Aye, Goodness C.; Edoja, Prosper Ebruvwiyo

Article

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Effect of economic growth on CO_2 emission in developing countries: Evidence from a dynamic panel threshold model

Goodness C. Aye[1]* and Prosper Ebruvwiyo Edoja[1]

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*Corresponding author: Goodness C. Aye, Department of Agricultural Economics, Federal University of Agriculture Makurdi, PMB 2373, Makurdi, Nigeria
E-mail: goodness.aye@gmail.com

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Abstract: This study investigated the effect of economic growth on CO_2 emission using the dynamic panel threshold framework. The analysis is based on data from a panel of 31 developing countries. The results indicate that economic growth has negative effect on CO_2 emission in the low growth regime but positive effect in the high growth regime with the marginal effect being higher in the high growth regime. Thus our finding provides no support for the Environmental Kuznets Curve (EKC) hypothesis; rather a *U*-shaped relationship is established. Energy consumption and population were also found to exert positive and significant effect on CO_2 emission. Including financial development indicator in the model did not change the conclusion about EKC hypothesis. Employing panel causality methods, there is evidence of significant causal relationship between CO_2 emission, economic growth, energy consumption and financial development. The findings emphasize the need for transformation of low carbon technologies aimed at reducing emissions and sustainable economic growth. This may include energy efficiency and switch away from non-renewable energy to renewable energy.

ABOUT THE AUTHORS

Goodness C. Aye obtained her PhD in Agricultural Economics from University of Pretoria. She is a senior lecturer; has presented papers in conferences in many continents; a reviewer and editor for high ranking international journals. Her research interests cover policy analysis, development economics, environmental and energy economics.

Prosper Ebruvwiyo Edoja holds MSc in Agricultural Economics from University of Agriculture, Makurdi in 2015. He is currently doing his PhD at the same University. His special interest is in Resource and Environmental Economics. He is a Certified Project Director; member and associate of renowned institutions in Nigeria; presented papers in international conferences and received many awards.

PUBLIC INTEREST STATEMENT

Carbon dioxide is one of the greenhouse gases considered as the main cause of global warming and environmental degradation. We examine the role of income in environmental quality. It has been postulated that during the early stage of economic development, high pressure on the environment leads to its deterioration. However, as the economy grows over time, environmental quality improves due to less pressure on the environment. Our results did not support the notion of improving environmental quality as income increases. We basically find that as the economy grows, more Carbon dioxide is released perhaps due to more industrial activities without employing environmentally friendly techniques that should enhance environmental quality. Economic growth also has predictive ability for carbon emission. Therefore, the need for transformation of low carbon technologies aimed at reducing emissions and sustainable economic growth is emphasized.

Subjects: Environment & Agriculture; Development Studies; Economics, Finance, Business & Industry

Keywords: CO_2 emission; economic growth; energy consumption; population; dynamic panel threshold model; panel causality

1. Introduction

There are two major challenges facing humanity: economic development and preserving the environment. However environment has come to the forefront of contemporary issues for both developed and developing countries since the deterioration of environmental quality raises concerns about global warming and climate change arising mainly from greenhouse gases (GHGs) emissions (Kasman & Duman, 2015; Uddin, Salahuddin, Alam, & Gow, 2017). Unlike many other resources such as financial benefits, environmental goods and services are such ecologically relevant decisions made today will impact on future generations (Clayton, Kals, & Feygina, 2016). Environmental degradation both in quantity and quality is a major hallmark of industrialization and development which are key drivers of economic growth. Environmental degradation is the deterioration of the environment through depletion of resources such as air, water and soil; the destruction of ecosystems; habitat destruction; the extinction of wildlife; and pollution (Conservation Energy Future [CEF], 2016). It is defined as the disintegration of the earth or deterioration of the environment through consumption of assets, for example, air, water and soil; the destruction of environments and the eradication of wildlife. It is characterized as any change or aggravation to nature's turf seen to be pernicious or undesirable (CEF, 2016). It is also defined as any change or disturbance to the environment perceived to be deleterious or undesirable (Johnson et al., 1997). As indicated by the $I = PAT$ equation, environmental impact (I) or degradation is caused by the combination of an already very large and increasing human population (P), continually increasing economic growth or per capita affluence (A), and the application of resource depleting and polluting technology (T) (Chertow, 2001; Huesemann & Huesemann, 2011).

Environmental degradation is one of the ten threats officially cautioned by the High-level Panel on Threats, Challenges and Change of the United Nations. Environmental degradation is of many types. When natural habitats are destroyed or natural resources are depleted, the environment is degraded. Ecological effect or degradation is created by the consolidation of an effectively substantial and expanding human populace, constantly expanding monetary development or per capita fortune and the application of asset exhausting and polluting technology. Environmental degradation occurs when earth's natural resources are depleted and environment is compromised in the form of extinction of species, pollution in air, water and soil, and rapid growth in population (CEF, 2016). We can, however, take action to stop it and take care of the world that we live in by providing environmental education to humanity which will help us pick familiarity with the surroundings that will enable us to take care of environmental concerns thus making it more useful and protected for our children and other future generations.

The level of economic growth and development in every country at any time is dependent on a number of factors. To encourage a high rate of growth, different economies' mechanisms have involved development based on each individual country's characteristics and the potential natural resources that are available. The growth may produce negative impacts on the environment through many aspects, such as environmental condition (pollution), overexploitation of natural resources, degradation and loss of wildlife habitat, and climate change (Phimphanthavong, 2013). These are the key issues that many countries have been facing; in particular, the decline in environmental quality is considered to be a serious issue for the living condition of the population from the current as well as the long-term perspective.

This paper highlights the situation of developing countries, and aims to investigate the relationship between economic growth and the pressure on nature from the environmental sustainability perspective. Considering issues on the environmental condition, it seems that many aspects are

included in environmental condition, such as water pollution, Carbon dioxide emissions (CO_2 emissions), soil erosion, solid waste, and deforestation. However, since we have limited time and data available of other aspects, this study has considered only the CO_2 emissions per capita to be a proxy for environmental degradation. Moreover, carbon emission has been identified as a major pollutant (Edoja, Aye, & Abu, 2016) and accounts for about 75% of greenhouse gas emissions (Abbasi & Riaz, 2016). CO_2 emissions are one of the most applied emissions in Environmental Kuznets Curve (EKC) applications (Tutulmaz, 2015) which this study intends to test. By definition, increase in CO_2 emissions mainly arises from burning oil, coal and natural gas for energy use. Furthermore, CO_2 emissions also enters the atmosphere from burning wood and waste material, from some industrial process such as cement production, garment manufacturing, alcohol factories, Tabaco companies, etc. The increase in number of economic activities is assumed to increase the proportion of environmental damage.

Contrary to the previous crude growth theories which focus much on labour and capital as major factors of production and ignore the importance of energy in the growth process, environmental degradation and energy consumption are few of the major factors of concern to both development economist and resource and environmental economist (Stern, 2011). Hence the focus of a number of researchers had been on the analysis of the causal relationship between energy consumption and macroeconomics variables in the past two decades. A good number of studies have examined the causal relationship between energy consumption and several independent variables such as economic growth, financial development, employment and population. Grossman and Krueger (1995) noted that to achieve a high level of growth a country needs more inputs to enlarge its outputs, leading to an increase in the waste and emissions generated through the production of economic activities. Kahia, Ben Aïssa, and Charfeddine (2016) further noted that the depletion of nonrenewable energy is the result of an unbalanced availability between finite energy resources, population growth and industrial development. Renewable energy resources provides opportunity for economic development and environmental quality improvement (Kahia, Aïssa, & Lanouar, 2017; Ozturk & Al-Mulali, 2015). The increased allocation of natural resources, accumulation of waste, and concentration of pollutants directly impacts on the degradation of environmental quality, leading to a decrease in the human living quality, despite the rising income (Daly, 1991). In all, energy is considered to be the life line of an economy, the most vital instrument of socio-economic development and recognized as one of the most important strategic commodities (Sahir & Qureshi, 2007).

