Environmental Science and Pollution Research (2021) 28:33072–33082
https://doi.org/10.1007/s11356-021-12967-x

RESEARCH ARTICLE

Environmental implications of N-shaped environmental Kuznets curve for E7 countries

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Received: 16 January 2021 / Accepted: 10 February 2021 / Published online: 26 February 2021

Abstract

The environmental Kuznets curve (EKC) hypothesis is of great importance to understanding the relationship between economic activity and environmental degradation. Given the current wave of climate change and environmental crisis traced to rising environmental pollution from economic activities, it has become important to investigate the impact of economic expansion on the environment especially in the emerging-7 countries that are responsible for a large amount of global economic activity. This study investigates the N-shaped EKC for the E-7 countries using data spanning the period 1995–2018. The study employs the use of PMG-ARDL estimator and heterogeneous causality tests to establish the long run and short run and direction of causality respectively regarding the variables of interest. According to study empirical results, the long-run results fail to confirm the presence of an N-shaped EKC in the emerging 7 countries but rather confirms the existence of an inverted U-shaped EKC in the study countries. While renewable energy and non-renewable energy have a positive and significant relationship with CO_2 emissions, short run results show that there is no significant relationship between economic expansion, renewable energy, non-renewable energy and CO_2 emissions. Causality tests showed a bi-directional causality between GDP- and GDP-squared and a uni-directional causality from CO_2 emissions to GDP-cubed, non-renewable energy and CO_2 emissions, renewable energy, and CO_2 emissions. The study suggests increased use of renewable energy to mitigate pollutant emissions in the E-7 countries.

Keywords Environmental Kuznets curve · Economic growth · Renewable energy · Non-renewable energy · CO_2 emissions

Responsible Editor: Nicholas Apergis

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Introduction

Pollution is one of the main critical issues in the globe currently (IPCC 2014). Following the ratification of Paris Summit meeting in 2015, popularly referred to as the 21st Conference of the Parties (COP21), a range of targets was set to hold atmospheric warming levels comfortably outside 2 °C (United Nations 2017). In an attempt to overcome the global warming problems against sustainable and social development and to meet the ambitions of COP21, it is essential to take into account the environmental effects of global development. Climate pollution could have catastrophic effects for society, such as natural hazards, flooding, water shortages, and habitat destruction, and negatively impacted global development (IPCC 2014). Around the very moment, mankind action was known as the primary cause of environmental warming (Steffen et al. 2011).

Within the ecological economics research, the correlation regarding ecological destruction and sustainable development is finely established as the Kuznets environmental curve (EKC). The EKC indicates that air pollution is gradually on the increase in income per capita. Furthermore, through global stability, there is a rise in request for waste management, contributing to a deteriorating degradation of the ecosystem (Hussen 2005). When the U-shaped EKC is reversed, climate changes will inevitably arise as populations develop. Consequentially, despite major variations, society would return to life as normal and yet maintain ecological protection (Stern 2004). Moreover, analyses have shown that the connection can sometimes be N-shaped as documented in a study of see (Bhattarai et al. 2016), indicating that ecological pollution would begin to increase immediately above a reasonable point of earnings.

The concept of the EKC phenomenon is focused on the relationship involving fiscal expansion and environmental devastation and how the trajectory of growth in the economy will adversely affect the nature of the ecosystem. As shown by Grossman (1995), this influence will occur across three sources, namely, the effect of scale, the effect of structure, and the effect of a technique. When economic expansion sets the tempo, it has a scale impact on the climate. To promote economic development, the market for natural resource extraction is growing, and, as a result, the internal and external use of valuable resources is converted into the manufacturing cycle. If the manufacturing cycle begins, a considerable amount of toxic chemicals is produced and this by-product of manufacturing and technological development poses a severe challenge to the sustainability of the ecosystem. To enhance growth in the economy, governments neglect the harm to ecological health and, as a result, climate harm beginnings to increase as economic development increases. This phenomenon is evident, particularly when the market is primarily based on dominant (farming) and supplementary (production and industrial) fields. Now since wages are increasing, the economic system of the country continues to experience transition, and so the makeup of the market begins to change. This is where sustainable expansion has a compositional influence on climate stewardship, and this is where the effects of socioeconomic progress on climate sustainability start to be beneficial. Throughout this process, the supplementary market is starting to grow, and the industry is moving towards sustainable technologies. This manufacturing transition is mirrored in the trend of urbanization, and the desire for a healthier society is beginning to increase. It is the moment when companies tend to adopt sustainable efficiency-enhancing technology. This advancement on the road of technological transformation is how social development has a scientific impact on climate sustainability. Throughout this cycle, the tertiary field is starting to develop, and the economic environment is progressively starting to become information-intensive rather than wealth-intensive. This is the moment when the government is beginning to spend more in innovation and production-based operations, and the outdated and polluting technology used in the secondary field is beginning to be replaced. Currently, if this complex trend is visually depicted, it can be shown that habitat destruction proceeds on a bell-shaped or inverted U-shaped curves when mapped toward sustainable development. This whole theory is pointed to as the EKC theory (Shahbaz and Sinha 2019; Agboola and Bekun 2019) (Fig. 1).

