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RESEARCH ARTICLE

Causal correlation between energy use and carbon emissions in selected emerging economies—panel model approach

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Abstract
Fossil fuels used in energy mix continues to dictate world heat usage. Demand for heat is considered as substantial contributor to carbon emissions and energy-related emissions equivalent to 12.5 Gt of carbon emissions. Data on heat is limited and therefore, a study on the causal correlation between energy use and emissions would provide policy guidance on how to decarbonize the heat sector to achieve Paris's Greenhouse Effect Treaty. Most empirical works aggregated energy consumption and ignore spatial dependence and heterogeneity in a panel dataset. Our study, however, disaggregated energy into renewable and non-renewable to find their distinct influence on emissions, which were tested for spatial dependence and heterogeneity and applied potential emissions as environmental impact. Using FGLS and PCSE estimators for the period 1971–2013, our findings revealed that the increase in renewable energy use and industrialization improves the ecological structure of emerging economies while the increase in population, economic expansion, and non-renewable energy use increases the carbon stock. We accordingly, investigated causation direction with pooled mean group estimator. Rising economic power states therefore encourage to ensure energy efficiency and replace fuel use with renewable source for heating to reduce carbon stock.

Keywords Carbon dioxide emission · Renewable energy use · Non-renewable energy use · Emerging economies

Introduction

Carbon footprint worldwide has increased as a result of human activities like burning of hydrocarbon deposits as coal, petroleum, and gas (Lackner 2010; Luo et al. 2017). Carbon footprint increase is a result of the movement of people from one place to another and power generation, which has shown an increase of methane, fluorinated gases, nitrous oxide, and carbon dioxide emissions. Carbon dioxide emissions account for 60% of world emissions (Wang and Dou 2013; Field et al. 2014). It is common to link energy consumption to CO_2 emissions as studied by other researchers. There is an urgent necessity to confront world environmental challenges, which has a detrimental effect on human habitat. Human activities are considered as one of the contributors to carbon footprint worldwide through the usage of energy. Energy is very important for any economic development particularly for economies as Russia, Brazil, India, South Africa, and China which have come together to form BRICS. However, the provision of energy and the use of it come with ecological problems. That is, energy use increase carbon stock.

Quite a number of scholars had looked at the contribution of energy usage to carbon emission in either advanced or developing countries (Chen et al. 2007; Huang et al. 2008; Lozano and Gutierrez 2008; Hatzigeorgiou et al. 2011; Ozturk and Acaravci 2011; Apergis and Ozturk 2015). Some of the researchers' findings indicate a unidirectional link from energy consumed to CO_2 (Pao and Tsai 2011; Gul et al. 2015;

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Jammazi and Aloui 2015) while Jalil and Mahmud (2009) and Jaunky (2011) established the connection from economic growth to CO_2. Others also found the causation from emissions to energy usage and economic progress (Soytas and Sari 2009). Alternatively, other studies found no evidence of causal correlations between the variables (Zhang and Cheng 2009). Even though studies had been conducted in BRICS countries, nevertheless, there are still shortfalls in looking at the casual novelties of various variables that are relevant in the determination of future energy needs and mitigation strategies. However, researchers have undertaken similar studies on the association between economic development, consumption of energy, ecological pollution, and other variables (Cowan et al. 2014; Al-Mulali and Ozturk 2016; Asumadu-Sarkodie and Owusu 2017a; b; c). As a contribution to empirical research work in BRICS, our study look at the distinct influence of renewable and non-renewable sources of energy practice on pollution. It is surprising that no empirical work had been undertaken to find the link between energy use, economic progress, industrialization, population, and environmental pollution in BRICS economies. It is against this background that the study introduces energy consumption into the nexuses by disaggregating it into sustainable energy and non-renewable fuel source. Evolution of energy-consuming activities of both human and industries of emerging economies leads to two precarious problems. Among them is the diminution of most available energy possessions (i.e., oil, gas, coal) and the proliferation in carbon stock such as carbon dioxide emissions and methane, which cause global warming (Shakouri and Khoshnevis Yazdi 2017). In relation to this (World Energy Council 2016), a report indicates CO_2 emissions in Europe have plunged by 22% between the period of 1990 and 2014, while resilient economic growth in countries such as China and India stemmed in triplicating CO_2 emissions. A rising number of people and economic development in BRICS economies are intensifying energy provision to meet high demand. This current trend of energy needs requires an increase in energy inputs leading to a large volume of greenhouse gas discharged (Shahbaz et al. 2012; Zeshan 2013). Countries that consume more energy continue to add to global emission stocks which end up causing ecological degradation. In contrast, energy resources globally are diminishing with regard to non-renewable. Therefore, universal research is now channeled towards environmental-friendly energy assets and particularly regards to policies on CO_2 emissions, which has high potential to disrupt ecological sustainability for future generation. The analysis of the correlation between energy use, economic growth, population, industrialization, and carbon emission would provide an emerging economy's significant findings relevant to policy stakeholders. The marginal elasticities for the long term would help emerging states policy assessment while the causation test results from the analysis would provide energy policy direction that is sustainable and eco-friendly (Payne 2010).

Recent studies related to our study used different methodologies to unravel the correlation between variables. However, we employed a feasible form of generalized least squares (FGLS) and panel-corrected SE (PCSE) to determine the long-run estimates while the pooled mean group (PMG) was applied to find the direction of interconnection. First, we are certain that no research study had analyzed the relationship between energy use, economic progress, industrialization, population, and carbon emissions in developing countries. Second, no empirical work had been done to examine inexhaustible and unrenewable energy sources to find their distinct influence on environmental pollutions in emerging countries. Third, the article also used FGLS and PCSE to estimate coefficients of predicting variable's relations with the dependent variable. Four, PMG estimator was used to determine the connection between variables of the model. Five, no study had been done on energy-related emission nexus using potential CO_2 emissions as a dependent variable in emerging economies. We applied panel cointegration modus operandi to examine the long-term correlation between variables. The adaption of panel cointegration in the analysis provides a greater number of independent parameters in addition to a variation of the sample size, than the time series data. Our paper, therefore, focused on energy consumption–related CO_2 emissions of selected emerging states. The motivation of the study was based on the IEA report, which indicates that over half of the global energy usage is for heat. The report further indicates energy consumption for heat alone in 2015 is equivalent to 205 EJ (4900 megatonnes of oil equivalent [Mtoe]). Nonetheless, half of the heat generated is for space, cooking, and warming buildings during cold weather. On the other hand, half of heat creation is used by industries to drive industrial operation through steam production. Fossil fuels used in energy mix continue to dictate world heat usage (REN21 2018). Heat demand is considered an important contributor to emissions and in 2015 accounted for 39% of annual energy-related emissions equivalent to 12.5 Gt of carbon dioxide emissions.

Despite this, the demand for heat varies across countries depending on climate conditions, industrial structures, level of economic expansion, and the efficacy of the equipment for heating. A country like China accounted for 53.7 EJ in 2015 which constitute 26% of global heat consumption (US Environmental Protection Agency 2017). Industries in China alone consumed 70% of 53.7 EJ of heat used up. The World Energy Council (2016) report predicted heat demand to increase in the years to come. Despite the effort of stakeholders to mitigate its negative effect through energy efficiency, fossil fuels use still play a relevant role in heat provision in years to come. Data on renewable heat is limited and therefore, a study on the causal relationship would provide policy guidance to decarbonize heat sector to achieve Paris's climate change agreement. However, US Environmental Protection Agency (2017) reiterated that two thirds the global energy is used to produce electricity which ends up going to waste in the form of heat quitted to the atmosphere in the process. A universal green energy policy is important because of the sharp increase in CO_2 emissions, which, if left unchecked, could jeopardize the prospects for sustainable development of emerging economies. It is therefore necessary to observe causal relation between energy production, energy use, economic fruition, and pollution of BRICS economies. It is believed the findings would serve as policy guidance for energy sustainability and ecological protection of emerging economies.