The level of CO_2 in the earth's atmosphere has been on the increase since the industrial revolution (Ayoade, 2003). At the beginning of Industrial revolution, CO_2 concentration was about 280 ppm, and this level was constant for about 700 years. However, at around 1860, the concentration of CO_2 has grown exponentially. The rate of growth of CO_2 in the atmosphere is about 0.5 per cent per year (Mohamed, Shaaban, Azza, & Mowafy, 2012). It was predicted that the level of CO_2 may rise to 450 ppm by year 2050 (Botkin & Keller, 1997). There is a general perception that as the economy grows, these industrial activities increase and hence leads to more release of CO_2 into the environment. Environmental effects of CO_2 emissions have been enormous, affecting both the ecosystem and human beings habiting it. The outbreak of various environmental hazards as a result of the changes in environmental temperature or atmospheric imbalance in recent years is alarming. The hazards include, among others, the vulnerability of the economic sector to the recurrent droughts, flood and cyclones, reduction of some plant and animal populations, spread of diseases vectors including malaria, freezing and breaking-up of ice on rivers and lakes, reduction in food production and agricultural productivity, increase in death rate and threat to sustainable development. Based on the carbon emission implications for fresh water resources, agriculture and food supply, natural ecosystems, biodiversity and human health, it is therefore important to quantify the impact of economic growth of developing nations on CO_2 emission.

Although there are quite a number of studies that examined the relationship between CO_2 emission and economic growth as evidenced in the literature section, to the best of our knowledge there is no study that employ the dynamic panel threshold model. Therefore, this study intends to fill this

knowledge gap. The motivation behind the choice of the dynamic panel threshold model is based on the fact that Panayotou (1997) noted that faster economic growth and higher population density (beyond a certain point) may increase moderately the environmental price of economic growth. This framework also avoids potential multicollinearity that may arise between the level of income, income squared and income cubed in estimation as used in many previous studies (Narayan & Narayan, 2010). This study focuses on the relationship between environmental CO_2 emission and economic growth and its further validation tests of the EKC hypothesis. This anchors on the inverted-*U* put forward by Grossman and Krueger (1995) regarding the relationship on economic growth and environmental quality named as the EKC by Panayotou (1993). According to EKC hypothesis, there is a positive relationship between economic growth and environmental degradation initially as countries attempt to raise standards of living from initial low levels, even at the expense of environmental degradation. However, as the economies attain higher levels of development, achieving better environmental quality becomes increasingly important. Thus the EKC has an inverted *U* shape (Abbasi & Riaz, 2016). In addition, we contribute by examining this relationship separately for the middle and low income groups within the developing countries in a robustness analysis where the latter comprises both low and low middle income countries according to World Bank classification. Following existing studies, we also examine the role of additional variables such as energy consumption, financial development and population (Boutabba, 2014; Charfeddine, 2017; Charfeddine & Khediri, 2016; Charfeddine & Mrabet, 2017; Kasman & Duman, 2015; Katircioğlu & Taşpinar, 2017, etc).

The rest of the study is organized as follows: Section 2 is a brief literature on empirical studies on the relationship between economic growth and CO_2 emission. Section 3 provides the data and Section 4 discusses the empirical models. Section 5 discusses the results. Section 6 provides policy implications while Section 7 concludes the study.

2. Literature review

There are a number of empirical studies on CO_2 and economic growth as well as studies that test EKC hypothesis. This section focuses on panel data studies. The review is grouped into two: studies that used regime switching/threshold models and those that used non-regime switching models. This classification will help to position the current paper in its appropriate place in the literature.

2.1. Regime switching or threshold panel methods

Aslanidis and Iranzo (2009) analysed the relationship between growth in per capita income and carbon dioxide (CO_2) emissions in 77 non-OECD countries using the panel smooth transition regressions (PSTR) developed by González, Teräsvirta, and van Dijk (2005) but modified for asymmetry. Their panel data covered from 1971–1997. The study found no evidence of environmental Kuznets curve (EKC). Chiu (2012) employed the PSTR model to examine the EKC for 52 developing countries from 1972–2003. The variables used in this study include arable land area, real GDP per capita, rural population density, trade openness, and political freedom. They found an EKC relationship for deforestation and the existence of a strong threshold effect between deforestation and GDP. They showed that the turning points were US$3,021 and US$3,103.

Using also the PSTR model, Duarte, Pinilla, and Serrano (2013) examined the relationship between water use per capita and income per capita of 65 countries from 1962–2008 including precipitation and political freedom as control variables. They found that the relationship between water withdrawal per person and GDP per capita is nonlinear, displaying an inverted-*U* with a marked downward limb that dominates the nexus. Chen and Huang (2014) examined the link between CO_2 per capita and economic growth for 36 countries using data from 1985–2012 and the PSTR model. The results revealed that the nonlinear relationship switched across countries depending on the lagged GDP per capita differential during the different regimes. CO_2 emissions also responded significantly to the changes in relative oil consumption, natural gas consumption, and coal consumption.

The study by Heidari, Turan Katircioğlu, and Saeidpour (2015) explored the relationship between economic growth, CO_2 emissions and energy consumption in five ASEAN (Association of South East

Asian Nations) countries using data from 1980–2008 and the PSTR model. The first regime (levels of GDP per capita below 4,686 USD) showed that environmental degradation increases with economic growth while the trend was reversed in the second regime (GDP per capita above 4,686 USD). The results also showed that energy consumption increased CO_2 in both regimes. These results thus support the EKC hypothesis in the ASEAN countries.

2.2. Non-regime switching panel methods

Narayan and Narayan (2010) tested the short and long run income elasticity of 43 developing countries to examine the EKC hypothesis from 1980–2004. They propounded as an evidence of EKC that if the long run income elasticity is smaller than the short run income elasticity, then a country has reduced CO_2 emissions due to the increased income. The long run relationship between per capita CO_2 emissions and per capita income was analysed using Pedroni panel cointegration tests while an error correction model was used to examine short run relationship. Panels of countries were constructed on the basis of regional location. According to the findings of the study, income elasticity in the long run was smaller than the short run only in two panels namely Middle Eastern and South Asian panels.

Applying the panel unit root tests, panel cointegration methods and panel causality test, Farhani and Rejeb (2012) investigated the relationship between energy consumption, GDP and CO_2 emissions for 15 MENA countries using data from 1973–2008. The finding of this study revealed that there is no causal link between GDP and energy consumption; and between CO_2 emissions and energy consumption in the short run. However, in the long run, there is a unidirectional causality running from GDP and CO_2 emissions to energy consumption. Using dynamic panel data model estimated by means of the Generalized Method of Moments (GMM), Saidi and Hammami (2015) analysed the impact of economic growth and CO_2 emissions on energy consumption for a global panel of 58 countries for the period 1990–2012. Similar analysis was conducted for three regional panels: Europe and North Asia, Latin America and Caribbean, and SubSaharan, North African and Middle East. The results indicate significant positive impact of CO_2 emissions and economic growth on energy consumption for the four global panels. The impact of financial development, capital stock and population on energy consumption are also positive and mostly significant.

Kasman and Duman (2015) employed panel unit root tests, several panel cointegration methods (Kao, Pedroni, Westerlund tests specifically), and panel causality tests (panel-based error correction model) to examine the causal relationship between energy consumption, CO_2 emissions, economic growth, trade openness and urbanization for a panel of 15 new EU member and candidate countries over the period 1992–2010. Their results provide evidence supporting the EKC hypothesis. The results also indicate that there is a short-run unidirectional panel causality running from energy consumption, trade openness and urbanization to CO_2 emissions. The results of the long-run causal relationship showed that carbon dioxide emissions, energy consumption, GDP and trade openness are important in the adjustment process as the system departs from the long-run equilibrium. Al-mulali, Tang, and Ozturk (2015) studied the effect of economic growth, renewable energy consumption and financial development on CO_2 emission in 18 Latin America and Caribbean countries for the period 1980–2010. The Kao cointegration test results revealed that the variables are cointegrated. Then using the Fully Modified OLS (FMOLS) model, the results indicated an inverted *U*-shape relationship between CO_2 and GDP. Also financial development had a negative long run effect, energy consumption had no long-run effect on CO_2. The VECM Granger causality results revealed feedback causality between GDP, electricity consumption from renewable sources, financial development and CO_2 in both short-and long-run. Additionally, Granger causality results also revealed that electricity consumption, GDP, and financial development can be a good solution to reduce environmental damage since they have a causal effect on CO_2.

