbon emission, respectively. Also, the urban population measured as a percentage of the total population was introduced to examine the impact of urbanization among the country for the study.

The result from the long-run estimates shows that fossil fuel utilization exerts a significant and positive impact on carbon emission in the long run, while the observed negative impact of renewable energy consumption on carbon emission was insignificant for the group of countries in the study. The Environmental Kuznets Curve (EKC) was not valid among the countries for the period of study, rather a U-shaped relationship between income and carbon emission is validated. The result further opined that urbanization is a catalyst for carbon emission reduction in the examined panel countries. Based on the panel causality test, urbanization was found to be Granger causing the consumption of fossil fuel and renewable energy among the countries which in turn increases carbon emission in the countries, thus strengthening the information regarding the positive impact of urbanization on carbon dioxide emission as projected in the obtained long-run coefficients.

Hence, it is strongly recommended that carefully designed energy conservation policies should be mapped out and strategically implemented for environmental sustainability among the countries that are included in the study. Based on the finding, income level is Granger causing renewable energy consumption among the countries, and this nexus reflects a better position for implementation of energy conservation policies without risking the detrimental effects of energy conservation on the general economic growth and income level (Ozcan and Ozturk 2019). Furthermore, the present ease of accessing fossil fuel energy offers a huge advantage to the OPEC member countries as they can easily earn foreign exchange through direct trade in energy and inflow of foreign direct investment from other countries. It is strongly recommended that this opportunity should be harness to ensure adequate investment in renewable energy to promote a green policy agenda. This in turn would also help to guarantee the needed sustainable economic growth and development in the wake of a possible energy revolution that could culminate the transition from dependence on fossil foil to cleaner forms of energy (Zou et al. 2016). Coincidentally, a majority of these OPEC member countries have a huge opportunity to harness the vast potential of renewable energy sources like wind and solar energy due to their natural endowments vis-à-vis their geographical location and climatic conditions.

Finally, the result of the study reveals that urbanization is not just critical to the rise in carbon emission alone, it is also a critical factor to income level among these countries as the bulk of economic activities in the majority of the countries is domicile and clustered in the major urban centers. As such, effective urban planning that is based on environmental protection agendas are very critical to the management and control of the threats posed by environmental degradation as the level of urbanization rises among the selected OPEC member countries. While governments are doing their best to ensure a reduction in the dependence on the use of fossil fuel in the wake of rapid urbanization by providing alternative clean energy sources that are accessible for both industrial and residential purposes, there is also a need to ensure that proper awareness is provided to the populace on the urgency of the need for environmental protection.

Authors' contributions Andrew Adewale Alola: Formal analysis, investigation, methodology, and corresponding
Stephen Taiwo Onifade: Writing - original draft and data curation
Savaş Erdoğan: Writing - original draft
Hakan Acet: Conceptualization and formal analysis

Data availability Not applicable

Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

Ethical approval Not applicable

Consent to participate Not applicable

Consent to publish Not applicable

Appendix

Table 6 Panel causality test results

Dependent variables	W-Stat/Zbar-Stat						
	$LnCO_2$	LnFOF	LnRWE	LnY	LnY2	LnURN	Decision
$LnCO_2$	_	5.6502/4.4203 ***	4.4317/2.8362 ***	3.3342/1.4095	2.9150/0.8645	3.6307/1.794 *	$CO_2 \rightarrow FOF, RWE, URN$
LnFOF	2.5495/0.3894	_	1.7091/-0.7031	2.7195/0.6103	2.4329/0.2378	3.6067/1.7637*	$FOF \rightarrow URN$
LnRWE	1.5923/0.8549	2.1053/-0.1880	_	2.2203/-0.0385	2.1589/-0.1183	4.9255/3.4781***	$RWE \rightarrow URN$
LnY	3.0995/1.1043	2.8240/0.7462	3.8088/2.0264 **	_	3.2670/1.3222	3.3041/1.3704	$Y \rightarrow RWE$
LnY^2	2.7594/0.6622	2.7243/0.6165	3.7116/1.9001 **	3.1048/1.1113	_	3.9554/2.2170***	$Y^2 \rightarrow RWE, URN$
LnURN	10.662/10.936***	4.0999/2.4049 **	7.1253/6.3378 ***	4.1126/2.4214 **	4.5148/2.9443 ***	_	$URN \rightarrow CO_2, FOF, RWE, Y$

Source: Authors' results. The superscripts *, **, and *** represent the rejection level of no causality between variables at 10%, 5%, and 1% levels of significance, respectively. The results report the *P* values for the Pairwise Dumitrescu Hurlin Panel Causality W-Stat/Zbar-Stat. CO_2 represents the amount of carbon emission, and Y and Y^2 denote per capita income and square value of income level, respectively. URN represents the level of urbanization, while FOF and RWE denote fossil energy and renewable energy, respectively. Variables are in natural log form

