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RESEARCH ARTICLE

The effects of economic growth and innovation on CO_2 emissions in different regions

Lamini Dauda[1] · Xingle Long[1] · Claudia Nyarko Mensah[1] · Muhammad Salman[1]

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Abstract

Economic growth and economic energy consumption have received greater attention due to its contribution to global CO_2 emissions in recent decades. The literature on CO_2 emissions and innovation for regional differences is very scanty as there is not enough study that considered different regions in a single analysis. We adopt a holistic approach by incorporating different regions so as to assess how innovation contributes to emission reduction. The study, therefore, examined the effects of innovation and economic growth on CO_2 emissions for 18 developed and developing countries over the period of 1990 to 2016. The study used panel technique capable of dealing with cross-section dependence effects: panel cross-sectional augmented Dickey-Fuller (CADF) unit root to determine the order of integration, Westerlund cointegration tests confirmed that the variables are co-integrated. We employed panel fully modified ordinary least square (FMOLS) and panel dynamic ordinary least square (DOLS) to estimate the long-run relationship. The results show that energy consumption increases CO_2 emissions at all panel levels. However, innovation reduces CO_2 emissions in G6 while it increases emissions in the MENA and the BRICS countries. Environmental Kuznets curve (EKC) hypothesis is valid for the BRICS. The pollution haven hypothesis (PHH) and pollution halo effect were confirmed at different panel levels. Based on the findings different policy recommendations are proposed.

Keywords Economic growth · Innovation · CO_2 emissions

Introduction

Sustainable economic growth has become a critical policy target for all economies. To achieve this objective, it is necessary to reduce CO_2 emissions, which makes achieving sustainable development goals difficult. Innovation is becoming a major focus in climate change policy discussion (Metz et al. 2007), because it is considered a solution to deal with the challenge between economic growth and improving environmental quality (Aronsson et al. 2010; Hübler et al. 2012). Innovation has therefore emerged as a key factor in achieving an efficient energy production and ensuring the sustainable development of both developed and developing economies. Al-Mulali et al. (2015) argue that the major reason GDP growth, electricity consumption, trade openness, and urbanization increase CO_2 emission is because the variables depend largely on fossil fuel energy. Moving from fossil fuel energy production sources that pollute the environment to sustainable energy sources require technologies and consumption decisions that have less negative environmental impact (Foxon 2011; Nordhaus 2007). Transforming the energy sources will promote economic growth and development without escalating environmental pollution. Technological innovation is a dominant channel to achieve this structural change toward economic growth (Schumpeter 1934). In the economic growth theory, many have studied relationship between economic growth and accumulation of knowledge through innovation (Grossman and Helpman 1991; Romer 1990; Young 1991), as the use of human capital and existing knowledge create technological innovation. From the perspective of economic

Responsible editor: Philippe Garrigues

✉ Lamini Dauda
dabremp@gmail.com

Xingle Long
longxingle@163.com

Claudia Nyarko Mensah
claudiamensahphd@yahoo.com

Muhammad Salman
dawarsalman@gmail.com

[1] School of Management, Jiangsu University, Zhenjiang 212013, China

growth motivated by fossil fuel consumption could lead to environmental pollution, a phenomenon known as environmental Kuznets curve (EKC) where economic growth and environmental pollution have an inverted *U*-shaped curve (Copeland and Taylor 2004; Dogan and Seker 2016; Grossman and Krueger 1991). Empirical study by

Antweiler et al. (2001) show that growth empowered by capital accumulation has a tendency to increase pollution, while growth supported by technological progress reduces pollution (CO_2 emissions) levels. The effects of technological progress on the evolution of the relationship between economic growth and environment have been explained by the endogenous growth theory which considers that production processes are improved by increasing the capacity or replacement of polluting resources with other resources which are more environmentally friendly (Arrow et al. 1995; Meadows et al. 1972; Stokey 1998). These models are based on a society committed to the environment that could invest more resources for protection as their income increases. Technology can play a vital role in emission reduction even when income increases as the EKC link economic growth to emission (Andreoni and Levinson 2001; Hicks 1963). Higher level of economic activity would lead to higher levels of energy consumption and could result in higher emission. On the other, hand innovation system or process may be less energy consuming and lead to less pollution (Fernández et al. 2018). The technology innovation of mitigating CO_2 emission and improved energy efficiency is not the final solution to environmental and economic growth issues because it could result in "rebound effect" where the process or system of innovation could not give expected outcome.