On the nexus between CO_2 emissions, economic growth, electricity consumption and financial development in six Gulf Cooperation Council (GCC) countries, Salahuddin, Gow, and Ozturk (2015) employed panel data for the period of 1980–2012 and various methods (dynamic ordinary least

squares (DOLS), FMOLS and the dynamic fixed effect (DFE) models) to examine the long-run relationship between the variables. Results showed that electricity consumption and economic growth have a positive long run relationship with CO_2 emissions while financial development had a negative and significant relationship. There was evidence of a bidirectional causal link between economic growth and CO_2 emissions and a unidirectional causal link running from electricity consumption to CO_2 but no causal link between financial development and CO_2 emissions. Magazzino (2016) investigated the relationship between CO_2 emissions, economic growth, and energy use for 10 Middle East countries over the period 1971–2006 using a panel VAR. Both the estimated coefficients and impulse response functions show that for the six GCC countries the response of economic growth to CO_2 emissions is negative. CO_2 emissions seem to be driven both by its own past values and by energy use. For the other four non-GCC countries, neither CO_2 emissions nor energy use seems to have an impact on growth, which is determined by its own lagged values.

The study by Antonakakis, Chatziantoniou, and Filis (2017) consider the link between energy consumption per capita growth (and its subcomponents), CO_2 emissions per capita growth and real GDP per capita growth using panel VAR. Analysis based on 106 countries classified by different income groups over the period 1971–2011 showed that the effects of the various types of energy consumption on economic growth and emissions are heterogeneous on the various groups of countries. Moreover, causality between total economic growth and energy consumption is bidirectional, thus making a case for the feedback hypothesis. Renewable energy consumption had no significant effect on economic growth and there was no evidence in support of the EKC hypothesis. Kais and Ben Mbarek (2017) investigated the causal relationship between energy consumption, carbon dioxide (CO_2) emissions and economic growth for three selected North African countries based on data covering 1980–2012. Using a panel co-integration test they found interdependence between energy consumption and economic growth in the long run. Results based on panel Vector Error Correction Model, detect unidirectional relationship from economic growth to energy consumption, a unidirectional causality running from economic growth to CO_2 and a unidirectional causal relationship from energy consumption to CO_2 emissions.

Using data from 1971–2013 on five selected economies of South Asia, Ahmed, Rehman, and Ozturk (2017) explored the relationship between CO_2 emission, energy consumption, income, trade openness and population. All the panel cointegration tests (Pedroni- Kao- and Johansen-Fisher-panel cointegration) employed confirm that all the variables are cointegrated. Using FMOLS, the results show that energy consumption, trade openness and population increases environmental degradation has negative impact. Further, results indicate that there is uni-directional causality running from energy consumption, trade openness and population to CO_2 emission. Uddin et al. (2017) analysed the effects of real income, financial development and trade openness on the ecological footprint (EF) of consumption the 27 highest emitting countries from 1991–2012. Results from Pedroni co-integration tests show that the variables are co-integrated. The panel DOLS indicate a positive and significant long run association between EF and real income, and a negative and insignificant impact of trade openness on EF. Financial development is also observed to reduce EF. These results were also confirmed by the group-mean FMOLS method. Based on the vector error correction model, a unidirectional causality runs from real income to EF. Results from variance decomposition analysis and impulse response functions indicate that real income will have an increasing effect on EF into the future.

Employing Pedroni panel cointegration test and Granger causality in panel VECM framework, Charfeddine and Mrabet (2017) evaluated the EKC hypothesis for 15 MENA (Middle East and North African) countries over the period 1975–2007. EF was used as a proxy of environmental degradation. Other variables are energy used, real GDP, life expectancy at birth, fertility rate and political institutional index. The estimation was done for all MENA 15 countries, for oil-exporting and non-oil-exporting countries sub-samples. The results show that energy use worsens ecological footprint, whereas real GDP per capita exhibits an inverted *U*-shaped relationship with EF in oil-exporting countries and in the sample as a whole, hence, the EKC hypothesis is validated. For the non-oil-exporting

countries, the relationship between EF and economic growth is *U*-shaped, hence EKC is not supported. Urbanization, life expectancy at birth and fertility rate improve the environment in the long term while political institutions did not improve environmental quality. In the short term, a strong evidence for bidirectional causality among the ecological, real GDP and energy-use variables were established. Shahbaz, Nasreen, Ahmed, and Hammoudeh (2017) used the Pedroni and Westerlund panel cointegration tests and explored the relationship between trade openness and CO_2 emissions while incorporating economic growth as an additional variable. Data from three groups of 105 high, middle and low income countries from 1980–2014 were used. The results show that the three variables are cointegrated. Trade openness hampers environmental quality but the impact varies in the diverse groups of countries. The panel VECM causality results indicate a feedback effect between trade openness and carbon emissions at the global level and the middle income countries but causality runs from trade openness to CO_2 emissions for the high income and low income countries.

From the foregoing the results are mixed even for some studies employing similar methodology. This may be due to differences in the variables included, transformations made, sample period and/or panel of countries studied. It can also be easily observed that most of the studies employed non switching panel models. The few that employed panel switching models relied on the panel smooth transition regressions (PSTR) developed by González et al. (2005). These studies basically estimated a static PSTR model. The current study implements a dynamic panel threshold model developed by Kremer, Bick, and Nautz (2013) which considers the role of initial CO_2 emission and hence the impact of time by including as explanatory variable the lagged dependent variable. The model also accounts for endogeneity and heteroscadasticity, respectively, by implementing a GMM (Generalized Method of Moments) framework and reporting the robust confidence intervals. The summary of the literature review is presented in Table 1.

Table 1. Summary of the literature review

Authors	Countries	Period	Variables	Methodologies	Main results
Aslanidis and Iranzo (2009)	77 non-OECD countries	1971–1997	Per capita income and carbon dioxide (CO_2) emission	Panel smooth transition regressions (PSTR)	No evidence of environmental Kuznets curve (EKC)
Chiu (2012)	52 developing countries	1972–2003	Arable land area, real GDP per capita, rural population density, trade openness, and political freedom	PSTR	EKC relationship exits for deforestation. Strong threshold effect between deforestation and GDP
Duarte et al. (2013)	65 countries	1962–2008	Water use per capita, income per capita, precipitation and political freedom	PSTR	Inverted-U relationship found, with a marked downward limb that dominates the nexus
Chen and Huang (2014)	36 countries	1985–2012	CO_2 per capita and GDP per capita, oil consumption, natural gas consumption, and coal consumption	PSTR	Regime switching relationship GDP per capita growth and CO_2 emissions. Significant effect of oil consumption, natural gas consumption, and coal consumption
Heidari et al. (2015)	Five ASEAN countries	1980–2008	Economic growth, CO_2 emissions and energy consumption	PSTR	Results support the EKC hypothesis
Narayan and Narayan (2010)	43 developing countries	1980–2004	Per capita CO_2 emissions and per capita GDP	Pedroni panel cointegration tests and panel VECM	Income elasticity in the long run was smaller than the short run only in two panels thus EKC exists in these two panels

(*Continued*)

Table 1. (*Continued*)