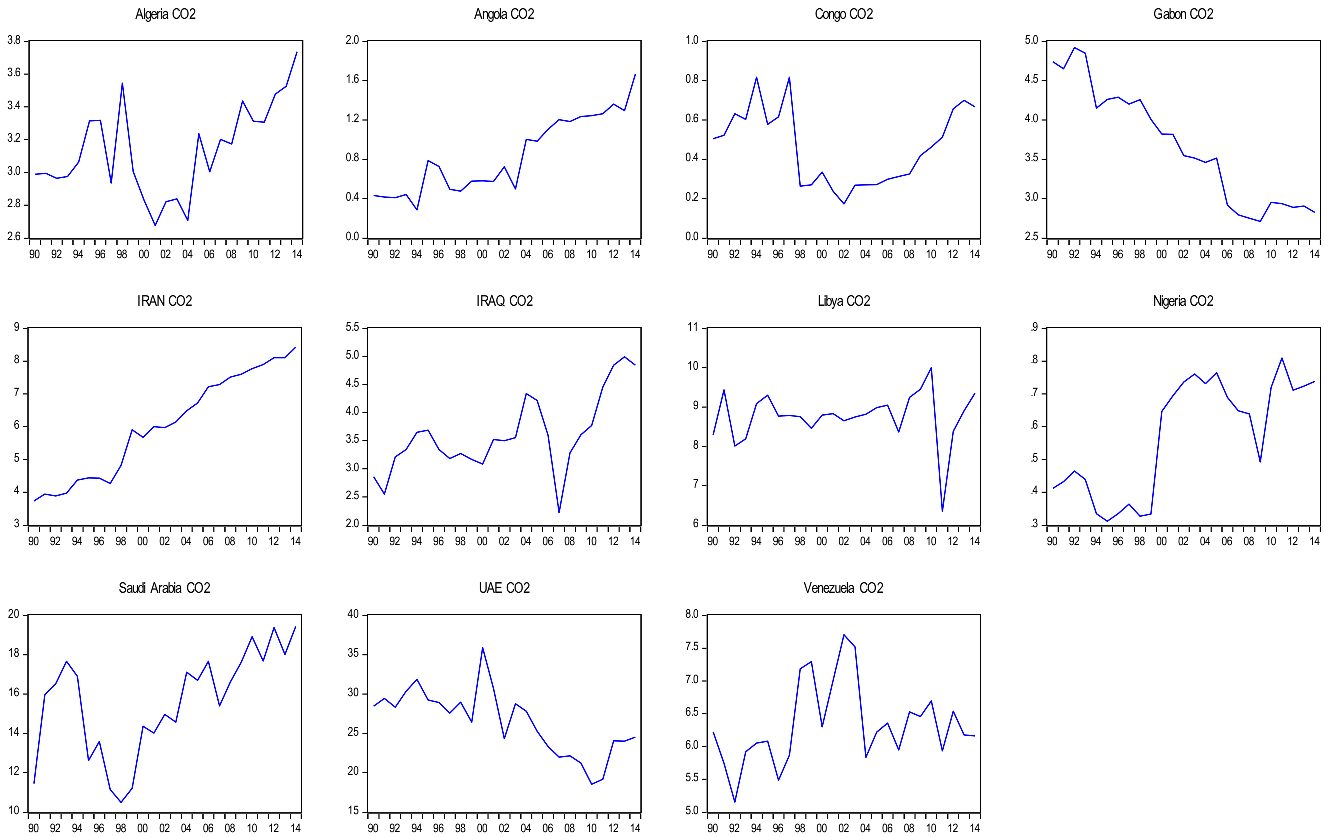

Fig. 1 Country-specific plots illustrating the trend of carbon emission in the 11 OPEC states

References

Acar Y, Gürdal T, Ekeryılmaz Ş (2018) Environmental Kuznets curve for CO2 emissions: an analysis for developing, Middle East, OECD and OPEC countries. Environ Socio-econ Stud 6(4):48–58

Ağbulut Ü, Ceylan İ, Gürel AE, & Ergün A (2019). The history of greenhouse gas emissions and relation with the nuclear energy policy for Turkey. Int J Ambient Energy 1-9.