The remaining of the study is divided into sections of four; the "Literature review" section will look at the literature review which is also sub-grouped into four strands; the "Materials and methods" section deals with materials and method; the "Empirical results and discussions" section covers empirical results and discussions while the "Conclusions and policy implications" section deals with the conclusions and policy recommendations respectively.

Literature review

Energy consumption-carbon emission nexus

Researchers have conducted extensive research to find the connection between energy use and carbon dioxide emissions from one country to another and also as a panel (Mensah 2014). However, the effects of energy consumption on emissions are also controversial. Several studies have established different effects both positive (Pao and Tsai 2011; Ahmed et al. 2017) and negative (Apergis et al. 2010; Menyah and Wolde-Rufael 2010a, b) energy uses on CO_2 emission. Some research results also revealed interesting findings whereby carbon emission was found to cause energy consumption increase (Soytas and Sari 2009). Even though previous studies had provided some insight on the effects of energy consumption on emissions, the studies still have some limitations relating to omissions of certain variables that are considered as contributors to CO_2 emissions. Hussain et al. (2012) studied the correlation between pollution, economic spreading out, and energy use in Pakistan, using CO_2 emission, energy per capita consumption, and growth per capita as variables for the study, which represent environmental indicator, energy consumption indicator, and economic indicator respectively. Performing VECM and Granger's connection tests, the study found bidirectional liaison between CO_2 and energy consumed. A study by Ahmada et al. (2016) in Malaysia between 1980 and 2011 used STATA to determine economic activities influence on CO_2 emissions. A study by Ahmad et al. is meant to find the association between GDP, energy consumption, international trade, and overseas investment towards CO_2, as well as to examine the effect that expansion of an economy has on environmental deterioration. Findings indicate a significant relationship between variables as GDP, energy consumed, foreign trade, and environmental deterioration.

Alam et al. (2015) investigated the influence of economic indicators as energy resources, energy used, population growth, and financial growth on environmental effluence over the time period from 1975 to 2013 in Malaysia. The analysis results postulate that energy use and financial increase do cause an increase in ecological pollution. Similar results were obtained by Menyah and Wolde-Rufael (2010b) in South Africa. They utilize the bound test approach and Granger's causation test to find cointegration and direction of the connection between economic development, environmental pollution, and energy usage. Their findings revealed a cointegration among variables and that emissions of CO_2 are caused by energy use. Menyah and Wolde-Rufael (2010a), on the other hand, also investigated the causal correlation between nuclear energy usage, emissions, and real growth in the USA between 1960 and 2007. Causation test results revealed unidirectional causation running from consumption of nuclear energy to CO_2 emissions. Nonetheless, the study further found nuclear energy use to improve the environment thereby, mitigating the negative effects of CO_2 emissions. Bloch et al. (2012) employed the Johansen cointegrating test, variance decomposition, and vector error correction to find the causality among the variables in China. The study period spanned from 1977–2008. Findings show an existence of a bidirectional connection between environmental pollution and coal use. They further concluded their study, which suggests that energy use and GDP contribute positively towards the ecological environment of China. Zhang and Lin (2012) examined the effects of economic indicators such as urbanization, population intensities, GDP, industrial production, services provision, and energy use and their relationship with carbon emissions in China between the periods of 1995 and 2010. They applied fixed effect ideal and least square generalized linear regression technique. Study findings reiterated some of the findings of other researchers that GDP, industrial production, energy usage, and demographics have an influence on emissions. Shahbaz et al. (2013) adopted a similar methodology of bounds tests to determine the cointegration between variables 1975Q1 and 2011Q4 in Indonesia. The study tried to find a link between CO_2 emissions, energy use, financial development, and international trade. Findings of causality relationships among variables indicate that economic increase and energy use intensifies carbon emissions.

Other studies examined the link between variables using panel data. Typical among them is the study by Apergis and Payne (2014) of seven countries as sample size in Central America for the period of 1980 to 2010 to scrutinize the relationship and the effects of renewable energy use, GDP, oil, coal, and population on carbon emissions. They applied fully modified ordinary least squares (FMOLS) to assess the peripheral effects of the predicting variables on emissions while using an error correction vector model to find the causative direction. Results established that energy use and GDP affects CO_2 emissions in Central America. Baek and Pride (2014) also took samples from six major nuclear power economies to examine the link between revenues, nuclear energy, and CO_2 emission nexus over the period 1990–2011. A multivariate cointegrated vector autoregression econometric model was used while the Johansen cointegrating test was performed. Empirical findings depict that economic indicators such as GDP and nuclear production and consumption positively affect the environment. Rafindadi et al. (2014) used the ordinary least square technique to find a causal relationship between hydrocarbon fuel use, other indicators of economic activity, and environmental pollution in the Asia-Pacific region from 1975 to 2012. Findings indicate a significant correlation between emissions and GDP. Their study discovered that energy use impacts the environment of Asia-Pacific states positively. Arouri et al. (2012) also found that the long-run energy use has a significant and positive bearing on carbon emissions of 12 Middle East and North African economies. A study by Jebli and Youssef (2017) investigated dynamic links between the use of renewable energy per capita, agronomic value added, carbon emissions, and GDP in five North Africa states. Through the use of panel cointegrating technique and the Granger causation test, the study showed that unidirectional interconnection ranged from renewable energy to emissions. The study, however, concluded that GDP or consumption of energy increases the CO_2 emissions level. Therefore, North African states should use clean renewable energies to reduce carbon emissions. On the contrary, the results of the study of Hossain (2011) showed the nonexistence of the long-term bond between energy use and emissions. Despite this, in the short term, the results suggest a unidirectional correlation from economic development and foreign trade to CO_2 emission. Ang (2007) examined the dynamic relationship between ecological pollution, energy usage, and productivity in France. Multivariate vector error correction technique was used for the period 1960–2000. Findings indicate that as France consumes more energy, CO_2 emissions also increase. The study found a quadratic nexus between CO_2 emissions and output in the long term. Similar work was also undertaken by Lim et al. (2014) to investigate both short- and long-term causation estimations among CO_2 emissions, oil use, and economic expansion in the Philippines. Results of the study spanning from 1965–2012 using an error correction model indicate a bidirectional connection between CO_2 emissions and oil consumption. A study by Marrero (2010) also found the elasticity between total energy use and emissions to be more than zero but lower than unity. This means that percentage reduction of energy consumption would not provide the same or equivalent percentage reduction in emissions. Dogan and Seker (2016a) explored the impact of the use of non-renewable energy, renewable energy, actual income, foreign trade, and financial increase of the major countries listed in RECAI disclosed by EY. The study applied the second-generation econometric model to test for panel unit root and cointegration using the covariate augmented Dickey-Fuller (CADF) and the cross-sectionally augmented Im, Pesaran, and (CIPS) and LM bootstrap cointegration test respectively. Findings revealed an increase in alternative energy, financial development, and international trade reduced the level of emissions, while the opposite increased non-renewable energy use.

Industrialization-environmental pollution relationship

Industrialization is a transformational change in human society, either socially or economically, from an agricultural society to an industrial society (Sadorsky 2014; Mgbemene et al. 2016). Industrialization is vital to wealth creation and a better life for society, but in reality, it presents unique opportunities and challenges. Industrialization affects the environment and eventually adds to change of weather pattern. Some of the challenges include an increased demand for energy, extreme weather conditions, increased industrial waste, higher temperatures, change in human life, and changes in philosophy. Generally, it is recognized that global warming is caused by carbon stocks as carbon dioxide, methane, nitrous oxide, chlorofluorocarbons, and the release of other particles into the atmosphere. According to Mgbemene et al. (2016), CO_2 emissions account for 98%, while methane and nitrous oxide emissions account for 24% and 18% of global carbon stock respectively, due to the combustion of hydrocarbon fuels for heating, cooking, and generating electricity as a source of energy to power factories. The intensification of carbons discharged is concomitant to human effort towards industrialization.