Authors	Countries	Period	Variables	Methodologies	Main results
Farhani and Rejeb (2012)	15 MENA countries	1973–2008	Energy consumption, GDP and CO_2 emissions	Panel cointegration methods and panel causality test	No causal link between GDP and energy consumption; and between CO_2 emissions and energy consumption in the short run. However, in the long run, there is a unidirectional causality running from GDP and CO_2 emissions to energy consumption
Saidi and Hammami (2015)	58 countries	1990–2012	Energy consumption per capita, GDP per capita, CO_2 emissions per capita, Financial development, Capital stock and Population	Dynamic panel data model with GMM	All variables had positively and mostly significant impact on energy consumption in all four panels
Kasman and Duman (2015)	15 new EU member	1992–2010	Per capita total primary energy consumption, per capita GDP, per capita CO_2 emissions, trade openness, and the share of urban population	Panel cointegration tests by Kao, Pedroni, Westerlund and panel-based error correction model	EKC hypothesis supported. Short-run unidirectional panel causality running from energy consumption, trade openness and urbanization to CO_2 emissions. Long-run causal relationship also exists
Al-mulali et al. (2015)	18 Latin America and Caribbean countries	1980–2010	GDP, electricity consumption, financial development and CO_2	Kao panel cointegration test, FMOLS, VECM Granger causality test	EKC between GDP and CO_2 supported. Financial development has a negative long run effect. Energy consumption had no long-run effect on CO_2. Bidirectional causality between CO_2 and all variables
Salahuddin et al. (2015)	Six Gulf Cooperation Council (GCC) countries	1980–2012	CO_2 emissions, economic growth, electricity consumption and financial development	DOLS, FMOLS, dynamic fixed effect, panel Granger causality test	Electricity consumption and economic growth have a positive long run relationship with CO_2 emissions while financial development had a negative effect. Bidirectional causality between economic growth and CO_2 emissions. Unidirectional causality from running electricity consumption. No causal link between financial development and CO_2
Magazzino (2016)	10 Middle East countries	1971–2006	CO_2 emissions, economic growth, and energy use	Panel VAR	For 6 countries, the effect of CO_2 emissions on growth is negative. CO_2 emissions is driven by energy consumption. CO_2 emissions and energy have no impact on growth in the rest 4 four

(*Continued*)

Table 1. (*Continued*)

Authors	Countries	Period	Variables	Methodologies	Main results
Ahmed et al. (2017)	106 countries	1971–2011	Energy consumption per capita growth, CO_2 emissions per capita growth and real GDP per capita growth	Panel VAR	EKC hypothesis is not supported. Heterogeneous effect of various types of energy consumption. Bidirectional causality between total economic growth and energy consumption
Kais and Ben Mbarek (2017)	Three North African countries	1980–2012	Energy consumption, CO_2 emissions and economic growth	Panel co-integration test and panel VECM	Unidirectional relationship from causality running from economic growth to CO_2 and also from energy consumption to CO_2 emissions
Ahmed et al. (2017)	Five South Asian countries	1971–2013	CO_2 emission, energy consumption, income, trade openness and population	Pedroni- Kao- and Johansen-Fisher-panel cointegration tests	In the long run, energy consumption, trade openness and population has negative impact on CO_2 and unidirectional causality from them to CO_2
Uddin et al. (2017)	27 highest emitting countries	1991–2012	Real income, financial development, trade openness, ecological footprint (EF)	Pedroni co-integration tests, DOLS and FMOLS	Long run relationship found. EF and real income share positive and significant long run relationship. Trade openness has negative effect on EF. Financial development reduces EF
Charfeddine and Mrabet (2017)	15 MENA countries	1975–2007	EF, energy-use, real GDP, life expectancy at birth, fertility rate and political institutional index	Pedroni panel cointegration test and Grange panel VECM	EKC hypothesis is validated in all countries and oil-exporting countries but not in non-oil exporting countries. Long term effect of Urbanization, life expectancy at birth and fertility rate is found. Energy use worsens ecological footprint. Bidirectional causality found between EF, GDP and energy-use variables
Shahbaz et al. (2017)	105	1980–2014	trade openness, CO_2 emissions and economic growth	Pedroni and Westerlund panel cointegration tests, panel VECM	The three variables are cointegrated. Trade openness worsens environmental quality. Feedback causality between trade openness and CO_2 at the global level and for middle income countries but unidirectional causality from trade openness to CO_2 for the high income and low income countries

3. Data

The study use panel data covering 1971–2013 on 31 developing countries namely: Argentina, Benin, Brazil, China, Cote d'Ivoire, Cameroon, Algeria, Ecuador, Egypt, Gabon, Ghana, Honduras, Indonesia, India, Iran, Kenya, Morocco, Mexico, Nigeria, Pakistan, Peru, Philippines, Sudan, Senegal, Thailand, Tunisia, Turkey, South Africa, Congo Demographic Republic, Zambia and Zimbabwe. These countries were selected based on data availability on all the variables of interest. Table 2 presents the variables used. CO_2 emission is measured as CO_2 emissions in metric tons per capita. Economic growth is measured as GDP per capita in constant 2010 US$. Population is measured as total population for midyear estimates and energy consumption is measured as energy use in kg of oil equivalent per capita. Domestic credit to private sector (% of GDP) is used as a proxy for financial development. All data were sourced from the World Bank Development Indicators and were transformed to the natural log before using them for analyses.

Table 2. Variable description

Variables	Symbol	Measure	Expected sign	Economic implication
CO_2 emission	CO_2	CO_2 emissions in metric tons per capita	N/A	–
Economic growth	GDP	GDP per capita in constant 2010 US$	±	On one hand, higher level of income CO_2 emissions if increases demand for more energy or promotes industries whose activities generate pollution. On the other hand, environmental quality may improve if higher income leads to adoption of environmental friendly production techniques and consumption of clean and green energy
Population	POP	Total population for midyear estimates	+	High population could lead to increased demand for energy and thus fossil fuel emissions. Also it can increase emission through deforestation
Energy consumption	ECONS	Energy use in kg of oil equivalent per capita	±	Electricity consumption will have negative effect on CO_2 emissions if the country uses friendly environment energy sources. Otherwise, it will have positive effect on CO_2 emissions
Financial development	FD	Domestic credit to private sector (% of GDP)	±	On one hand, financial development may help firms in adopting advanced cleaner and environment friendly technology in the energy sector; it may also attract foreign direct investment, which enhance research and development activities that improve economic activities. On the other hand, financial sector may increase manufacturing activities which in turn leads to an increase in industrial pollution and environmental degradation

Note: N/A implies not applicable since CO_2 is the dependent variable. However, its lag as an explanatory variable can provide indication of its persistence.

4. Empirical model

4.1. Dynamic panel threshold model

The study employs a dynamic panel threshold model developed by Kremer et al. (2013) that extends Hansen's (1999) original static setup to endogenous regressors to analyse the role of economic growth thresholds in the relationship between economic growth and CO_2 emission ($y_{it} = dCO_{2it}$), the endogenous regressor will be CO_2 emission (CO_{2it-1}).

This model is extension of the cross-sectional threshold model of Caner and Hansen (2004) where GMM type estimators are used in order to allow for endogeneity. Consider the following general panel threshold model

$$y_{it} = \mu_i + \beta_1' z_{it} I(q_{it} \leq \gamma) + \beta_2' z_{it} I(q_{it} > \gamma) + \varepsilon_{it} \tag{1}$$

where subscripts $i = 1, \ldots, N$ represents the country and $T = 1, \ldots, T$indexes time. μ_i is the country specific fixed effect and the error term is $\varepsilon_{it} \overset{iid}{\sim}(0, \sigma^2)$.$I(\cdot)$is the indicator function indicating the regime defined by the threshold variable q_{it} and the threshold level γ. Z_{it} is a m-dimensional vector of explanatory regressors which may include lagged values of y and other endogenous variables. The vector of explanatory variables is partitioned into a subset z_{1it}, of exogenous variables uncorrelated with ε_{it}, and a subset of endogenous variables z_{2it}, correlated with ε_{it}. In addition to the structural Equation (1) the model requires a suitable set of $k \geq m$ instrumental variables x_{1it} including z_{1it}.