Akadiri SS, Alola AA, Alola UV, Nwambe CS (2020) The role of ecological footprint and the changes in degree days on environmental sustainability in the USA. Environ Sci Pollut Res 27:24929–24938 1-10

Alam MM, Murad MW, Noman AHM, Ozturk I (2016) Relationships among carbon emissions, economic growth, energy consumption and population growth: testing environmental Kuznets curve hypothesis for Brazil, China, India and Indonesia. Ecol Indic 70: 466–479

Al-Mulali U, Fereidouni HG, Lee JY, Sab CNBC (2013) Exploring the relationship between urbanization, energy consumption, and CO2 emission in MENA countries. Renew Sust Energ Rev 23:107–112

Al-Mulali U, Solarin SA, Ozturk I (2016a) Investigating the presence of the environmental Kuznets curve (EKC) hypothesis in Kenya: an autoregressive distributed lag (ARDL) approach. Nat Hazards 80(3):1729–1747

Al-Mulali U, Ozturk I (2015) The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region. Energy 84:382–389

Al-Mulali U, Ozturk I, Solarin SA (2016b) Investigating the environmental Kuznets curve hypothesis in seven regions: the role of renewable energy. Ecol Indic 67:267–282

Alola AA, Bekun FV, Sarkodie SA (2019) Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Sci Total Environ 685:702–709

Alola AA, Joshua U (2020) Carbon emission effect of energy transition and globalization: inference from the low-, lower middle-, upper middle-, and high-income economies. Environ Sci Pollut Res 27(30):38276–38286

Apergis N, Ozturk I (2015) Testing environmental Kuznets curve hypothesis in Asian countries. Ecol Indic 52:16–22

Asongu SA, Agboola MO, Alola AA, Bekun FV (2020) The criticality of growth, urbanization, electricity and fossil fuel consumption to environment sustainability in Africa. Sci Total Environ 712:136376

Bekun FV, Alola AA, Sarkodie SA (2019) Toward a sustainable environment: nexus between CO2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. Sci Total Environ 657:1023–1029

Ben Jebli M, Ben Youssef S, Ozturk I (2015) The role of renewable energy consumption and trade: environmental Kuznets curve analysis for sub-Saharan Africa countries. Afr Dev Rev 27(3):288–300

Breitung J (2000) The local power of some unit root tests for panel data'. In: Baltagi B (ed) Non-stationary panels, panel cointegration, and dynamic panels, Advances in Econometrics, 15th edn. JAI Press, Amsterdam, pp 161–178

British Petroleum, BP (2019) Statistical Review of World Energy June 2019. Available at http://www.bp.com/statisticalreview. Accessed 13 Sep 2020

Clark G, Jacks D (2007) Coal and the industrial revolution, 1700–1869. Eur Rev Econ Hist 11(1):39–72

Çoban O, Onifade ST, Yussif AB, Haouas I (2020) Reconsidering trade and investment-led growth hypothesis: new evidence from Nigerian economy. J Int Stud 13(3):98–110. https://doi.org/10.14254/2071-8330.2020/13-3/7

Da Silva PP, Cerqueira PA, Ogbe W (2018) Determinants of renewable energy growth in Sub-Saharan Africa: evidence from panel ARDL. Energy 156:45–54

Dickey DA, Fuller WA (1979) Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc 74:427–431

Dogan E, Ozturk I (2017) The influence of renewable and non-renewable energy consumption and real income on CO 2 emissions in the USA: evidence from structural break tests. Environ Sci Pollut Res 24(11):10846–10854

Dogan E, Inglesi-Lotz R (2020) The impact of economic structure to the environmental Kuznets curve (EKC) hypothesis: evidence from European countries. Environ Sci Pollut Res 27:12717–12724 1-8

Farhani S, Ozturk I (2015) Causal relationship between CO 2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. Environ Sci Pollut Res 22(20): 15663–15676

Fernihough A, & O'Rourke KH (2014). Coal and the European industrial revolution (No. w19802). Natl Bur Econ Res.

Finkelman RB, Tian L (2018) The health impacts of coal use in China. Int Geol Rev 60(5-6):579–589

Haseeb M, Hassan S, Azam M (2017) Rural–urban transformation, energy consumption, economic growth, and CO2 emissions using STRIPAT model for BRICS countries. Environ Prog Sustain Energy 36(2):523–531

Hill MK (2020) Understanding environmental pollution. Cambridge University Press, Cambridge

Hopke PK (2009) Contemporary threats and air pollution. Atmos Environ 43(1):87–93

Hughes L, Rudolph J (2011) Future world oil production: growth, plateau, or peak? Curr Opin Environ Sustain 3(4):225–234

Kuznets S (1955) Economic growth and income inequality. Am Econ Rev 45(1):1–28

Im KS, Pesaran MH, Shin Y (2003) Testing for unit roots in heterogeneous panels. J Econ 115:53–74

Levin A, Lin CF, Chu CS (2002) Unit root tests in panel data: asymptotic and finite-sample properties. J Econ 108:1–24

Mert M, Bölük G, Çağlar AE (2019) Interrelationships among foreign direct investments, renewable energy, and CO 2 emissions for different European country groups: a panel ARDL approach. Environ Sci Pollut Res 26(21):21495–21510

Moshiri S (2015) Asymmetric effects of oil price shocks in oil-exporting countries: the role of institutions. OPEC Energy Rev 39(2):222–246

Nwaka ID, & Onifade ST (2015). Government size, openness and income risk nexus: New evidence from some African countries (No. WP/15/056). AGDI working paper.