Luken and Castellanos-Silveria (2011) investigated the negative and positive impact of industrial transformation on sustainable development of developing economies. They grouped the developing economies into five based on how the countries have managed to transform and reoriented their manufacturing sector. Results exposed economies that are experiencing massive industrial transformation have less impact on energy intensity although the transformation contributes a lot to economic development and employment in general. Lin et al. (2015) investigated the impact of industrialization on carbon emissions in Nigeria using Kaya Identity technique, the Dickey-Fuller augmented unit root analysis, the Johansen cointegrating method, and vector error correction for the analysis. The study results show industrial value to have significant but the inverse correlation with CO_2 emissions. Meaning, no evidence was found to show that industrialization influences the increase of emissions in Nigeria. The study, however, found population and economic evolution to have positive and substantial control on emissions. Asumadu-Sarkodie and Owusu (2017a) also looked at causal effects of these variables: carbon emissions, electricity consumed, economic development, and industrial value added to the economy of Sierra Leone for the period 1980 to 2011. Using linear regression and the vector error correction method, the study found a long-run connection between the variables. Asumadu-Sarkodie and Owusu 2017c) conducted a similar study in Senegal by performing multivariate scrutiny of carbon emissions, electricity use, economic growth, industrialization, and urbanization. The research study was conducted between the periods spanning from 1980–2011 using nonlinear iterative partial least squares. Empirical results show that the increasing variables as industrialization and electricity use lead to increase emissions in Senegal. A study by Asumadu-Sarkodie and Owusu 2016a) found industrialization to cause an increase in long-term environmental pollution in Benin while an increase in electricity consumption resulted in both short- and long-term emission increases. The study was undertaken between the periods 1980 and 2012 using autoregressive distributed lag approach. An empirical work by Brahmasrene and Lee (2017) in Southeast Asia depicts a long-run association between environmental pollution, urbanization, industrialization, globalization, and economic growth. Findings revealed an intriguing paradox that industrialization in Southeast Asia was found to be insignificant in the short term. However, in the long term, industrialization and urban growth generate emissions. In a paper by Raheem and Ogebe (2017) on CO_2 emissions, urban growth, and industrialization, data from direct and indirect panel analysis examined the effect of two variables on emissions in 20 African states for the period 1980–2013. Unexpectedly, the findings of industrialization and urban increase effects on CO_2 was seen in direct and indirect ways. In a direct sense, the study found industrialization and urbanization to increase environmental degradations while indirectly, two variables were found to decrease environmental degradation. That is, at a certain point, the indirect effect of industrialization will swarm the direct effect leading to a reduction of environmental degradation.

Economic development-carbon dioxide emission causal relationship

The third area of research focuses on the study of the link between economic growth and ecological pollution. Most of the previous empirical studies in this research division were designed to analyze the validity of the environmental Kuznets curve. The Kuznets environmental curve hypothesis (EKC) clarifies that, initially, environmental pollution escalates as the country begins to develop, but at a certain stage of economic development and growth, the level of pollution decrease (Kuznets 1955; Appiah et al. 2017). Therefore, the attainment of high economic development means countries now have sufficient resources to mitigate any form of environmental destruction (Apergis and Ozturk 2015; Baek 2015; Babu and Datta 2016; Jebli et al. 2016; Narayan et al. 2016). In other words, EKC is proposed as a U-shape. The revelation of the EKC hypothesis existence in a particular study means that economic progress which is expected to be a threat to the ecological system now becomes the source of environmental enhancement. The causal link between economic progress and carbon emissions has been analyzed in several empirical studies. While some empirical work was done based on individual countries, others were dealt with as a group of countries. Among the two, the latter group of research is most of the time done in developed states. In all these studies, a significant correlation was found between economic development and carbon emissions (Apergis and Ozturk 2015; Bento and Moutinho 2016; Jebli et al. 2016; Ozturk et al. 2016). Some studies on EKC hypothesis found a positive relationship (Kivyiro and Arminen 2014; Lau et al. 2014; Al-Mulali et al. 2016; Balaguer and Cantavella 2016; Tedino 2017; Appiah et al. 2018), neutral or no evidence of EKC (He and Richard 2010; Saboori and Sulaiman 2013; Boamah et al. 2018), and even negative relationship (Lapinskienė et al. 2014) between emissions and economic advancement. Hussain et al. (2012) examined the association concerning environmental pollution, economic development, and the use of energy in Pakistan. Using vector error correction and conservative Granger's connection tests, the study discovered the unidirectional link between CO_2 and GDP proxy of economic growth. Comparable findings by Ahmada et al. (2016) in Malaysia from 1980–2011, applying STATA software, found that economic activities have an impact on carbon releases into the atmosphere. The findings revealed significant affiliation between economic improvement and emissions. Study results by Jaunky (2011) also added to other research findings. The research found unidirectional causation from economic growth to environmental emissions.

Abdullah (2015) applied multiple linear regressions, *F*-test statistics, and error analysis to study the linear bond between CO_2 emissions and economic variables of the UK (i.e., energy supply, business, transport, population, agriculture, industrial process, and waste management) and Malaysia (i.e., fuel mix, transport, GDP, and population). The study explored the relationship with different variables and years for both the UK (1990–2010) and Malaysia (1981–2005). The study found the UK prediction model outperformed Malaysia model and that Malaysia predictors are not considered as good predictors of CO_2. Tang and Tan (2015) also conducted a similar study in Vietnam between 1976 and 2009 to understand the correlation between CO_2 emissions, energy use, overseas investment, and economic evolution. Tang and Tan (2015) applied the Johansen cointegration and Granger's causality technique. Long-term correlations were established between the variables and the results of EKC theory tests support the U-shaped inverse link between CO_2 emissions and economic development in Vietnam. Likewise, the study by Kacar and Kayalica (2014) also supports U-shaped link between economic growth and sulfur emissions from 42 countries with induced parameters as trade and population.

Population growth—carbon dioxide emissions

There is an increasing nervousness which considers the growth of the population as one of the factors behind swift upturn of universal emissions. The population growth, complemented by the industrial uprising, necessitates the need to have land for farming and urban expansion. This then drives considerable precipitation of deforestation thereby changing the ecological system. The eruption of the population implies more fossil fuel combustion to mollify their energy needs. Pragmatic studies have shown that population increase has the driving elements behind rapid universal carbon emissions in both developing and developed economies (Engelman 1998; Lutz et al. 2001; Shi 2003). Emerging economies, increase in population, energy use, and economic progress will become major elements in magnifying the environmental impact. There is no doubt increases in population add to global carbon stock. That is, fossil fuels are used by humans as the energy source to power their increasing mechanized standard of living. The high mechanized lifestyle calls for more use of oil, coal, and other hydrocarbons which when burned emit carbon dioxide emissions into the atmosphere.

Most previous studies found that population growth impacts on the environment negatively (Shi 2003; Asumadu-Sarkodie and Owusu 2016b) while other researchers found population increase to have a positive effect on the environment (Wang et al. 2011a, b; Lin et al. 2015; Appiah et al. 2018; Sasana and Putri 2018). Further studies by Birdsall (1992) revealed that population contribution to carbon emissions could be assessed in two ways. Firstly, the increase in population could result in a greater demand for energy, industry, and transport, which would generate an increase in non-renewable fuel source emissions. Secondly, rapid population growth can lead to deforestation, land use changes, and combustion of wood for fuel as source of energy. These actions contribute significantly to carbon footprints. Shi (2003) investigated how population pressure impact changes on universal carbon footprint. Using national data from 93 states from 1975 to 1996, the study found population changes to have a pronounced influence on emissions, particularly in less developed countries. In other words, the proportional change of world population does more than just change in carbon emissions. Ahmed et al. (2017) found a one-way connection from energy use, international trade, and population to CO_2 emission. The study was investigated in selected countries in South Asia to find the relationship between energy use, income, foreign trade, population, and CO_2 emissions using FMOLS. A study by Lantz and Feng (2006) found economic progress to be unrelated to carbon emissions in Canada. In another breath, the study found an inverted *U*-shaped association existence between population and carbon discharged. That is, population increase in Canada initially increase conservational degradation but at the certain point of population increase, environmental impact reduces. Appiah et al. (2018) also investigated the causal link between agronomic production and carbon emissions of some emerging states. Using the FMOLS and DOLS for the period 1971 to 2013, the study found that population growth and energy consumption help to improve the environment of emerging countries.