From a different viewpoint, this whole scenario can be seen from the point of view of the Group of Rome economists who managed to come up with their notion of The Limits to Growth in 1972. From their studies, economic development cannot proceed indefinitely due to an insufficient supply of natural resource extraction (Meadows et al. 1972). In 1992, when they publish The First Global Revolution, the Club of Rome claimed that man interference in social systems has contributed to issues such as emissions levels, water shortages and climate change, which had been known to be the key indicators of climate destruction (King and Schneider 1992). Despite being disputed by many economists on the grounds of different points of view and relevant theoretical structure problems (Turner and Hanley 2011), the advent of principles such as socioeconomic equality (Solow 1974) and the ideal ordinary reserve exploitation track (Stiglitz 1974a, b) has shown that the problems posed by the Club of Rome economists are noteworthy for sustained progress development. The expansion of this theory was embodied in the principle of an endogenous self-regulatory ordinary resource business system (Unruh and Moomaw 1998). In the initial stages of socioeconomic development, additional emphasis is assumed to the main (agricultural) in addition to supplementary (industrial as well as production) areas and thus a high degree of extraction of natural resource extraction has been confronted. This misuse of natural resources leads to a greater loss of natural resources. As long as the supply of real resource extraction is unchanged at the start of industrial expansion and increased rates of global development result in increased demands for real resources, the cost of real resources is continuing to climb. This increase in the price of real resources discourages manufacturing homes from using more renewable resources because it raises the production costs and thus tends to move to less asset-overriding or commodity-effective technology (Duflou et al. 2012). This transition is taking effect at the latter periods of social and social development and is thus accountable for enhancing the efficiency of the atmosphere. We may also now see that the market apparatus is also liable for choosing the form of the EKC.

From the concept above, this study, therefore, looks into the N-shape EKC association regarding output and pollution by analyzing if EKC theory can be identified within the E7 states. Additionally, the U-shape EKC has been widely investigated therefore we consider to add to the existing literature by filling the unfilled gap in the literature. However, to our point of view, none of the existing researchers analyzed the EKC N-shaped association among CO_2 pollutants and GDP

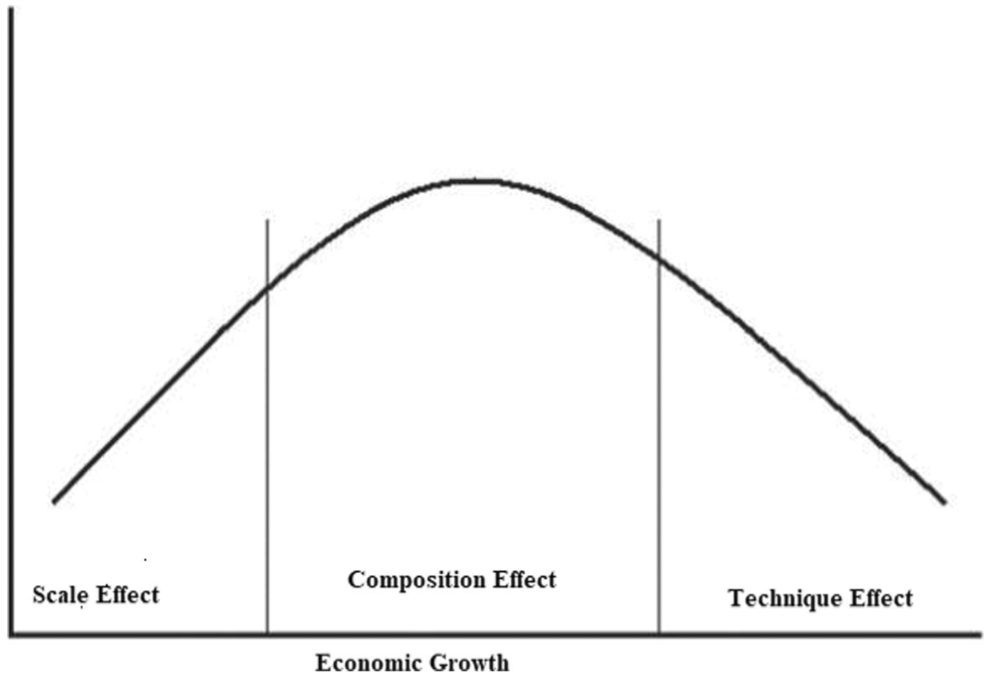

Fig. 1 Environmental Kuznets curve and frequencies of sustainable development effect by Shahbaz and Sinha (2019)

growth by utilizing the PMG-ARDL technique, incorporating external control variables such as green power usage as well as non-renewable power usage. Therefore, the main purpose of this analysis is to analyze the N-shaped EKC within the E7 ecosystem by using data from the WDI from the period of 1995 to 2018. Nevertheless, we examine if the environmental pollution of E7 societies impacts their commercial activity. There are many strategic explanations for classifying nations into separate categories. For instance, it is essential to research the E7 economies collectively (China, India, Indonesia, Brazil, Russia, Mexico and Turkey) because they are developing economies, most of which are middle-income economies and subject to 73% of the poor in the world citizens around five billion of the earth's seven billion population. Moreover, middle-income nations are the primary engines of economic development (World Bank 2017).