Following Kremer et al. (2013), we use the forward orthogonal deviations transformation suggested by Arellano and Bover (1995) to eliminate the fixed effects in the first step of the estimation. The advantage of the forward orthogonal deviations transformation is that it avoids serial correlation of the transformed error terms and hence maintains the distributional assumptions underlying Hansen (1999) and Caner and Hansen (2004). Therefore instead of first-differencing which leads to serial correlation of the error terms or subtracting the mean from each observation (within transformation) as in Hansen (1999) which could result in inconsistent estimates the forward orthogonal deviations transformation method subtracts the average of all future available observations of a variable. Therefore, for the error term, the forward orthogonal deviations transformation is given by:

$$\varepsilon_{it}^{*} = \sqrt{\frac{T-t}{T-t+1}}\left[\varepsilon_{it} - \frac{1}{T-t}(\varepsilon_i(t+1) + \ldots + \varepsilon_{iT})\right] \tag{2}$$

Therefore, the forward orthogonal deviation transformation maintains the uncorrelatedness of the error terms, that is

$$\text{Var}(\varepsilon_i) = \sigma^2 I_T \Rightarrow \text{Var}(\varepsilon_i^{*}) = \sigma^2 I_{T-1}$$

According to Hansen (2000), this ensures that the estimation procedure derived by Caner and Hansen (2004) for a cross-sectional model can be applied to the dynamic panel Equation (1).

The estimation procedure involves determining and selecting the threshold value γ with the smallest sum of squared residuals. Once $\hat{\gamma}$ is determined, the slope coefficients can be estimated by the generalized method of moments (GMM) for the previously used instruments and the previous estimated threshold $\hat{\gamma}$.

Applying the dynamic panel threshold model to the analysis of the impact of economic growth on CO_2 emission in developing countries, we specify the threshold model of the CO_2 emission–growth nexus as:

$$CO_{2it} = \mu_i + \beta_1 gdp_{it} I(gdp_{it} \leq \gamma) + \delta_1 I(gdp_{it} \leq \gamma) + \beta_2 gdp_{it} I(gdp_{it} > \gamma) + \phi z_{it} + \varepsilon_{it} \tag{3}$$

gdp_{it} is both the threshold variable and the regime-dependent regressor in our application. z_{it} denotes the vector of partly endogenous control variables, where slope coefficients are assumed to be regime independent. Following Bick (2010) and Kremer et al. (2013), we allow for differences in the regime interceptδ_1. Initial CO_2 emission is considered as endogenous variable, i.e. $z_{2it} = initial_{it} = CO_{2it-1}$, while z_{1it} contains the remaining control variables which for our application are energy consumption (ECONS) population growth (POP). In the robustness analysis, a financial development variable (FD) is included. We use lags of the dependent variable (dCO_{2t-1}, ..., dCO_{2t-p}) as instruments following Arellano and Bover (1995) and Kremer et al. (2013). There is a bias/efficiency trade-off in finite samples when it comes to choice of the number (p) of instruments. On the one hand using all the available lags of the instrument variable ($p = t$) may to increase efficiency while on the other hand, reducing the instrument count to 1 ($p = 1$) may avoid an overfit of instrumented variables that might lead to biased coefficient estimates. However, as demonstrated in Kremer et al. (2013), the choice of instruments did not have important impact on their results. Hence, we limit our analysis to one lag of the instrument variable. Matlab was used to implement the model.

4.2. Panel causality test

In addition to examining the short run effect of economic growth and some control variables on CO_2 emission, the study investigated the causal relationship between the variables. This is important because association or correlation between variables does not necessarily imply causation. Causality answers the question on as to whether the past values of one variable (say GDP) can help improve the prediction of another variable (say CO_2) aside the one provided by its own past values. Causality measures the precedence and information content of GDP for CO_2 and vice versa. In this study, we employ Dumitrescu and Hurlin (2012) panel causality test. The test accounts for possible heterogeneity in the data by allowing all coefficients to be different across cross sections. It also accounts for cross section dependence using critical values obtained from block bootstrap procedure. The test is implemented in Matlab. Here, the basic specification of Dumitrescu and Hurlin (2012) test is given. Consider two stationary variables, x and y, the Granger non-causality is tested in a panel data context using the following VAR model:

$$y_{i,t} = \lambda_{1i} + \sum_{k=1}^{K} \alpha_{1i}^{(k)} y_{i,t-k} \sum_{k=1}^{K} \beta_{1i}^{(k)} x_{i,t-k} + \varepsilon_{1i,t} \qquad i = 1, \ldots, N, t = 1, \ldots, T \tag{4}$$

$$x_{i,t} = \lambda_{2i} + \sum_{k=1}^{K} \alpha_{2i}^{(k)} y_{i,t} - k \sum_{k=1}^{K} \beta_{2i}^{(k)} x_{i,t} - k + \varepsilon_{2i,t} \qquad i = 1, \ldots, N, t = 1, \ldots, T \tag{5}$$

where the index i denotes individual cross-sectional units and the index t denotes time periods. λ_i is a p dimensional vector of individual effects which are fixed in time dimension. K is the lag order assumed to be identical for all cross sections. The panel is also assumed to be balanced. $\alpha_i^{(k)}$ and $\beta_i^{(k)}$are parameters that are allowed to vary across groups but constant in time. $\varepsilon_{i,t}$ is a column vector of error terms assumed to be independently and identically distributed across individuals with $E(\varepsilon_{i,t} = 0)$ and $E(\varepsilon_{i,t}^2) = \sigma_{\varepsilon,i}^2$.

Under the null hypothesis of Homogenous Non Causality (HNC) hypothesis, there is no causality from x to y for all the cross-units of the panel.

$$H_0{:}\beta_i = 0 \qquad \forall_i = 1, \ldots, N \tag{6}$$

Under the alternative, there is a causality from x to y for at least for one cross-unit.

$$H_0{:}\beta_i = 0 \qquad \forall_i = 1, \ldots, N_1$$

$$\beta_i \neq 0 \qquad \forall_i = N_1 + 1, N_1 + 2, \ldots, N \tag{7}$$

An analogous null and alternative hypothesis can be specified for the causality from *y* to *x*.

This test computes the *W* bar and *Z* bar test statistics of the Homogenous Non Causality (HNC) hypothesis. The *W* bar statistic corresponds to the cross sectional average of the *N* standard individual Wald statistics of Granger non causality tests and is given as:

$$W_{N,T}^{Hnc} = \frac{1}{N}\sum_{i=1}^{N} W_{i,T} \tag{8}$$

The *Z* bar statistic corresponds to the standardized average statistic (for fixed *T* sample) and is given as:

$$\tilde{Z}_N^{Hnc} = \sqrt{\frac{N}{2\times K}\times\frac{(T-2K-5)}{(T-K-3)}}\times\left[\frac{(T-2K-3)}{(T-2K-1)}W_{N,T}^{Hnc}-K\right]\underset{N\to\infty}{\overset{d}{\to}} N(0,1) \tag{9}$$

As a robustness check, a second approach was employed whereby the panel data is treated as one large stacked set of data, and then the Granger causality test is performed in the standard way, with the exception of not letting data from one cross section enter the lagged values of data from the next cross section. In other words this test assumes the cross sections are homogenous and hence all coefficients are same across all cross-sections.[1]

5. Empirical results

To understand the relevant properties of the data, a number of analytical tools were employed such as mean and standard deviation. The mean indicates average value of the sample and standard deviation is the positive square root of the variance. It is a measure of dispersion, that is, it shows the extent of the deviation from the mean. The summary statistics of the variables used for the analysis are presented in the Table 3; the mean for CO_2 is 2,18,149.7 with standard deviation of 7,94,536.3. For GDP, the mean and standard deviation are 3,040.7 and 2,934.6 respectively. While the corresponding values for mean and standard deviation for ECONS and POP are 760.9 and 550.4, and 1.07E + 08 and 2.52E + 08, respectively. For FD, the mean and standard deviation are 30.242 and 27.356, respectively. The correlation matrix is presented in Table 4. The results display both the correlation coefficients and the probability. All the variables exhibit positive and significant correlation with each other except population and economic growth where a negative albeit low correlation is observed. Focusing specifically on CO_2 emission (first row), it can be seen that economic growth, energy consumption and population has positive correlation with CO_2 emission.