Materials and methods

The use of panel data generally in empirical research analysis such as ours comes with its own advantages and disadvantages. One of the key disadvantages of panel data used is that it suffers from heterogeneity and spatial dependence problem. Notwithstanding this, panel data provides more degree of freedom and more sample variation than individual country dataset (Dogan and Seker 2016a, b; Appiah et al. 2018) but with the advent of current econometric techniques (Pesaran 2004) besides (Pesaran and Yamagata 2008) test takes care of those drawbacks associated with panel data. Therefore, one fundamental step of our analysis is to address diminutive snags so that suitable panel econometric models could be applied. We examined the connection between energy use, industrialization, population, economic progress, and carbon emissions of four emerging states namely: Brazil, India, Russia, South Africa, and China. These countries have come together to form BRICS. To ensure complete, efficient, reliable, and accurate results, we excluded Russia from the analysis, with data available from 1992, which makes the analysis and comparison difficult or impossible. In order for us to achieve study objectives, panel data for four of BRICS states were obtained from World Development Indicators. The data period obtained for the analysis was from 1971 to 2013 applying FGLS and PCSE estimators to assessment coefficients for the long term. Our study disaggregated the use of energy into renewable and non-renewable energy to determine their individual influence on environmental pollutant like carbon dioxide.

Data collection and methodology

The study looked at the energy consumption, industrialization, economic growth, population, and CO_2 emission in selected emerging economies using data of World Development Indicators (2017). To explore distinctive impact or contribution of both inexhaustible and exhaustible energy uses to environmental emissions in emerging economies, the study used panel data of 1971–2013. Variables in the analysis include fossil fuel use (NRE; kilogram of oil equivalent) as proxy of non-renewable energy use; renewable energy use (REN; kilogram of oil equivalent); economic growth proxied by gross domestic product per capita (GDP; current US$); industry value added (IND; current US $) as proxy of industrialization; and population (POP; total) all as predictors while CO_2eq-carbon dioxide equivalent emissions (Kt CO_2e) as proxy of environmental emissions was used as the dependent variable. In order to compare emissions from energy consumption, industrialization, population, and economic growth, global warming potential factor was applied to transform quantities of other pollutants into gases equivalent to carbon emissions. Since the increase in industrialization, population, economic progress, and energy usage does not only produce one source of carbon, there is the need to convert the various gases to carbon dioxide equivalent emissions. That is, carbon stock relative to carbon dioxide over a 100-year timescale (GWP_{100}). GWP_{100} is used to transform greenhouse gases into common metric emissions known carbon dioxide equivalents. This is achieved by multiplying the mass of particular gas by its GWP_{100} factor. The use of potential carbon emissions (CO_2eq) was also based on the research results of Amuakwa-Mensah and Adom (2017), Adom et al. (2018), and Appiah et al. (2018) which revealed that the application of potential CO_2 emission improves the efficiency of the study model. Potential emissions used in analysis us ours provide better results relating to elasticities, which will represent the true estimates for long-term parameters. Additionally, the use of equivalent emissions helps to avoid cyclicality issues and therefore, the problem of reverse causation is limited in the short-term analysis. Table 1 makes available details on an abbreviation of our variables, variable used name, unit of measure, and how the data was obtained.

Descriptive analysis

Descriptive statistics demonstrated in Table 2 provides the characteristics of the datasets before any attempt is made to proceed to the model estimation. The table provides mean, standard deviation, minimum, maximum, skewness, kurtosis, Jarque-Bera test, probability, and extent of variability with regard to mean of variables of the dataset. Using kurtosis to measure the viscosity or enormity of distribution tails, the study found the existence of platykurtic distribution, which includes discrete uniform distributions. Evidence from the analysis clearly depicts that variables such as REN, GDP, and POP displayed long-left tail skewness while CO_2eq, NRE, and IND, on the other hand, exhibited long-right tail skewness. The Jarque-Bera test statistics shows that all the variables are normally distributed. The mean results in the descriptive scrutiny show NRE as the variable with highest mean, hence, making it critical variable in developing economies. However, our standard deviation also exposed population (i.e., POP) as the most volatile variable with the highest deviation. The relative standard for the panel variables specifies the existence of a discrepancy between the variables. The findings further revealed economic growth with the highest degree of difference of 17.80% followed by CO_2eq with 8.26% among variables.

Empirical model

An empirical literature review revealed that most studies related to our study in developed and developing economies are based on a country by country and therefore use time series data (Hatzigeorgiou et al. 2011; Asumadu-Sarkodie and Owusu 2016a, b, 2017a, b, c). This then provides results with fewer numbers of observations. Hence, present study applied panel framework, which is more robust in terms of analysis (Chen et al. 2007; Ozturk and Acaravci 2011; Wang et al. 2011a). The framework behind our study was formulated based on endogenous growth theory of which the unwanted environmental impact of energy use, economic development, industrialization, and the population is analyzed. Since our study focused on unraveling effects of predictors on the environment, we posit a Cobb-Douglas relationship. We,

Table 1 Variable name and definitions

Abbreviation	Variable name	Unit	Source
CO_2eq	Carbon dioxide equivalent emissions	Kt CO_2e	WDI (2017)
NRE	Fossil fuel energy consumption	Kilograms of oil equivalent	WDI (2017)
REN	Renewable energy consumption	Kilograms of oil equivalent	WDI (2017)
GDP	Gross Domestic Product per capita	Current US $	WDI (2017)
IND	Industry, value added	Current US $	WDI (2017)
POP	Population	Total	WDI (2017)

WDI World Development Indicators 2017

Table 2 Descriptive analysis

	CO_2eq	NRE	REN	GDP	IND	POP
Mean	13.32	25.85	24.98	7.08	25.40	19.42
Std. dev.	1.10	1.07	1.18	1.26	1.23	1.41
Min	11.54	24.14	22.27	4.77	22.67	16.96
Max	16.14	28.60	26.61	9.49	29.07	21.03
Skewness	0.78	0.80	− 0.81	− 0.15	0.64	− 0.34
Kurtosis	2.67	2.72	2.35	1.83	3.59	1.55
The Jarque-Bera	18.11	18.82	21.69	10.47	14.35	18.52
Probability	0.00*	0.00*	0.00*	0.01*	0.00*	0.00*
CV	8.26	4.14	4.72	17.80	4.84	7.26