This is premised on the fact that ecological deterioration cannot be influence only by socioeconomic growth, and we do add parameters to monitor the impact of clean power usage and non-renewable power usage on ecological deterioration. We plan to address the relevant hypotheses: what is the connection regarding ecological destruction and socio-economic growth in the E7 nations? What can ecological pollution be clarified by the use of green energies and non-renewable resources? We used the PMG-ARDL panel to answer our study hypothesis. Also, the heterogeneous causality investigation was used to describe the causal connection regarding the variables. Yearly statistics were collected from the World Development Indicators (WDI) databank representing the E7 nations (made up of Brazil, China, India, Indonesia, Russia, Mexico, and Turkey) throughout the span 1995–2018.

This paper adds to current studies by strengthening our understanding of the potential N-shaped association regarding countries and ecological deterioration base on the E7 economy. Established research focuses primarily on specific nations, OECD countries, or broader sampling sizes of nations, but none has a focus on E7 states. This is a void in the current EKC documentation which we plan to fill by using PMG-ARDL regressions to recognize EKC in the E7 nations. Lastly, the literature on the N-shape EKC has not well been established which scholars are still investigating; therefore, this current study will add up to the existing literature.

This paper is structured as follows: the "Literature review" section provides a review of related literature. The "Data and methods" section focuses on data and methodological procedure employed, while the "Results, discussions, and implication of research findings" section concentrates on the interpretation of empirical findings. Finally, the "Conclusion and policy implications" section concludes the study with policy prescriptions accordingly.

Literature review

The EKC was originally introduced by Grossman and Krueger (1991), to demonstrate the connection regarding sustainable development as well as ecological destruction has the nature of an inverted U. Consequently, several studies have made efforts to empirically assess the hypothesis (Adedoyin et al. 2020a, b, c; Etokakpan et al. 2020; Kirikkaleli et al. 2020; Udi et al. 2020; Gyamfi et al. 2020a, b, Sarpong et al. 2020). The N-shaped EKC shows that perhaps the initial EKC theory would not be preserved in the longer term. Alternatively, the rise in wages more than a specific amount of income could contribute to a favourable correlation regarding sustainable development and ecological destruction Torras and Boyce (1998) indicate that perhaps the N-shaped dynamic takes place as the level impact overwhelms structure and technological consequences. This may be attributed to limited incentives to somehow develop the production of resources or to decreased gains on technical progress (Álvarez-Herranz and Balsalobre Lorente 2015).

After Grossman and Krueger (1991) first recorded an inverted U-shaped association regarding emission as well as revenue, detailed work has been performed into the EKC phenomenon (Ekins 1997; Acaravci et al. 2009). All of these analyses have studied the connection among sustainable development and ecological degradation under the EKC analytical framework, suggesting a connection among economic development and ecological sustainability, whereas ecological degradation is a growing aspect of the degree of socioeconomic development before a crucial threshold is achieved, after which better earning levels contribute to an increase in ecological performance.

The central point is that global development influences the world in 3 contexts: the impact of size, the impact of structure, and the technological influence (Grossman and Krueger 1991). The effect of sustainable development on ecological destruction can thus also be split together into the same 3 sections (Grossman and Krueger 1995).

(a) The scale impact ensures that although the socioeconomic system and infrastructure of a nation do not shift, an improvement in demand would contribute to a decline in ecological sustainability. It may therefore be claimed that the influence of sustainable development on the scale has a detrimental environmental influence.
(b) The compositional influence can have a beneficial influence on the ecosystem because, at the initial phases of socioeconomic activity, emissions rise as the socioeconomic system changes from farming to more asset-intensive large industrial enterprises, while at the subsequent phases, emission declines as the framework changes to utilities and small processing companies. As a result of this shift in the manufacturing system, the compositional impact may reduce the negative impact of sustainable development on ecological emissions. The compositional influence happens as the manufacturing industry, with its heavy power usage and harmful pollution, is substituted by the retail industry, which reduces contaminating pollution and tends to change the bend (Hettige et al. 2000).
(c) The economic impact applies to efficiency improvements, also, the introduction of green technology, contributing to an improvement in ecological standards. The technological impact applies to new technology that allows the utilization of fewer supplies per amount of manufacture or the introduction of healthier technology to substitute outdated ones in the development of products. The creation of sustainable technology is promoted by investments in ecological RD&D, which, in effect, involve adequate global expansion (Neumayer 1998).

Panayotou (1993) explains the development of global degradation and sustainable development in terms of size, structure, and technological impact. At a reduced stage of production, ecological degradation relies on agricultural capital and a small supply of environmentally friendly pollution. When global development accelerates by production, energy utilization, and industrialization, consumption levels tend to eclipse recycling levels, and pollution rises in both volume and pollution. This is accompanied by the advent of knowledge and manufacturing sectors, along with increasing climate issues, contributing to ecological protections, technical change, and increased expenditure in the ecosystem, which, in effect, promotes stability and a steady decline in ecological degradation, in which technological advancement assumes a significant part (Andreoni and Levinson 2001).