To determine the unit root properties of the data, a battery of unit root tests were employed namely Im, Pesaran and Shin, Augmented Dickey and Fuller (ADF)-Fisher χ^2, Phillip and Perron—Fisher χ^2, Levin, Lin & Chu and Breitung unit root tests. The results of these are presented in Table 5. For all the variables in levels the null hypothesis of unit root cannot be rejected as evidenced by large

Table 3. Descriptive properties of carbon (iv) oxide, GDP, ECONS, POP and FD

	CO_2	GDP	ECONS	POP	FD[a]
Mean	2,18,149.700	3040.665	760.8745	1.07E + 08	30.242
Maximum	1,02,49,463.000	19,492.680	2979.074	1.36E + 09	166.504
Minimum	260.357	234.922	180.671	6,01,734.000	0.198
Std. Dev.	7,94,536.300	2,934.601	550.389	2.52E + 08	27.356

[a]The financial development variable is for only 30 countries as Zimbabwe was dropped due to large missing data points. It is used in the robustness analysis only.

Table 4. Correlation matrix

	CO_2	GDP	ECONS	POP
CO_2	1.000			
GDP	0.418*** (0.000)	1.000		
ECONS	0.540*** (0.000)	0.800*** (0.000)	1.000	
POP	0.819*** (0.000)	−0.081*** (0.003)	0.086*** (0.002)	1.000

Note: *p*-values are in parenthesis.

***Indicates significance at 1%.

Table 5. Unit root tests

	Level				First difference			
Test	**CO_2**	**GDP**	**ECONS**	**POP**	**CO_2**	**GDP**	**ECONS**	**POP**
Im, Pesaran and Shin	0.949 (0.829)	4.783 (1.000)	1.569 (0.942)	−16.857*** (0.000)	−21.361*** (0.000)	−14.406*** (0.000)	−18.236*** (0.000)	−10.729*** (0.000)
ADF-Fisher	72.363 (0.173)	31.490 (1.000)	57.531 (0.637)	183.341*** (0.000)	525.637*** (0.000)	330.759*** (0.000)	436.292*** (0.000)	277.269*** (0.000)
PP-Fisher	76.806 (0.098)	34.089 (0.999)	68.272 (0.273)	637.900*** (0.0000	866.732*** (0.000)	550.324*** (0.000)	748.659*** (0.000)	45.265 (0.946)
Levin, Lin & Chu	−0.853 (0.197)	1.388 (0.918)	0.755 (0.775)	−28.732*** (0.001)	−16.303 (0.000)	−10.744*** (0.000)	−14.420*** (0.000)	−18.140*** (0.000)
Breitung	0.545 (0.707)	2.393 (0.992)	1.920 (0.973)	5.637 (1.000)	−10.389*** (0.000)	−11.082*** (0.000)	−9.413*** (0.000)	−4.076*** (0.000)

Note: *p*-values in parenthesis.

***Indicates significance at 1%.

p-values (i.e. $p > 0.1$) for all tests. The only exception is that of POP were all tests except Breitung rejected the null of unit root. This implies that CO_2, GDP and ECONS have unit roots and hence are non-stationary. However, the conclusion for and POP is weaker. Based on this, the unit root tests were performed again on the first difference of these variables. The null hypothesis is rejected for all four variables in basically all the tests. This implies that the series are stationary in their first difference and hence are integrated of order one, I(1).

The results for the empirical relation between economic growth and CO_2 emission in developing countries are presented in Table 6. The analysis were conducted based on the first difference of log variables or growth rates (that is with stationary series) to avoid spurious regression. This is also consistent with Hansen (1999) and Kremer et al. (2013) where all the variables used in the panel threshold model are stationary. The upper part of Table 6 shows the estimated inflation threshold and the corresponding 95% confidence interval. The regime-dependent coefficients of economic growth on CO_2 emission are presented in the middle part. Specifically, $\hat{\beta}_1(\hat{\beta}_2)$ denotes the marginal effect of economic growth on CO_2 emission in the low (high) growth regime, that is, when economic growth is below (above) the estimated threshold value. The lower part of Table 6 displays the coefficients of the control variables.

The estimated GDP threshold estimate is 0.93% and the value is contained in the confidence interval. Therefore, the low regime corresponds to the values of the transition variable, GDP, that is below the threshold parameter (0.93%) and the high regime corresponds to the value of the transition variable that is above the threshold parameter. Economic growth is negatively correlated with CO_2 emission if below the threshold ($\hat{\beta}_1 = -0.061$) but positively correlated if above the threshold ($\hat{\beta}_2 = 0.156$). This implies that when GDP growth is below 0.93%, it will have an inverse effect on CO_2 emission. When an economy is at its early stage of development, there is a greater possibility that such economy will be characterized by more service sector which contributes less to CO_2 emission compared

Table 6. Economic growth thresholds and CO_2 emission

Threshold estimates:	
$\hat{\gamma}$	0.934%
95% confidence interval	[0.929, 1.073]
Impact of economic growth:	
$\hat{\beta}_1$	−0.061 (0.512)
$\hat{\beta}_2$	0.156 (0.127)
Impact of covariates:	
Initial CO_2 emission	−0.125 (0.089)
Energy consumption	0.740*** (0.119)
Population	0.503* (0.266)
$\hat{\delta}_1$	−0.116 (0.071)
N	31
T	43
Total observation	1,333

*Indicate significance at 10% level, respectively.

***Indicate significance at 1% level, respectively.

to the manufacturing sector. Moreover, GDP being in low regime implies depression or recession, hence in this situation people will focus more on consumption of basic life needs and reduce other unnecessary consumption, this may affect energy intensive sectors consequently reducing energy consumption and CO_2 emissions. However, an increase in GDP growth will lead to an increase in CO_2 emissions at high levels of income due perhaps to increasing presence of manufacturing industries. In other words, during the early stages of development, CO_2 emissions would decrease but increases at later stages after GDP exceeds the threshold parameter. Again since being in upper regime connotes economic boom period, individuals as well as firms will have more income and this may lead to increased consumption of energy from electric devices, transportation, appliances among others that contribute to high pollution. The absolute sizes of the economic growth coefficient suggest that the correlation between economic growth and CO_2 is stronger when economic growth is higher.

Since our results show negative effect of economic growth on CO_2 emission in the low regime but positive effect in the high regime, then the EKC hypothesis is not valid in our sample. This is consistent with Aslanidis and Iranzo (2009) and Ahmed et al. (2017) among others. Instead we observe a *U*-shaped relationship between economic growth and CO_2 emission whereby an increasing economic growth initially leads to declining CO_2 emission levels, reaches a threshold, beyond which increasing levels of GDP increases CO_2. This implies that beyond a certain level of GDP, a further rise of GDP can be achieved at the cost of environmental degradation. When a country industrializes, this will lead to increased pollution. As increasing production and consumption cause rising environmental damage, then economic growth will have a negative environmental impact (Everett, Ishwaran, Ansaloni, & Rubin, 2010). This is intuitive because higher income levels will lead to pursuit of more manufacturing economy. If there are no complementary policies that constrain the industries to limit their level of pollution by adopting environmentally friendly production techniques and processes, the presence of these industries will ultimately result in high environmental degradation.

The effect of initial CO_2 emission is negative albeit not significant. The value of initial CO_2 emission (−0.125) implies that CO_2 emission is corrected by about 0.125% each year. Energy consumption and population exert significant positive effects on CO_2 emission. This implies that increasing energy consumption and population would lead to more release of CO_2 emission to the environment. The positive sign of the energy consumption variable is consistent with economic theory as it implies that the energy sources consumed in this panel of countries are not environmentally friendly. For

instance, non-renewable energy sources like fossil fuel based energy consumption is associated with high levels of emission. Therefore, high dependence on this form of energy as it is currently the case in developing countries reduces the energy efficiency of the economy and deteriorates the environment. The positive effect of population also conforms to a priori expectation and may be explained in that population increases could lead to increases in energy consumption and, consequently, to greater atmospheric pollution. This is in line with the two channels identified by Birdsall (1992). First, a larger population could result in increased demand for energy for power, industry, and transportation, hence the increasing fossil fuel emissions. Second, population growth could contribute to greenhouse gas emissions through its effect on deforestation. The destruction of the forests, changes in land use, and combustion of fuel wood could significantly contribute to greenhouse gas emissions.