In order to check the convergence among the emerging countries, the coefficients of variation (CV) are calculated as follows: Std. dev. Mean × 100. * denotes *p* value of statistical significance at 5% level

therefore, transformed the variable into their log-form and imposed non-zero assumptions on regressors. Our study employed a stochastic form of IPAT model called STIRPAT which was articulated by Dietz and Rosa (1997). The STIRPAT model is therefore stated as follows:

$$CO_2eq = \alpha P^{\beta} A^{\gamma} T^{\partial} \varepsilon \tag{1}$$

where CO_2eq is a dependent variable, *P* is the population, *A* is the affluence, and *T* is the technology respectively as independent variables. The estimated exponents (i.e., β, γ, ∂) are considered as elasticities and therefore, any change in one of the explanatory variables can cause a change to the dependent variable. Diverse empirical research work has used different pollutants to represent environmental impact. Our study used CO_2 equivalent emissions which are converted the form of all gases due to their significance to global carbon stock. Population variables are the total number of people. Affluence in Eq. (1) is the proxy by gross domestic product per capita, industrialization, and energy use which are therefore classified as technology under the STIRPAT model technique. STIRPAT was used based on its flexibility. That is, it allows the use of many variables and classified them as technology if they do not fall into population or affluence. It is expected that CO_2eq and population should have a positive relationship since the increase in population will increase the emission level. Both hypothetical and research-based studies postulate that economic advancement and technology causes emissions increase. Using multiple regression models, we formulated our theoretical and empirical framework as:

$$CO2eq_{it} = f(POP_{it}, GDP_{it}, IND_{it}, EC_{it}) \tag{2}$$

where POP is the population; GDP is the gross domestic product; IND is the industry value added while EC is for the energy use. Equation (2) is expressed as Eq. (3) after disaggregation of energy usage into renewable and non-renewable.

$$CO2eq_{it} = f(POP_{it}, GDP_{it}, IND_{it}, NRE_{it}, REN_{it}) \tag{3}$$

To determine the marginal effect of important variables as renewable and non-renewable energy use, the study applied (Coma and Douglas 1928) production function following the work of Apergis and Payne (2012) by transforming Eq. (3) in its stochastic form as:

$$\begin{aligned} CO2eq_{it} = {} & \alpha_{it} + \psi_1 POP_{it} + \psi_2 GDP_{it} + \psi_3 IND_{it} \\ & + \psi_4 NRE_{it} + \psi_5 REN_{it} + \varepsilon_{it} \end{aligned} \tag{4}$$

where $i = 1, \ldots, N$ for each country and $t = 1, \ldots T$ refers to the time period. α and ε epitomize the intercept and error term of the model respectively while ψ is the elasticities of variables.

Econometric methodology

It is mostly anticipated when cross-section dimension (*S*) is large that the panel data would display cross-sectional independence. However, most of the time, spatial dependence test is eminent in panel regression settings. Disregarding the relevance of cross-section estimation in an analysis can have a detrimental effect of unaccounted residual dependence leading to estimation inefficiency and provision of invalid results (Dogan and Seker 2016a, b). Performance of spatial dependence test provides the yardstick for selection of further econometric method to undertake in the analysis such as panel unit root test and cointegrating test. We therefore tested the cross-section dependency or independency in the series with the Pesaran CD (2004). The Pesaran CD provides a reliable means of dealing with any widespread unobserved factors or indirect effects in the economies due to factors as the achievement of equal economic development (Dogan and Seker 2016a, b). The Pesaran CD test was used that it requires a predetermined model and at the same time, our time dimension (*D*) is greater than the number of cross-section dimensions (*S*). Homogeneity test on the other hand was performed using the Pesaran and Yamagata (2008). Subsequent to spatial dependence test, which revealed a dependency of the cross-sections means that the use of conventional techniques in panel non-stationary test and cointegration test becomes invalid in our analysis. We, therefore, applied CADF and CIPS to test stationarity or non-stationarity of variables. Then, we examined the long-term link between energy use, economic progress, population, industrialization, and carbon emissions with feasible generalized least squares and panel-corrected standard errors. It is likely that the panel data, like ours, would demonstrate significant dependence on cross-section due to existence of common shocks and unobservable factors that become part of residuals. These situations arise due to global economic and financial integration among countries.

$$CD = \sqrt{\frac{2D}{S(S-1)}}\left(\sum_{i=1}^{S-1}\sum_{j=i+1}^{S}\rho_{jn} \Rightarrow S(0,1)\right. \tag{5}$$

where D shows the time period, S is sample size or individual observations andρ_{jn} is sample estimate for spatial correlation of errors of country i and j given as:

$$\rho_{jn} = \rho_{nj} = \frac{\sum_{t=1}^{D} v_{it} v_{jt}}{\left(\sum_{t=1}^{D} v_{it}^2\right)^{1/2}\left(\sum_{t=1}^{D} v_{jt}^2\right)^{1/2}} \tag{6}$$

where a number of possible pairings (v_{it}, v_{jt}) increase with S and therefore indicate our null premise of cross-sectional independence, $H_0 : \rho_{jn} = \rho_{nj} = \mathrm{cor}(v_{it}, v_{it}) = 0$ for $i \neq j$, as opposed to other proposition of cross-wise dependence, $H_1 : p_{jn} = p_{nj} \neq 0$ for some $i \neq j$. It is extremely important to determine if the gradient coefficients are homogeneous or heterogeneous to verify the causality of the panel. It is assumed that the theory of homogeneity of zero slope is $H_0 : \gamma_i = \gamma$ for all i and an alternative hypothesis that is determined $H_1 : \gamma_i \neq \gamma_j$ for a fraction other than zero of paired slopes for $i \neq j$. Uniformity test of the inclined based on $\tilde{\Delta} = \sqrt{S}\left(\frac{S^{-1}\tilde{R}-X}{\sqrt{2X}}\right)$ is expected to have better size properties while $\tilde{\Delta}_{adj} = \sqrt{S}\left(\frac{S^{-1}R-\tilde{E}\left(\hat{H}_{iD}\right)}{\sqrt{Var\left(\hat{H}_{iD}\right)}}\right)$ has the correct size for all combination of sample sizes, when D is very small relative to S, and it also seems reasonable power properties. Succeeding the cross-sectional dependence test, we analyzed integration levels of variables by CADF and CIPS test. Application of CADF and CIPS for panel non-stationarity was based on spatial dependency test results. That is, the test results revealed that cross-sectional dependency exists and therefore, the use of a first-generation technique for panel unit root test becomes invalid. Reasons have been that the first-generation methods for panel non-stationarity test rely upon the spatial independence assumption. That is, the CADF and CIPS tests produce efficient and reliable results in the manifestation of the dependence and heterogeneity of the cross-sections among the countries studied. The applications of the two unit root test methods are the same, except that the CIPS uses the arithmetically averaged transversal dimension of the CADF test as follows:

$$\begin{aligned} \Delta CO2eq_{it} &= \alpha_i + \kappa_i CO2eq_{i,t-1} + \gamma_i \overline{CO2}eq_{t-1} \\ &\quad + \sum_{j}^{k} \gamma_{ij} \Delta\overline{CO2}eq_{i,t-j} + \sum_{j=0}^{k} \Delta CO2eq_{i,t-j} + \varepsilon_{it} \end{aligned} \tag{7}$$

where $\overline{CO2}eq_{t-1} = \left(\frac{1}{S}\right)\sum_{i=1}^{S} CO2eq_{i,t-1,} \Delta\overline{CO2}eq_t = \left(\frac{1}{S}\right)\sum_{i=1}^{S} CO2eq_{it,}$ and $t_i(S, D)$ is the t value of the analysis and κ_i is the individual statistics.

$$CIPS(S,D) = t\text{–}bar = S^{-1}\sum_{i=1}^{S} t_i(S,D) \tag{8}$$

where $t_i(S, D)$ is the increased cross-wise augmented Dickey-Fuller statistics for the ith spatial unit known by the t ratio of the elasticities of the model. To find the possible cointegration relationship between our variables, the study used the cointegration tests of Kao, Pedroni, and Westerlund. Following the results of cointegration, the long-term effects or the elasticity of explanatory variables could be estimated using the FGLS and PCSE estimation for all countries. To find the direction of the causal link between the variables, our study used the pooled mean group (PMG) estimator.