The scale impact applies to the allowance for incremental developments to maximize the benefit on the elimination of pollution (Torras and Boyce 1998). The scale effect creates an increasing pattern of the EKC as demand moves to urban demand, in so much as global growth leads to the ability to expand in data-based industries and services, as well as in the advancement of manufacturing technologies (composition impact) and the introduction of sustainable technologies (technical impact). All of these latter impacts may surpass the level impact to create a decline in the EKC slope. Additionally, Dinda (2004) suggest that, as industrial development rises, the degree of ecological toxicity is being reversed, primarily by technical influences. This insight connects the EKC with advances in technology since the scientific influence is greater than the structure and scale impact.

Although the N-shaped EKC is regarded as a recent discovery, it was revealed in the 1990s. Grossman and Krueger (1995) in addition to Panayotou (1997) identified the N-shaped association involving socioeconomic progress as well as sulfur dioxides (SO2). For in cooperation instances, there were little results during the 2nd changing stage, because it remained towards the far edge of the information gathering, as well as indeed the N-shape was rejected. Moomaw and Unruh (1997) consider the N-shaped EKC while utilizing FEM as well as cross-section OLS. Nevertheless, the researchers have employed a systemic change method that suggested that the move to reducing CO_2 pollution was the most probable outcome of the oil shock of 1973.

The effect of clean power on ecological destruction has been extensively researched in modern decades. Various reports show that greenhouse gas (GHG) emissions will be decreased when coal and oil are substituted by clean energies (Shafiei and Salim 2014; Salim et al. 2019; Al-Mulali et al. 2016, Bekun and Gyamfi 2020, Ozcan and Ozturk 2019). Clean power use would also have a detrimental effect on pollution (Shahbaz and Sinha 2019). Currently, Shahbaz et al. (2017) have shown that power conservation use is essential for long-term sustained economic growth in twenty-five advanced economies over the duration 1970 to 2014. Furthermore, Lu (2017) reports that there is a long-term correlation between green power use, pollutant, and GDP, considering panel information for twenty-four Asian states regarding the duration of 1990–2012 (Paramati et al. (2017)). Examination of the following 11 states shows that clean power growth and different business operations are necessary for stable business growth. In the 1980–2010 panel of 24 nations of sub-Saharan Africa, Ben Jebli et al. (2015) examined the short-term and long-term link regarding CO_2 emissions, GDP, clean energy use, and foreign trade, based on an environmental Kuznets curve (EKC) hypothesis. Short-run Granger causality findings showed a bidirectional causality regarding pollution and economic development, bidirectional causality from pollution to actual exports, unidirectional causality from real imports to emission levels, and unidirectional causation from trade to the use of renewables. Long-term forecasts indicate that these nations do not accept the inverted EKC U-shaped hypothesis: exports have a positive effect on CO_2 emissions, whereas imports harm the environment. Nevertheless, Rauf et al. (2018) studied for the Belt and Road Initiative (BRI) economics on environmental curve Kuznets theory that mega-projects in BRI will be an indicator of environmental damage. The on-site analysis includes new data from 1981 to 2016 with a specific emphasis on heterogeneity and cross-sectional dependency. The measured results show that the average group estimator offers good evidence and favours EKC in nearly every area. The long-term effect is calculated by pooled mean group estimates, which display substantial effects in each region; also, in the long term, the EKC hypothesis has been proven in particular for the economies created.

The trajectory of the highlighted literature survey shows a vacuum in the extant literature for the need to explore the connection between output and CO_2 comprehensively by accessing for the N-Shape EKC. The variables covered in this current study is timely and worthwhile given the inconclusive outcomes in the literature in the energy-environment debate. To the best of our knowledge, none of the previously mentioned studies used a battery of techniques such as PMG-ARDL and the heterogeneous causality test to estimate N-Shape EKC in terms of both long- and short-run which this study intends to fill this gap. Furthermore, studies such as Shahbaz et al. (2019) concentrated on the N-shape for the Middle East and North Africa countries while Halliru et al. (2020) concentrate on six West Africa countries. Therefore these current studies differ in countries selection by investigation the N-Shape for the E7 economics.

Data and methods

Data

This section of the study outlines the material, method, and variables. Subsequently, model construction based on economic intuitions and empirical backing and onward results interpretation and discussion. The data for this study covers the period 1995 to 2018. Data was sourced from two sources namely the World Bank and The US Energy Information Administration. The data on CO_2 emissions and GDP (GDP growth annual %) were collected from the World Bank, while renewable energy and non-renewable energy data were obtained from the US Energy Information and Administration database. A more detailed description of the data is shown in Table 1.