Ogbeide-Osaretin EN (2020). Analysing energy consumption and poverty reduction nexus in Nigeria. Int J Sustain Energy 1-17.

Onifade ST, Çevik S, Erdoğan S, Asongu S, Bekun FV (2020a) An empirical retrospect of the impacts of government expenditures on economic growth: new evidence from the Nigerian economy. J Econ Struct 9(1):6

Onifade ST, Ay A, Asongu S, Bekun FV (2020b) Revisiting the trade and unemployment nexus: empirical evidence from the Nigerian economy. J Public Aff:e2053

OPEC (2020). Organization of the Petroleum Exporting Countries. OPEC Ann Stat Bull. Available at https://www.opec.org Accessed 3rd of September 2020

Ozcan B, Ozturk I (2019) Renewable energy consumption-economic growth nexus in emerging countries: a bootstrap panel causality test. Renew Sust Energ Rev 104:30–37

Pedroni P (1999) Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxf Bull Econ Stat 61:653–678

Pedroni P (2004) Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Econ Theory 20:597–625

Perera FP (2017) Multiple threats to child health from fossil fuel combustion: impacts of air pollution and climate change. Environ Health Perspect 125(2):141–148

Pesaran MH, Shin Y, Smith RP (1999) Pooled mean group estimation of dynamic heterogeneous panels. J Am Stat Assoc 94(446):621–634

Phillips PCB, Perron P (1988) Testing for a unit root in time series regressions. Biometrika 75:335–346

Randers J (2012) Greenhouse gas emissions per unit of value added ("GEVA")—a corporate guide to voluntary climate action. Energy Policy 48:46–55

Sarkodie SA, Strezov V (2019) Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci Total Environ 646:862–871

Shahbaz M, Balsalobre-Lorente D, Sinha A (2019) Foreign direct investment–CO2 emissions nexus in Middle East and North African countries: importance of biomass energy consumption. J Clean Prod 217:603–614

Shahbaz M, Chaudhary AR, Ozturk I (2017) Does urbanization cause increasing energy demand in Pakistan? Empirical evidence from STIRPAT model. Energy 122:83–93

Shahbaz M, Sbia R, Hamdi H, Ozturk I (2014) Economic growth, electricity consumption, urbanization and environmental degradation relationship in United Arab Emirates. Ecol Indic 45:622–631

Shahbaz M, Solarin SA, Ozturk I (2016) Environmental Kuznets curve hypothesis and the role of globalization in selected African countries. Ecol Indic 67:623–636

Smith B (2019) Dutch disease and the oil boom and bust. Can J Econ/Revue canadienne d'économique 52(2):584–623

Taiwo S, Alagöz M, Erdoğan S (2020) Inflation, oil revenue, and monetary policy mix in an oil-dependent economy: empirical insights from the case of Nigeria. Int J Bus 7(2):96–109

Udemba EN, Agha CO (2020) Abatement of pollutant emissions in Nigeria: a task before multinational corporations. Environ Sci Pollut Res 27(21):26714–26724 1-11

Udemba EN (2020a) Mediation of foreign direct investment and agriculture towards ecological footprint: a shift from single perspective to a more inclusive perspective for India. Environ Sci Pollut Res 27: 26817–26834 1-18

Udemba EN (2020b) Ecological implication of offshored economic activities in Turkey: foreign direct investment perspective. Environ Sci Pollut Res 27(30):38015–38028

Usman O, Alola AA, Sarkodie SA (2020a) Assessment of the role of renewable energy consumption and trade policy on environmental degradation using innovation accounting: evidence from the US. Renew Energy 150:266–277

Usman A, Ullah S, Ozturk I, Chishti MZ, Zafar SM (2020b) Analysis of asymmetries in the nexus among clean energy and environmental quality in Pakistan. Environ Sci Pollut Res 27:20736–20747 1-12

World Development Indictors, WDI (2019). https://data.worldbank.org/ Accessed 15th Sept 2020

Wu S, Zheng X, You C, Wei C (2019) Household energy consumption in rural China: Historical development, present pattern and policy implication. J Clean Prod 211:981–991

Zhao H, Guo S, Zhao H (2019) A panel co-integration analysis for economic development, energy consumption, urbanization, and carbon dioxide emissions in China's six provinces. Environ Prog Sustain Energy 38(6):e13247

Zou C, Zhao Q, Zhang G, Xiong B (2016) Energy revolution: from a fossil energy era to a new energy era. Nat Gas Ind B 3(1):1–11