As a robustness check, we estimated the model with domestic credit to the private sector as a financial development indictor. This led to dropping of Zimbabwe from the panel given large missing data points which could not be effectively interpolated or extrapolated for. We conducted the analysis first for all developing countries in the panel, second for middle income countries only and third for low and low middle income countries only. The results are presented in Table 7. The findings are qualitative similar to our initial estimation in that the validity of the EKC effect is not established. For all countries, we found a *U*-shaped relationship between economic growth and CO_2 emission as in the model without the financial development indicator. For middle income countries, we found a scale effect whereby an increasing economic growth leads to continuously rising CO_2 emission levels. Scale effect represents income as an indicator level of economic activities. Higher economic activity per capita will likely cause a higher level of pollution. It manifests a monotone increasing relationship between income and pollution (Islam, Vincent, & Panayotou, 1999). For low income countries, the relationship is negative in both regimes. Financial development has negative and positive but insignificant effect in middle and low income countries, respectively. The negative effect shows that these countries may be adopting environmentally friendly techniques to enhance environmental quality due to financial development. That is to say that financial development may help the energy sector in these middle income countries to adopt advanced cleaner and environment

Table 7. Economic growth thresholds and CO_2 emission

	All developing countries	Middle income	Low income
Threshold estimates:			
$\hat{\gamma}$	0.934%	1.053%	0.934%
95% confidence interval	[0.934, 0.937]	[0.978, 1.081]	[0.934, 0.937]
Impact of economic growth:			
$\hat{\beta}_1$	−0.105 (0.558)	0.328** (0.166)	−0.537 (0.862)
$\hat{\beta}_2$	0.149 (0.133)	0.146 (0.147)	−0.104 (0.252)
Impact of covariates:			
Initial CO_2 emission	−0.127 (0.091)	0.128 (0.092)	−0.121 (0.018)
Energy consumption	0.710*** (0.122)	0.567*** (0.172)	0.862*** (0.167)
Population	1.378* (0.733)	0.899 (0.897)	1.552 (1.133)
Financial development	0.013 (0.028)	−0.004 (0.019)	0.022 (0.043)
$\hat{\delta}_1$	−0.123* (0.075)	−0.046 ** (0.019)	−0.192* (0.114)
N	30	12	18
T	41	41	
Total observation	1,230	492	738

*Indicate significance at 10% level, respectively.

**Indicate significance at 5% level, respectively.

***Indicate significance at 1% level, respectively.

friendly technology. Financial development may also provide avenue for foreign direct investment, which will promote research and development activities that improve economic activities. The positive effect could be explained by the fact that financial development may boost industrial sectors who are not using CO_2 reduction techniques in the production processes consequently leading to increased industrial pollution and environmental degradation.

We also investigated the causal relationship between CO_2 emission and the other variables included in the model. Tables 8 and 9 present the results from Dumitrescu and Hurlin (2012) panel average and individual Wald causality statistics and the associated probability values, respectively. Focusing first on Table 8 which pertains to the panel statistics, it can be observed that the null hypothesis that GDP growth does not homogeneously cause CO_2 emission growth is rejected and this is robust to all lag orders. However, there is no reverse causality form CO_2 emission to GDP, implying a unidirectional causal relationship. This result provides evidence that GDP has a predictive ability for CO_2 emission. In other words, aside the previous value of CO_2 emission, the past value of GDP can also help to predict the path of CO_2 emission. For energy consumption and population, the null hypothesis is rejected only when the lag order is equal one. Again, this is evidence of unidirectional causality from energy consumption and population to CO_2 emission. The causal relationship between financial development CO_2 emission seems to be bidirectional with FD Granger causing CO_2 with one lag while CO_2 causes FD at all three lags. This could be explained by the fact that financial development can help to determine whether CO_2 emission would increase or decrease and at the same time CO_2 emission could spur the financial sector to embark on developments that would help to mitigate such emissions.

Table 8. Dumitrescu and Hurlin (2012) panel causality test in heterogeneous panels

	k = 1			*k* = 2			*k* = 3		
	***W*-Stat.**	***Z* bar-Stat.**	**Prob.**	***W*-Stat.**	***Z* bar-Stat.**	**Prob.**	***W*-Stat.**	***Z* bar-Stat.**	**Prob.**
GDP does not cause CO_2	2.372	4.706	**0.000**	3.784	4.107	**0.000**	4.685	2.914	**0.004**
CO_2 does not cause GDP	1.082	0.096	0.924	2.161	0.098	0.922	3.058	−0.279	0.780
ECONS does not cause CO_2	2.031	3.489	**0.001**	2.686	1.395	0.163	3.041	−0.312	0.755
CO_2 does not cause ECONS	1.468	1.474	0.141	2.123	0.005	0.996	3.422	0.436	0.663
POP does not cause CO_2	1.607	1.971	**0.049**	1.912	−0.516	0.606	2.967	−0.458	0.647
CO_2 does not cause POP	0.741	−1.126	0.260	1.679	−1.093	0.274	3.293	0.182	0.856
FD does not cause CO_2	1.574	1.822	**0.069**	2.413	0.709	0.478	3.317	0.225	0.822
CO_2 does not cause FD	1.526	1.656	**0.098**	3.621	3.645	**0.000**	4.794	3.078	0.002

Notes: The *W* bar test statistic corresponds to the cross sectional average of the *N* standard individual Wald statistics of Granger non causality tests. The *Z* bar statistic corresponds to the standardized statistic (for fixed *T* sample). FD results pertain to all countries excluding Zimbabwe. Values in bold indicates rejection of the null hypothesis of homogenous non causality.