Model and methods

This analysis aim is to look at the presence of N-shaped EKC in the emerging 7 states. As mentioned in the literature review, few studies have been carried out for other groups of countries. Hence, this study is one of the first to consider this topic for the E7 countries. In other to estimate the impact of GDP, renewable energy and non-renewable energy intake on CO_2 emissions and to analyse the development of the EKC in the E7 countries, the following model equation is proposed:

$$LNCO_2 = f(\mathrm{GDP}, \mathrm{LNREC}, \mathrm{LNNREC}) \tag{1}$$

$$LNCO2 = \alpha_0 + \beta_1 GDP_{it} + \beta_2 GDPsquare_{it} + \beta_3 GDPcubed_{it} + \beta_4 LNEC_{it} + \beta_5 LNNEC_{it} + \varepsilon_{it} \tag{2}$$

The variables in the model have undergone a logarithmic transformation to ensure they maintain a constant variance across all the series, where $\mathrm{LNCO_2}$, *LNEC*, and *LNNEC* are logarithmic transformations of all variables and ε_{it} , α and β's represent the stochastic, intercept, and partial slope coefficients, respectively. Hence, the GDP, GDP, square and GDP cubed were not in their logarithmic form because the GDP annual growth % was employed which does not need to be logged.

We employ the pooled mean group-autoregressive distributed lag (PMGARDL) estimator to analyze the variables of interest. This method will enable us to assess together the short and long run approximations utilising the Pesaran et al.

Table 1 Description of variables

Variable	Description	Source
$LNCO_2$	Carbon dioxide emissions, thousands of tonnes	The World Bank
GDP	GDP growth (annual %)	The World Bank
LNNREC	The sum of Gasoline production; Jet fuel production; and Oil production (thousand barrels per day)	The US Energy Information Administration
LNREC	Renewable power generation, billion kilowatt-hours	The US Energy Information Administration

Source: Authors compilation

(1999) technique. The analysis will involve an autoregressive distributed lag (ARDL: p, q) structure that integrates lags of $C0_2$ pollutants and other control variables, shown by:

$$LNCO2_{it} = \beta_i + \sum_{j=0}^{p} \delta_{ij} LNCO2\, Z_{it-j} + \sum_{j=1}^{q} \varphi \delta_{i,j} Z_{it-j} + \varepsilon_{it} \quad (3)$$

where Z_{it} = ($LNREC_{it,}$ $LNNEC_{it}$, GDP_{it}) which is a vector of descriptive variables utilised in this analysis. β_i symbolizes the country-level fixed effects, δ_{ij} symbolizes slope of the lagged emissions variable, and $\varphi_{i,\ j}$ symbolizes the slope of lagged explanatory variables.

The ARDL cointegration estimator is more useful than the traditional panel data models. It is capable of accounting for endogeneity matters in econometric representations and at the similar period accommodate together short-run and long-run strictures. The ARDL cointegration assessment also allows the use of variables in a varied order of combination for instance I(0) and/or I(1), not I (2). According to Pesaran et al. (1999), the pool mean group (PMG) estimator is dependable, robust, as well as durable to lag orders and outliers.

Results, discussions, and implication of research findings

Pre-estimation diagnostics

Descriptive statistics and correlation

Table 2 shows the summary statistics of the variables in the model. It appears that GDP has the highest average value of 5.11 million dollars per annually, single maximum values of 14.23 million dollars per annually, and minimum value of 4.69 million dollars per annually and is the most dispersed variable in the model. The next is nonrenewable energy which has an average of 4.42 metric tons per year, a minimum of 3.94 metric tons per year, and a maximum of 4.53 metric tons per year. Renewable energy fellow with an average of 3.05 metric tons per year, a minimum of 1.17 metric tons per year, and a maximum of 3.99 metric tons per year. While emission is the least with an average of 1.15 metric tons per year, a minimum of −0.17 metric tons per year and a maximum of 2.55 metric tons per year. The Jaque-Bera values show that the observations are typically dispersed. Table 3 presents the relationship matrix and it reveals that there is a negative linear connection regarding GDP, clean energy in addition to the dependent variable CO_2 emissions. On the other hand, there seems to be a positive linear connection regarding non-renewable energy as well as CO_2 emissions. Again, the output is found to have a positive correlation with clean energy and non-renewable energy, while clean energy has a negative correlation with non-renewable energy.

Cointegration and unit root tests

In other to test for cointegrating associations regarding the variables, the investigation adopts the Johansen Fisher Panel cointegration test (Table 4) and the Kao's residual cointegration tests (Table 5). As can be seen, the *p* values obtained from the outcomes of both analysis endorse the existence of a cointegrating connection regarding the variables $C0_2$, GDP, clean energy, and non-renewable energy utilisation.