Panel cointegration tests

Having established that variables are integrated at first order, we then explore further to find the long-term cointegration between renewable energy use, non-renewable energy use, economic growth, industrialization, population, and carbon emissions. We, therefore, implemented the ADF-type residual-based panel cointegrating test by Kao (1999). This was based on homogeneous cointegrating vector assumption on the null proposition. Therefore, our ADF-statistics are calculated as:

$$ADF = {}^{tt}\frac{DF + \left(\frac{\sqrt{6S\tau_q}}{2\tau_{0q}}\right)}{\sqrt{\left(\frac{\tau_{0q}^2}{2\tau_q^2}\right) + \left(10\tau_{0q}^2\right)}} \tag{9}$$

where $\tau_q^2 = \sum_{\zeta\pi} - \sum_{\zeta\pi}\sum_{\pi}^{-1}, \tau_{0q}^2 = \varpi_\zeta - \varpi_{\zeta\pi}\varpi_\pi^{-1}, \varpi$ is the long-run average of the estimated covariance matrix, ^{t}DF is the t-statistics in ADF regression for cointegration. As the assumptions about uniformity between units of spatial dependence may be too strong, we proceeded to use the Pedroni (2004) panel cointegration test. The Pedroni panel cointegrating test offers substantial flexibility as it permits for heterogeneity in the long-term cointegrating vectors. The technique of cointegration of the Pedroni is associated with several tests that allow heterogeneous interceptions and a coefficient of the tendency in cross-sections. It hypothesizes seven (7) test statistics which cover both within and between the dimensions of the panel. The Pedroni (2004) approach of cointegration is considered a robust framework of heterogeneous error terms in spatial dependence and several regressors (Asteriou 2009). Pedroni's methodology is based on the following model:

$$InCO2eq_{i,t} = \alpha_i + \kappa_{i,t} + \beta_{1i}X_{1i,t} \ldots. + \beta_{Mi}X_{Mi,t} + \varepsilon_{i,t} \tag{10}$$

where $i = 1, \ldots, S$ is for each country; $t = 1, \ldots, D$ refers to the time period. The parameters α_i and $\kappa_{i,\ t}$ are individual and trend effects. With the null proposition of no cointegration, the residual $\kappa_i = 1$ while homogeneous alternative $\kappa_i < 1$ for all i. β_{1i},β_{2i}, and $\beta_{Mi}$are panel-specific cointegration parameters, where $\varepsilon_{i,\ t}$denotes the estimated error terms set to be equal to zero which represents deviances from the long-term relationship. The residuals and whether the residuals are I (1) was obtained by estimating the auxiliary regression from Eq. (10) as:

$$\varepsilon_{i,t} = \kappa_i \varepsilon_{i,t-1} + u_{i,t} \tag{11}$$

Notwithstanding the above merits of both the Kao and Pedroni panel cointegrating tests, one fundamental weakness is that they enforce a collective factor restriction; that is, they assume that the parameters of long term for the level variables are equal to short-run parameters in their first differences (Dogan and Inglesi-Lotz 2017). Therefore, failure of this assumption to hold in analysis reduces the power of cointegration technique (i.e., Kao and Pedroni). Hence, as robustness check of the above panel cointegration tests, (Westerlund 2005) panel cointegration approach was used, which imposes fewer restrictions and is more appropriate when transverse dependence and heterogeneity exist. The application of the Westerlund panel cointegration test tests for the same null proposition as the Kao and Pedroni, but an alternative hypothesis is different. That is, in a version of the Westerlund test, the alternative hypothesis is that the variables are cointegrated in some panels. This statistics is what is called the statistics of the group mean (VR). In a different form of the alternative theory, variables are said to be cointegrated in all panels. This is also known as the panel VR statistic. The Westerlund (2005) cointegration test derives test statistics based upon a model in which the AR parameter is either panel-specific or is the same over the panels. Our study, however, used panel-specific and is expressed as:

$$VR = \sum_{i=1}^{S} \sum_{t=1}^{D} \hat{\varepsilon}_{it}^{2} \hat{R}_i^{-1} \tag{12}$$

where $\hat{\varepsilon_{it}} = \sum_{j=1}^{t} \hat{\varepsilon_{ij}}, = \sum_{t=1}^{D} \hat{\varepsilon}_{it,}^{2}$ and $\hat{\varepsilon_{it}}$ are the residuals from the panel data model in (10). The hypothetical distribution of all test statistics, after appropriate standardization, converges to S (0, 1).

Long-run estimates

Subsequent to findings of the Kao, Pedroni, and Westerlund panel cointegration tests, we went further to find the elasticity of the predicting variables using FGLS and PCSE estimators. One of the key pre-condition of FGLS is that to produce an efficient estimation D (time period) should be more than or equal to S (cross-section) because the associated dispersion matrix cannot be reversed. Additionally, at a point whereby the time period is over and above the number of cross-sections, there may be relatively few observations per error variance-covariance matrix parameter that has connected elements of the dispersion matrix to be estimated with boundless inaccuracy. Since our study time period is more than the number of cross-sections, FGLS was used. FGLS is an ideal technique to deal with heterogeneity, serial correlation, and spatial dependence in panel dataset as ours. Notwithstanding the positive side of FGLS, it comes with some shortfalls. One major shortfall of Park's FGLS is that it is known to underestimate SEs in the finite samples which are often severe. FGLS only exhibits poor analytical performance when the true error variance-covariance matrix is unknown. Therefore, to address this shortfall, our study further applied the panel-corrected standard errors proposed by Beck and Katz (1995) which is a modified version of the "inefficient" ordinary least square. The PCSE analyzes the weighting of the observations for autocorrelation, but uses an interleaved estimate to integrate the lateral dependency in the calculation of standard errors. The PCSE as an estimator performs significantly better than the asymptotically efficient evaluation of FGLS in many aspects.

Empirical results and discussions

Spatial dependency or independency and homogeneity or heterogeneity in the series between the variables exhibit importance for selection of further econometric tests to be used for analysis such as unit root test and cointegration test. Therefore, we first verify the cross-sectional independence between the series (Pesaran 2004), since S (cross-section dimension) = 4 less than D (time dimension) = 43 and check the uniformity of the cross-sections with adjusted delta tilde tests by Pesaran and Yamagata (2008). Later, we analyzed integration levels of the variables with CIPS and CADF panel non-stationary test that regards transverse dependence. Then, we investigated the long-run relationship between energy use, population, economic progression, industrialization, and carbon emissions. The result of spatial independency test is shown in Table 3. The null hypothesis, which is independent of the cross-section, was rejected with a level of significance of 5%, since the p values of the variables were found to be less than 0.05. Therefore, we discovered a transverse dependence in the series. Evidence from the results signifies that a shock in emerging economies can be transferred easily to any rising emerging power states. In addition, we analyzed the homogeneity with delta tilde (Pesaran and Yamagata 2008) and our results showed that the null hypothesis, which is homogeneity, was rejected and the coefficients were found as heterogeneous.

Panel unit root test

We conducted CADF and CIPS tests and the results given in Table 4. Our findings in the data series confirm the presence of non-stationary of variables at the level. However, variables

Table 3 Cross-section dependence and homogeneity test results

Cross-sectional dependency tests (H_0: there is cross-sectional independency)		
Variable	Statistic	*p* value
CO_2eq	15.38	0.00*
POP	16.03	0.00*
GDP	14.94	0.00*
IND	14.88	0.00*
NRE	15.49	0.00*
REN	15.24	0.00*
Homogeneity tests (H_0: slope coefficients are homogeneous)		
Test	Statistic	*p* value
Delta_tilde	3.085	0.003*
Delta_tilde_adj	− 3.301	0.001*

*Rejection of CD test and homogeneity test of the null hypothesis at 5% significance level

became static at their first difference and therefore failed to accept the null theory that unit root exists at first difference. Results in Table 4, hence, settled that variables are integrated at same order.