Table 9. Dumitrescu and Hurlin (2012) individual wald granger causality test

	GDP does not Granger cause CO_2						CO_2 does not Granger cause GDP					
	k = 1		*k* = 2		*k* = 3		*k* = 1		*k* = 2		*k* = 3	
	W_i	p_i	W_i	p_i	W_i	p_i	W_i	p_i	W_i	p_i	W_i	p_i
Argentina	0.339	0.560	1.228	0.541	2.125	0.547	0.412	0.521	0.865	0.649	1.041	0.791
Benin	3.816	**0.051**	8.385	**0.015**	8.083	**0.044**	0.246	0.620	4.528	**0.104**	6.069	0.108
Brazil	0.015	0.904	1.058	0.589	1.236	0.745	0.398	0.528	0.340	0.844	0.332	0.954
China	1.234	0.267	2.470	0.291	2.188	0.534	0.081	0.776	0.318	0.853	1.113	0.774
Côte d'Ivoire	0.605	0.437	1.167	0.558	1.653	0.648	0.499	0.480	0.798	0.671	1.097	0.778
Cameroon	0.980	0.322	1.058	0.589	2.064	0.559	0.220	0.639	1.199	0.549	6.489	**0.090**
Algeria	5.405	**0.020**	1.320	0.517	6.687	**0.083**	0.004	0.952	0.904	0.636	4.423	0.219
Ecuador	2.234	0.135	3.244	0.198	2.051	0.562	0.025	0.875	1.721	0.423	1.336	0.721
Egypt	2.696	**0.101**	2.749	0.253	2.680	0.444	5.584	**0.018**	9.316	**0.010**	8.476	**0.037**
Gabon	1.974	0.160	3.681	0.159	5.847	0.119	2.763	**0.097**	3.349	0.187	6.112	0.106
Ghana	2.344	0.126	2.568	0.277	5.236	0.155	0.079	0.779	0.497	0.780	0.765	0.858
Honduras	0.033	0.855	1.033	0.597	2.294	0.514	5.739	0.017	5.183	0.075	5.005	0.171
Indonesia	0.001	0.977	0.428	0.807	1.840	0.606	0.059	0.808	0.178	0.915	1.399	0.706
India	0.037	0.848	1.561	0.458	1.454	0.693	0.173	0.678	0.261	0.878	0.027	0.999
Iran	4.030	**0.045**	4.979	**0.083**	4.442	0.218	1.077	0.300	1.550	0.461	3.032	0.387
Kenya	0.740	0.390	2.119	0.347	1.829	0.609	0.003	0.961	0.299	0.861	0.144	0.986
Morocco	0.040	0.842	0.372	0.831	5.762	0.124	0.060	0.806	0.160	0.923	2.102	0.552
Mexico	6.213	0.013	5.216	**0.074**	9.755	**0.021**	0.072	0.788	1.821	0.402	4.560	0.207
Nigeria	1.044	0.307	2.911	0.233	4.601	0.204	0.320	0.571	0.375	0.829	1.209	0.751
Pakistan	3.429	**0.064**	9.747	**0.008**	10.921	**0.012**	0.412	0.521	2.067	0.356	4.369	0.224
Peru	5.764	**0.016**	10.426	**0.005**	10.366	**0.016**	0.001	0.982	1.965	0.374	1.795	0.616
Philippines	0.590	0.443	8.480	**0.014**	9.722	**0.021**	2.664	**0.103**	5.548	**0.062**	4.447	0.217
Sudan	0.067	0.796	0.586	0.746	3.228	0.358	8.359	**0.004**	14.009	**0.001**	14.436	**0.002**
Senegal	3.299	**0.069**	3.172	0.205	5.267	0.153	0.267	0.606	1.352	0.509	2.012	0.570
Thailand	0.953	0.329	4.433	0.109	2.989	0.393	0.296	0.587	1.698	0.428	0.835	0.841
Tunisia	0.187	0.666	0.272	0.873	0.905	0.824	0.696	0.404	0.910	0.634	4.981	0.173
Turkey	0.023	0.881	0.069	0.966	0.097	0.992	1.508	0.220	1.850	0.396	2.149	0.542
South Africa	2.746	**0.098**	2.659	0.265	2.727	0.436	0.940	0.332	0.672	0.715	0.613	0.894
Dem. Rep. Congo	12.322	**0.000**	13.674	**0.001**	12.652	**0.006**	0.057	0.811	0.148	0.929	0.234	0.972
Zambia	8.825	**0.003**	15.127	**0.001**	13.554	**0.004**	0.374	0.541	0.349	0.840	0.456	0.928
Zimbabwe	1.545	0.214	1.105	0.576	0.972	0.808	0.164	0.685	2.760	0.252	3.736	0.291

Note: Values in bold indicates rejection of the null hypothesis of homogenous non causality.

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Table 10. Panel causality test for homogenous panels

	k = 1		*k* = 2		*k* = 3	
	***F*-Stat.**	**Prob.**	***F*-Stat.**	**Prob**	***F*-Stat.**	**Prob.**
GDP does not cause CO_2	23.624	**0.000**	18.370	**0.000**	15.183	**0.000**
CO_2 does not cause GDP	5.511	**0.019**	4.020	**0.018**	3.640	**0.012**
ECONS does not cause CO_2	25.147	**0.000**	17.656	**0.000**	12.164	**0.000**
CO_2 does not cause ECONS	0.518	0.472	0.566	0.568	0.473	0.701
POP does not cause CO_2	0.234	0.629	0.281	0.755	0.322	0.810
CO_2 does not cause POP	0.003	0.958	0.043	0.958	0.035	0.991
FD does not cause CO_2	3.382	**0.066**	4.644	**0.010**	4.208	**0.006**
CO_2 does not cause FD	3.111	**0.078**	10.665	**0.000**	7.970	**0.000**

Note: FD results pertain to all countries excluding Zimbabwe. Values in bold indicates rejection of the null hypothesis of homogenous non causality.

Looking at Table 9 which relates to the individual panel statistics, here we have presented results for only the main variables of interest, CO_2 emission and GDP to conserve space. The results in the first six columns show that in 10 out of 31 cross sections (countries), the null hypothesis of GDP not Granger causing CO_2 emission is rejected. These countries are Benin, Algeria, Egypt, Iran, Pakistan, Peru, Senegal, South Africa, Dem. Rep. Congo and Zambia. Unfortunately, one cannot attribute this causality to whether these countries belong to the middle income, or low income countries as four out of these are middle income while the remaining six are low or low middle income countries. Now looking at the last six columns which test the null hypothesis of Granger non causality from CO_2 emission to GDP, this is rejected for six out of 31 countries. These are Benin, Cameroon, Egypt, Gabon, Philippines and Sudan. Immediately, from these results one can infer that only Benin and Egypt show evidence of bidirectional causality between CO_2 emission and GDP.

As a robustness check on the causal relationship, the study also presented the panel causality results when all the cross sections are treated to be homogenous. In other words, the slope coefficients are the same in this case and hence only group or panel statistics can be presented. This result is presented in Table 10. The results largely confirm that obtained when the assumption of heterogeneity is made in that GDP, ECONS and FD all Granger cause CO_2 emission, the only exception being population. Here we observe bidirectional causality between GDP and CO_2 emission and between FD and CO_2 emission. Overall, the two approaches unequivocally confirms the causal role of economic growth, energy consumption and financial development for CO_2 emission in these developing countries.

6. Policy implications

It has been established by this study that extensive output growth coupled with increasing population leads to more fossil fuel consumption that contributes towards higher level of emissions. The findings have important practical and policy implications. The need for transformation of low carbon technologies aimed at reducing emissions and sustainable economic growth cannot be overstressed since these not only keep the economy green but also preserve the environment for future generations. It calls for policies to promote long term investment in clean and renewable energy sources such as solar power, wind power and natural gas and less emphasis on non-renewable energy such as coal, petroleum and their derivatives that deplete very fast and hence are detrimental to the environment. Also policies to promote energy efficiency is necessary as this would increase energy security and decrease CO_2 emission without adversely affecting economic growth. While it is difficult to reduce the demand for energy as the population increases, there is need to increase environmental awareness among the citizens. Awareness of citizens aligned with governmental regulatory pressures can be a possible solution to environmental degradation problem. They should be made aware of the consequences of using low quality petroleum products and be encouraged to use energy

saving gadgets and facilities such as solar powered household items, LPGs for cooking and energy conserving electric bulbs. Where these items are costly to purchase, the government can provide them at subsidized rates. Measures to curb deforestation by the citizens of the countries should be strengthened since these activities release CO_2 emission into the atmosphere. Emission standards should be set for industries and emission monitoring strategies should be put in place to ensure compliance. The development of the financial markets in these countries can also assist in enhancing investment in research and development in modern energy efficient technologies thus ensuring lower emissions. Further, since CO_2 is not a local pollutant but a global one, perhaps international cooperation would help to also reduce its emissions. Perhaps creating a union between these countries to establish unified environmental acts will increase the effectiveness of such regulations on the pollution levels. This does not however rule out individual national environmental laws and regulations.

7. Conclusion

Although the literature on economic growth, energy consumption, population and CO_2 emission has grown over the last few years, there is no known study that examined the effect of economic growth on CO_2 emission using the dynamic panel threshold framework. This study investigated this relationship using data from 1970 to 2013 based on a panel of 31 developing countries. The results show that economic growth has negative effect on CO_2 emission when the economy is in the low growth regime but positive effect when in the high growth regime. The effect in the high growth regime is however stronger. Thus the validity of the Environmental Kuznets Curve (inverted-*U*) hypothesis could not be established for these panel of countries for the period under study. Also energy consumption and population exert positive and significant effect on CO_2 emission. Robustness check with the inclusion of a financial development indictor and separation of middle and low income countries produced qualitatively similar results. In addition, the study performed causality analysis and it is concluded based on two alternative approaches that economic growth, energy consumption and financial development have significant causal relationship with CO_2 emission.

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Author details
Goodness C. Aye[1]
E-mail: goodness.aye@gmail.com
ORCID ID: http://orcid.org/0000-0001-6648-1546
Prosper Ebruvwiyo Edoja[1]
E-mail: edojaprosper@gmail.com
[1] Department of Agricultural Economics, Federal University of Agriculture Makurdi, PMB 2373, Makurdi, Nigeria.

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Note
1. EVIEWS user guide.

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