Table 2 Summary statistics

	$LNCO_2$	GDP	LNREC	LNNREC
Mean	1.161160	5.087110	2.912826	4.330405
Median	1.151564	5.109085	3.046483	4.427331
Maximum	2.548271	14.23139	3.997909	4.530320
Minimum	-0.172050	4.687110	1.171799	3.938051
Std. Dev.	0.739137	4.089790	0.909775	0.187458
Skewness	0.259702	-1.100349	-0.583705	-0.557863
Kurtosis	2.177571	5.205376	2.081083	1.766685
Jarque-Bera	6.623185	67.94725	15.45078	19.36136
Probability	0.036458	0.000000	0.000441	0.000062
Sum	195.0748	787.4345	489.3548	727.5081
Sum Sq. Dev.	91.23601	2793.306	138.2242	5.868471
Observations	168	168	168	168

Source: Authors computation with data from WDI

Table 3 Correlation matrix

VARIABLES	$LNCO_2$	GDP	LNREC	LNNREC
$LNCO_2$	1.0000			
p value	-			
GDP	−0.085029	1.0000		
p value	(0.2731)	--		
LNREC	−0.948447***	0.145825*	1.0000	
p value	(0.0000)	(0.0593)	---	
LNNREC	0.783964***	0.070418	−0.845635***	1.0000
p value	(0.0000)	(0.3644)	(0.0000)	---

Note: ***, **, and * are 1, 5, and 10% significant level, respectively

Table 5 Kao's (1999) residual cointegration test results

	t-Statistic	*p* value
ADF	−1.641311*	(0.0504)
Residual variance	0.003214	
HAC variance	0.003059	

Note: ***, **, and * are 1, 5, and 10% significant level, respectively

Table 6 shows the results for the unit root analysis. From the observation of the Augmented Dicker Fuller (ADF) and Philips Perron (PP), unit root estimations agree that all variables are first difference stationary. At levels with constant only, one variable is stationary for both tests while at level with constant and trend all variables are stationary in the ADF tests and only three for the PP test. However, all variables are stationary at I(1) for all tests. Hence, we agree that all variables are first difference stationary.

Estimation results

Table 7 shows long-run PMG-ARDL results for two models. The long-run estimation of the main model in column 2 of Table 3 fails to confirm the existence of an N-shaped EKC in the emerging 7 states which are unlike the study of Shahbaz et al. (2019) that affirms the N-Shape EKC for the Middle East and North African countries. Rather, the outcome approves the presence of an inverted U-shaped EKC in the focus states as shown by a positive coefficient of GDP and the negative coefficient of GDP squared at 1% level of significance. This signifies that at an earlier stage of economic expansion emissions increases, but a later stage of economic expansion emissions begins to fall after which there no further rise in emissions as is evidenced by the insignificant coefficient of GDP cubed. This finding is similar to that of Luzzati and Orsini (2009) and Acaravci et al. (2009). But it is different from that of Álvarez-Herranz and Balsalobre Lorente (2015). There is no significant connection regarding clean energy utilisation and $C0_2$ pollutants and it does not affirm the finding of Gyamfi et al. (2020c) which states that clean energy is significant in the G7 economy. From a different point of view, non-renewable energy has a positive influence on pollutant at a 1% level of significance. Specifically, a percentage increase in non-renewable power utilisation will lead to a 4.301% rise in pollutants which is a more than proportional change. This outcome implies that non-renewable energy is a major driver of pollutants in the emerging 7 states. Studies by Attiaoui et al. (2017) reached similar conclusions.

Similarly, results from the second-long run model affirm the presence of an inverted U-shaped EKC in the emerging 7 countries. The nature of the EKC is shown by the positive connection regarding GDP and pollutants and the negative association regarding GDP squared and pollutants. Going further, outcomes show that renewable energy leads to high pollutants in the focus countries by an average of 0.4881 %. This result is not as expected given that renewable energy comprises of non-CO_2 emitting energy resources. Similarly, non-renewable energy harms pollutants at a 1 % level of significance. This outcome is as expected since non-renewable energy often comprises of CO_2 emitting energy resources which is a major source of energy among the E-7 countries.

Table 8 presents the short-run results for the estimated models. The negative and significant error correction terms signify that there is a significant long-run association concerning the variables in the model. Also, short-run results for the main model (column 2, Table 8) reveal that there is no significant relationship between the lagged values of CO_2 ($LNC0_2$ (-1), $LNCO_2$ (-2)) and CO_2 emissions in the current

Table 4 Johansen Fisher panel cointegration test

Hypothesis no. of CE(S)	Fisher stat (from trace)	*p* value	Fisher stat (from max-eight)	*p* value
r≤ 0	52.54***	(0.0000)	30.56***	(0.0064)
r ≤ 1	31.14***	(0.0053)	29.92***	(0.0078)
r ≤ 2	12.74	(0.5474)	14.01	(0.4488)
r ≤ 3	8.985	(0.8320)	8.985	(0.8320)

Note: ***, **, and * are 1, 5, and 10% significant level, respectively

Table 6 Unit root test

	ADF				PP			
	At level		At 1st level		At level		Ar 1st level	
VARIABLES	$\pi\tau$	$\pi\vartheta$	$\pi\tau$	$\pi\vartheta$	$\pi\tau$	$\pi\vartheta$	$\pi\tau$	$\pi\vartheta$
$LNCO_2$	0.8590	0.7462**	0.0005***	0.0033***	0.8617	0.7058	0.0005***	0.0033***
GDP	0.0023*	0.0076**	0.0000***	0.0002***	0.0023**	0.0005**	0.0000***	0.0000***
LNREC	0.9893	0.5866*	0.0669***	0.1242***	0.9960	0.7302*	0.0730***	0.1296***
LNNREC	0.8675	0.4162*	0.0002***	0.0016***	0.8675	0.4098*	0.0002***	0.0016***

Note: ***, **, and * are 1, 5, and 10% significant level respectively Note: ***, **, and * are 1, 5, and 10% significant level, respectively; thus, $\pi\tau$ is with constant, $\pi\vartheta$ is with constant and trend

period. Similarly, economic expansion has no significant short-run effect on pollutants as shown by the insignificant coefficients of GDP, GDP-squared, and GDP-cubed. Likewise, clean energy utilisation and non-renewable energy utilisation have no significant impact on emissions in the short run.