Table 4 Unit root test results

Variables	CIPS		CADF	
	Level	Δ	Level	Δ
CO_2eq	[− 2.055]	[− 4.662]**	[− 1.439]	[− 2.775]**
POP	[− 2.445]	[− 2.254]**	[− 2.160]	[− 3.707]**
GDP	[− 1.494]	[− 5.584]**	[− 1.594]	[− 3.450]**
IND	[− 1.021]	[− 5.778]**	[− 1.519]	[− 3.333]**
NRE	[− 1.898]	[− 4.961]**	[− 1.593]	[− 2.971]**
REN	[1.069]	[− 1.696]**	[0.049]	[− 1.179]**

**denote the statistical significance at 5% level, while the values in brackets and the Δ represent the value of t-statistics and the first difference of the variables respectively. Critical values are not provided for the sake of brevity but can be provided upon request

Table 5 Results of panel cointegration test

	Statistic	Prob.
Kao panel cointegration test		
ADF	−4.216	0.000*
	Statistic	Weighted
Pedroni panel cointegration test		
Common AR coefficients (within-dimension)		
Panel v-statistics	0.987 (0.162)	1.181 (0.119)
Panel rho-statistics	−1.155 (0.124)	−1.312 (0.095)
Panel PP-statistics	−3.014 (0.001)*	−3.309 (0.001)*
Panel ADF-statistics	−2.996 (0.001)*	−3.358 (0.000)*
Individual AR coefficients (between-dimension)		
Group rho-statistic	−0.881 (0.189)	
Group PP-statistic	−3.663 (0.000)*	
Group ADF-statistic	−3.707 (0.000)*	
	Statistics	Prob.
Westerlund test for cointegration		
Variance ratio	−1.505	0.006*

Values in parentheses denote probability values while * indicates the statistical significance at 5% level

Subsequent to the unit root test, we proceeded with our analysis by examining the cointegrating connection between the variables. Table 5 provides results of the Kao (1999), Pedroni (2004), and Westerlund (2005) panel cointegrating checks. The results of the Kao cointegration study show that our variables are cointegrated and, therefore, have a long-term association. This, therefore, gives us reasons to reject the null hypothesis of the absence of cointegration with a level of significance of 5%. The Pedroni panel cointegration test, on the other hand, also points out seven tests under two subdivisions, within-dimension statistics, and between-dimensions statistics. Our findings of the Pedroni cointegrating test revealed that variables are cointegrated with respect to the majority (i.e., 6 out of 11) of the statistics, that is, except the panel v-statistics which shows positive statistics value and therefore accepted the null premise of no cointegration. The rest of panel statistics test shows negative values but important and therefore failed to agree on the null assumption of no cointegration among variables. On the other hand, the group test shows negative values for all the test statistics with the probability of PP-statistics (0.000), ADF-statistics (0.000), and rho-statistics (0.189). In this case, at a level of significance of 5%, the analysis of the PP- and ADF-statistics group rejected the null hypothesis, while the results of rho-statistics tests showed the opposite in this case. As means of confirming results of the Pedroni and Kao cointegration tests, we run a second-generation test called the Westerlund panel cointegrating test. The variance ratio test statistics rejects the null theory of no cointegration among renewable energy consumption, non-renewable energy consumption, industrialization, economic growth, population, and carbon emissions in favor of the alternative that at least some panels are cointegrated. Our results of the Westerlund panel cointegration analysis included panel-specific in the cointegrating vectors with no trend and AR parameters varies by a panel. Results of the Westerlund test for cointegration confirm our results of both the Kao and Pedroni cointegrating tests as shown in Table 5.

Long-run estimates

A key inference of our empirical research work is to estimate long-term coefficients on the predicting variables once panel cointegrating test result shows a long-run association. With the manifestation of the issues of transverse dependence and heterogeneity in the model, the study therefore applied second-generation estimators such as the feasible generalized least squares (FGLS) and the panel-corrected standard error (PCSE). FGLS and PCSE consider the aforementioned issues of spatial dependence and heterogeneity. The results of both estimators indicate that POP, NRE, and REN are the variables that are considered as significant contributors negatively or positively towards emissions in emerging economies while other variables (i.e., GDP and IND) were found statistically insignificant. Results suggest that a 1% increase in POP and NRE causes an upsurge of CO_2 emissions by 0.108% and 1.068% respectively. It signifies that higher energy usage with regard to the non-renewable energy source contributes to carbon emissions significantly in emerging economies. On the other hand, the increase in population also affects the environment of emerging economies significantly. Notwithstanding these findings, other significant variables like REN help to improve the environment. That is, a 1% increase of REN of these rising emerging power states would cause a drip of emissions by 0.158%. R^2 in Table 6 shows that 99.9% of the model can explain the variance of our response variable by the explanatory variables.

Pooled mean group causality test

Pooled mean group (PMG) estimator is applied to unearth the direction causality once we have been able to establish a long-term association between the variables. That is, the results of coefficients obtained from FGLS and PCSE estimators undeniably provided significant extrapolations but failed to reveal the direction of causality between the scrutinized variables. Notwithstanding, it was of high interest of researchers to dig more to find the causal link between energy use, population, economic growth, industrialization, and emissions in the emerging economies. We therefore pragmatically used PMG to uncover this. The fundamental reason for PMG estimator use is that it countenances the short-term dynamic specification being different from one country to another while making long-term elasticities to be same for the cross-sections. PMG also allows for distinctive heterogeneity to be taken into account when estimating individual equations for each country and averaging the parameter estimates. That is, the PMG accounts for both heterogeneity and cross-wise dependence in the panel. Moreover, PMG estimator can also be applied irrespective of whether the variables are integrated at $I(1)$ or $I(0)$. Hence, short- and long-run causality inference can be pinched whether the cointegration was spotted earlier or not.

Results of Table 7 show unidirectional causation from population to carbon dioxide emissions, non-renewable energy consumption to renewable energy consumption, and carbon emissions to renewable energy use in the short term. However, in the long-term unidirectional causativeness was found from renewable energy use to emissions and industrialization, while non-renewable energy consumption to economic growth and industrialization was found in both short and long terms. On the other hand, bidirectional causality was found between emissions and non-renewable energy use in both terms. However, long-run results indicate a two-way causation between economic expansion and carbon emissions; emissions and industrialization; and economic growth and industrialization. Additionally, PMG causation estimation provided enough evidence, which exposed bidirectional causality between population and economic progress; population and industrialization; and renewable energy usage and economic development and between renewable energy usage and non-renewable energy use in the long run. The issue of bidirectional causality in our results supports feedback proposition and that industrialization, economic growth, and non-renewable energy use and carbon emissions are symbiotic. Therefore, the provision of policies that enhances these variables would help in mitigating or curtailing the impact of emissions in emerging economies. Likewise, the bidirectional

Table 6 Results from the FGLS and PCSE estimators (dependent variable: CO_2eq)

Regressors	FGLS		PCSE	
	Coefficient	*p* value	Coefficient	*p* value
POP	0.108	0.028*	0.108	0.018*
GDP	0.002	0.951	0.002	0.947
IND	− 0.031	0.433	− 0.031	0.389
NRE	1.068	0.000*	1.068	0.000*
REN	− 0.158	0.000*	− 0.158	0.000*
Constant	− 11. 937	0.000	− 11.659	0.000
The Wald chi^2	11,712.34		16,659.90	
R^2			0.999	

*denotes the statistical significance at 5% level

Table 7 The pooled mean group (PMG) estimator causality test results

Estimator	Short-run causality	Long-run causality
PMG	CO_2eq ↔ NRE	GDP ↔ CO_2eq
	POP → CO_2eq	CO_2eq ↔ IND
	NRE → GDP	GDP ↔ IND
	NRE → IND	CO_2eq ↔ NRE
	CO_2eq → REN	POP ↔ GDP
	NRE → REN	POP ↔ IND
		REN ↔ GDP
		REN ↔ NRE
		REN → CO_2eq
		NRE → GDP
		NRE → IND
		REN → IND

connection between renewable and non-renewable energy use and evidence of auxiliary advocates that the improvement of the renewable energy sector may provide liberation from carbon stock created by non-renewable energy use. The interdependence between the consumption of renewable and non-renewable energy and economic growth confirms the importance of both energy sources in the development of energy policies for a more sustainable energy future (Apergis and Payne 2011). The lack of a causal link between the population and the consumption of energy, both renewable and non-renewable, promises the existence of hypotheses of neutrality in emerging economies. Zabel and Economics (2009) argues that if the population does not cause energy use increase, it implied that the population is not growing as thought of, since the growing populations consume energy more. On the other hand, if energy usage does not cause population, it means that the energy resources of emerging economies operate at a sub-optimal level. That is, energy use exerts a demand for energy resources, which makes them scares. As expected, the increase in energy use will increase energy resources and, ultimately, increase the population of developing economies.