The outcome for the second short run estimation ARDL (2, 1, 1, 1, 1) is similar to that of ARDL (3, 1, 1, 1, 1). The lagged value of $C0_2$ ($LNCO_2$ (-1)) does not have a significant influence on pollutants in the short run. Also, the insignificant coefficients of GDP and GDP-squared show that there is no significant short-run association concerning economic expansion and pollutants in the E-7 countries. In the same vein, the results for clean energy utilisation and non-renewable energy utilisation reveal that both have no significant effects on emissions in the E7 countries.

Heterogeneous causality test

Apart from assessing the long- and short-run interconnectedness among variables, it is important to evaluate the legitimacy of the direction of causality among the selected variables. This will help inform policy direction. Table 9 displays the outcomes for the heterogeneous causality test. The outcomes display that there is bi-directional causality concerning GDP and GDP-squared. This signifies that there is a feedback mechanism between GDP and GDP squared further implying that income at the initial stage of development (GDP) can predict income at a later phase of development (GDP-squared) and vice versa. From the other point of view, there is unidirectional causality from CO_2 pollutants to GDP-cubed, non-renewable energy and CO_2 pollutants, renewable energy and CO_2 pollutants. This illustrates that CO_2 emissions have a direct effect on income at a third phase of development (GDP-cubed) in the E7 countries and that non-renewable energy use has a direct effect on pollutants which is a positive impact (according to the estimation results in table 7). Similarly, cleaner energy also has a direct effect on pollutants which appears to be a negative impact (see results in Table 7), implying that increased use of cleaner energy will cause a fall in emissions. Based on the results of this paper, it is prudent for the E7 countries to actively invest in research and

Table 7 ARDL long run estimation results

Variables	ARDL(3, 1, 1, 1, 1, 1)	ARDL(2, 1, 1, 1, 1)
GDP	0.057257***	0.064897**
p value	(0.0075)	(0.0135)
GDP^2	−0.009240***	−0.006666***
p value	(0.0059)	(0.0049)
GDP^3	0.000385	-
p value	(0.1878)	-
LNREC	0.224716	0.488172**
p value	(0.2226)	(0.0405)
LNNREC	4.301323***	4.621717***
p value	(0.0000)	(0.0000)

Note: ***, **, and * are 1, 5, and 10% significant level, respectively

Table 8 Short-run ARDL test

Short-run equation			
ARDL (3, 1, 1, 1, 1, 1)		ARDL(2, 1, 1, 1, 1)	
Variables	Coefficient	Variables	Coefficient
COINTEQ01	−0.175277*	COINTEQ01	−0.123474**
D($LNCO_2$(-1))	0.158827	D(LNCO2(-1))	0.147377
D($LNCO_2$(-2))	−0.038580	D(GDP1)	0.019936
D(GDP)	−0.026704	D(GDP2)	−0.000989
D(GDP^2)	0.006916	D(LNREC)	−0.080294
D(GDP^3)	−0.000393	D(LNNREC)	0.063209
D(LNREC)	0.293390	**C**	−2.570884**
D(LNNREC)	0.524887		
C	−3.266532*		

Note: ***, **, and * are 1, 5, and 10% significant level, respectively

Table 9 Result of causality test

Null hypothesis:	Zbar. Stat	*p* value
GDP ≠ $LNCO_2$	−1.09002	(0.2757)
$LNCO_2$ ≠ GDP	1.49685	(0.1344)
GDP^2 ≠ $LNCO_2$	−0.85429	(0.3929)
$LNCO_2$ ≠ GDP^2	0.63815	(0.5234)
GDP^3 ≠ $LNCO_2$	−1.12777	(0.2594)
$LNCO_2$ ≠ GDP^3	1.76631*	(0.0773)
LNNREC ≠ $LNCO_2$	4.75937***	(2.E-06)
$LNCO_2$ ≠ LNNREC	−0.45317	(0.6504)
LNREC ≠ $LNCO_2$	2.59323***	(0.0095)
$LNCO_2$ ≠ LNREC	−1.02562	(0.3051)
GDP^2 ≠ GDP	1.99719**	(0.0458)
GDP ≠ GDP^2	2.01135**	(0.0443)
GDP^3 ≠ GDP	0.34293	(0.7316)
GDP ≠ GDP^3	0.79047	(0.4293)
LNNREC ≠ GDP	−0.13602	(0.8918)
GDP ≠ LNNREC	−1.43364	(0.1517)
LNREC ≠ GDP	0.56759	(0.5703)
GDP ≠ LNREC	−0.75735	(0.4488)
GDP^3 ≠ GDP^2	2.54868**	(0.0108)
GDP^2 ≠ GDP^3	4.07425***	(5.E-05)
LNNREC ≠ GDP^2	0.47231	(0.6367)
GDP^2 ≠ LNNREC	−1.52168	(0.1281)
LNREC ≠ GDP^2	1.84577*	(0.0649)
GDP^2 ≠ LNREC	−0.32369	(0.7462)
LNNREC ≠ GDP^3	0.63014	(0.5286)
GDP^3 ≠ LNNREC	−1.45476	(0.1457)
LNREC ≠ GDP^3	2.71433***	(0.0066)
GDP^3 ≠ LNREC	−0.73576	(0.4619)
LNREC ≠ LNNREC	1.34950	(0.1772)
LNNREC ≠ LNREC	8.85108***	(0.0000)