Conclusions and policy implications

Ponderous changes in all the interconnected weather elements of our planet show an exigent danger to human species that requires hasty and decisive action. Climatic impacts include floods, droughts, hurricanes, and rising sea level and the catastrophic effect of all these impacts are being felt globally and is perceived to worsen if nothing is done to save the situation. Continuous delay in dealing with global warming has a serious repercussion on living species and therefore, all stakeholders need to come on board to steer the world into a better and much safer environment for all. That is, to deal with climate change entails dramatic changes to how individuals (i.e., population) and industries make use of available energy. Global warming is affected by increasing usage of fossil energy, and therefore, one of the key measures of energy policy is the use of renewable resources to implement the Kyoto Protocol of greenhouse gas emissions. The proliferation of energy use intensifies the proportion of CO_2 emissions in the environment, which causes pollution. With an uninterrupted increase in energy needs of emerging economies, the depletion of fossil fuels globally is causing levitated interest in renewable energy as energy options for heating in developing economies. Unlike the previous studies in this area, this study examines the simultaneous use of renewable and non-renewable energy sources to differentiate the relative impact of each one on carbon emissions. In addition to renewable and non-renewable energy measures, processes of industrialization, economic growth, and population were also included in the multidimensional error correction model for the four countries between 1971 and 2013. The purpose of this study is to empirically investigate the link between environmental emissions, economic growth, industrialization, population, renewable, and non-renewable energy consumptions for emerging economies.

Other researchers have used different econometric methods to assess the elasticity and causality associated with our research work. Our study, on the other hand, used FGLS and PCSE estimation method to determine the elasticity, and we also used the combined mean group (PMG) method to determine the direction of the causality instead of the usual causal approach of Granger. To our knowledge, not much study has been done to find the linkage between the variables using these estimators for elasticities and causality approach. In terms of the policy formulation process, associations between variables are very important. Therefore, our findings of causal relationship between renewable energy consumption, non-renewable energy use, economic expansion, population, industrialization, and emissions of some emerging states are in the right place. Primary analysis displays that variables are cross-sectionally dependent and heterogeneous. Our study employed second-generation techniques such as CADF and CIPS to test for unit root which takes into account the presence of heterogeneity and spatial dependence. Our empirical findings revealed that variables were not stationary at the level. However, at the first difference, the variables became stationary. We analyzed the cointegrating linkage between the variables of the Kao, Pedroni, and Westerlund cointegration test techniques which show that variables are cointegrated, hence, having a long-run affiliation. Our research result of the long-run elasticities of explanatory variables on the outcome variable for the four economies was based on FGLS and PCSE techniques. The results of both FGLS and PCSE estimators point to the fact that POP, NRE, and REN are the variables that are considered significant contributors towards emissions in emerging economies while GDP and IND were found statistically insignificant. The results specify that a 1% escalation in POP and NRE causes an upsurge of CO_2 emissions by 0.108% and 1.068% correspondingly. This implies that the increase in energy consumption with regard to the non-renewable energy source contributes to emissions severely in emerging economies. On the other hand, the increase in population also affects the environment of emerging economies significantly in terms of the increase in emissions. Notwithstanding these findings, another significant variable REN was also found to help improve the environment of emerging economies. That is, a 1% increase of REN of rising economic power states would cause a decrease of emissions by 0.158%. The results show a difference in the elasticity estimates between the consumption of renewable and non-renewable energy. The relationship between renewable and non-renewable energy consumption and carbon dioxide emissions presents both types of energy sources as important for carbon dioxide emissions. However, the difference between the two energy sources (i.e., renewable and non-renewable) resides in their influence on carbon stock.

To unravel the causality between the variables, the study showed that, in the short run, a unidirectional cause and effect relationship comes from population to carbon dioxide emissions, non-renewable energy use to renewable energy use, and carbon dioxide emissions to renewable energy usage. However, in the long term, unidirectional causality runs from renewable energy use to carbon dioxide emissions and industrialization, while non-renewable energy consumption to economic growth and industrialization was found in the short and long terms. On the other hand, a bidirectional causality has been found between carbon dioxide equivalent emissions and the consumption of non-renewable energy both in the short and long terms. However, long-run results indicate a bidirectional connection between economic evolution and emissions; carbon dioxide emissions and industrialization; and economic growth and industrialization. In addition, the PMG cause-effect evaluation gave sufficient evidence that revealed a bidirectional causal relationship between the population and economic growth; population and industrialization; use of renewable energy sources and economic development; and the use of renewable energy sources and non-renewable energy consumption in the long term. The issue of bidirectional causality in our results supports the feedback premise and that industrialization, economic growth, and non-renewable energy use and carbon dioxide emissions are interdependent. Therefore, the provision of policies that enhances these variables would help in mitigating or curtailing the impact of emissions in emerging economies. Likewise, the bidirectional causal correlation between renewable and non-renewable energy usage and evidence of auxiliary advocates that the improvement of the renewable energy sector may provide liberation from carbon stock created by non-renewable energy use. The availability of renewable energy sources compared to non-renewable energy sources allow developed and developing economies to improve their renewable energy policies and the introduction of carbon taxes to reduce the use of non-renewable sources of energy so as to cut down carbon stocks. In order to bring down the level of carbon stock, emerging economies are advised to increase energy efficiency, particularly non-renewable energy consumption, stimulate industrialization, and increase the share of renewable energy use. With regard to policy implications and recommendations, policymakers of emerging economies are encouraged to ensure energy use efficacy and fuel switching to renewable energy source such as biofuels, photovoltaic solar, biogas, hydropower, and geothermal. Although renewable heat sources such as solar and geothermal are not easy to integrate into all industrial facilities, they are considered economical applications. Bioenergy, on the other hand, is also another source of renewable heat that becomes more useful when the demand for heat is high. The only problem with renewable energy from bioenergy is that resources are limited and only become sustainable and operational in certain areas and conditions. The emerging economies should also focus more on the creation of awareness of the merits associated with the renewable source of energy for heating particularly in the reduction of carbon stock, and last but not the least, emerging economies should continue to specialize in the production of non-energy-intensive products. Emerging countries can enter into the production of chemical manufacturing products such as paint and coatings, detergents, chemical feed stocks, and adhesives. Emerging countries can as well as look at industries manufacturing products as computer and electronic products, fabricated metal products, machinery, and electrical and transportation equipment. These chemical and industrial products are non-energy-intensive products.

Future studies will also analyze the influence of different renewable and non-renewable energy sources in emerging countries on the environment using a set of individual chronological data or a panel-type approach. A second direction for future research would be to study the causal link between energy use and environmental pollution by adding non-structural variables, such as urbanization. A study conducted by Pata (2018) showed that urbanization had adverse environmental effects in Turkey. Liddle and Lung (2010) also found urbanization to be positively related to energy usage in the residential sector of developed countries. Lastly, the use of another econometric estimation method, such as Driscoll and Kraay, to address the concerns of the association between energy consumption and environmental pollution would provide more information on established connections. For this reason, the estimated covariance matrix of Driscoll and Kraay is perfectly versatile and by no means exclusive to linear models. Although heteroskedasticity is consistent, these standard error estimators are robust over large areas, especially in the presence of transverse and temporal dependence.

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