Note: ***, **, and * are 1, 5, and 10% significant level respectively while ≠ represents does not "Granger cause"

development and identify a more refined technical means to increase the consumption clean energy to shift away from non-renewable which has a direct impact on the economy. This will help play a key role in combating carbon dioxide for a healthy atmosphere for its population.

Conclusion and policy implications

The connection concerning economic activity and the environment has become an important topic of discussion, given the current wave of climate and environmental crisis traced to rising environmental pollution from economic activities. It is even more important to investigate this relationship in the Emerging-7 countries that are responsible for a large amount of global economic activity. This analysis varies from the previous examination in the literature as it examines the N-shaped EKC for the E-7 countries using data spanning the period 1995 to 2018. To analyze this relationship the study employs the use of PMG-ARDL estimator and heterogeneous causality tests to establish the long run and short-run and direction of causality respectively regarding the variables of interest.

The study findings are interesting. The long-run results fail to affirm the presence of an N-shaped EKC in the emerging 7 states but rather confirms the presence of an inverted U-shaped EKC in the examine nations. While non-renewable energy has a positive and significant relationship with CO_2 pollutants. Short-run outcomes display that there is no significant connection concerning economic expansion, cleaner energy, non-renewable energy, and CO_2 emissions. Causality tests showed a bi-directional causality regarding GDP and GDP-squared, and a uni-directional causality from CO_2 emissions to GDP-cubed, non-renewable energy and $C0_2$ emissions, clean energy, and CO_2 emissions.

Following results obtained in the study, we make the following policy recommendations. First and foremost, this study recognizes the significance of energy in powering sustainable development in the E7 countries. Despite the importance of achieving high target sustainable development and the improved standards of living that follow, the harm imposed on the environment as a result of energy-related emissions cannot be ignored. It then becomes necessary to look for sustainable means to achieve economic development goals and improvement in the quality of the environs simultaneously. This can be attained through the increased use of clean energy sources to power economic activities as opposed to carbon-emitting energy resources. It, therefore, becomes necessary that more investments be channelled towards harnessing renewable energy sources sufficient to drive economic needs and other forms of energy demand. With renewable energy, the E7 countries will pursue ambitious economic growth without threatening the quality of the environment. In the same vein, the government can encourage the use of renewable energy by providing economic incentives such as tax breaks for firms that agree to adopt clean energy for production activities. With such motivation, there will be increased use of renewable energy in the E7 countries, and emissions will be on a downward slope. In the same vein, the government should discourage the use of fossil fuels by imposing a carbon tax on high carbon-emitting activities. Such a measure could go a long way to discourage the use of fossil fuels thus, arresting emissions and its harmful impact on the environment. With the implementation of these measures will aid the E7 countries in contributing to the attainment of the Paris accord-global agreement to cut emissions by 1.5 °C.

This study employed CO_2 emissions as a proxy for the quality of the environment. future studies can consider using ecological footprints (EFP) as a proxy for environmental quality considering its ability to represent natural resources. Individual studies could also be carried out on a related topic to have a more appropriate document for environmental policy for specific countries.

Acknowledgments Author gratitude is extended to the prospective editor(s) and reviewers that will/have spared time to guide toward a successful publication.

Authors' contributions The first authors (Dr Bright Akwasi Gyamfi) were responsible for the conceptual construction of the study's idea. The second author (Dr Festus Fatai Adedoyin) handled the literature section while third authors (Dr Festus Victor Bekun) managed the data gathering, preliminary analysis and Prof. Dr Murad A. Bein was responsible for proofreading and manuscript editing.

Funding I hereby declare that there is no form of funding received for this study.

Data Availability The data for this present study are sourced from the World Development Indicators (https://data.worldbank.org/). The current data specific data can be made available upon request but all available and downloadable at the earlier mentioned database and weblink.

Declarations

Ethical approval Authors mentioned in the manuscript have agreed for authorship read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.

Consent to participate Note Applicable

Consent to publish Applicable

Competing interests I wish to disclose here that there are no potential conflicts of interest at any level of this study.

Disclosures The authors of this article also assures that they follow the springer publishing procedures and agree to publish it as any form of access article confirming to subscribe to access standards and licensing.

Many thanks in advance look forward to your favourable response

Yours truly,

Authors

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