In the long run, the cumulative impact of technological innovation may resolve the conflicts between economic growth and environmental quality (Jaffe and Stavins 1994; Schultz 1975). This means investment in innovation could reduce CO_2 emissions without necessarily affecting economic growth. The transition to low-carbon economies will need provision of secure and affordable energy for economic growth and social development (IEA 2014). The Paris Agreement on climate change has set a target for basic transformation of the global economy in the coming decades, purposely to reduce the global temperature which requires transforming energy system to make the environment conducive for habitation (IEA 2016). It is therefore necessary to incorporate innovation into CO_2 emission mitigation policies.

In this wise, our study contributes to the existing literature in the following areas; first, the study compares the effects of economic growth and innovation on CO_2 emissions in three regions. This is necessary because it will afford countries or regions that are performing poorly in terms of reducing CO_2 emissions to learn best practices that are carried out in other economies. This study will highlight on the regions that are doing well in terms of mitigating emissions through the use of innovation.

Second, in the environmental economics literature, there are many research on innovation and its impact on emission. However, literature on regional differences is very scanty as there is no enough study that considered all the blocs in a single analysis. Therefore, this study adopts a holistic approach by incorporating different regions so as to assess how innovation contributes to emission reduction at various regional levels.

The paper is organized as follows: the "Literature review" section reported the literature review. Methodology and data are presented in the "Methodology and data" section. The "Results" section displayed the results, the "Discussions" section discusses the findings, and the "Conclusion and policy implications" section offers the conclusion and policy implications.

Literature review

Environmental pollution is a global challenge that needs a consented effort to mitigate CO_2 emission menace. To ensure proper understanding of the subject matter relevant literature on CO_2 emissions and innovation are reviewed.

From empirical perspective, Yii and Geetha (2017) examined the causal relationship between technology innovation and CO_2 emissions in Malaysia over the period of 1971 to 2013. The authors found that technology innovation is negatively related to CO_2 emissions in the short run, suggesting that policymakers should promote innovation research to boost economic development and environmental sustainability. Long et al. (2018) concluded that innovation depresses CO_2 emission intensity in China. In a similar vein, Wang et al. (2018) and Yu and Du (2018) noted that progress made in energy technology has played a major role in CO_2 emission reduction. Balsalobre-Lorente et al. (2018a) examined the link among economic growth and CO_2 emission for EU-5 over the period of 1985–2016. The results indicated that energy innovation promotes quality environment. In supporting Samargandi (2017) substantial technology innovation in production will ultimately reduce the deterioration effects of emissions. From the above empirical analysis it can be inferred that innovation improves production and consumption choices to reduce negative impact of emissions from all sources on the environment.

A part from the foregoing developments, others have extensively researched the relationship between R&D and other determinants of CO_2 emissions. Most of the studies have proxy R&D as an indicator for innovation. For example, Apergis et al. (2013) demonstrated that R&D expenditures reduce CO_2 emission in European firms. Kahouli (2018) examined linkages among CO_2 emissions, R&D stocks, and economic growth for the Mediterranean countries (MCs) over 1990–2016. The author found strong feedback effects between electricity, CO_2

emissions, R&D stocks, and economic growth, while Irandoust (2016) found a unidirectional causality running from technological innovation to renewable energy in four Nomadic countries. Furthermore, Mensah et al. (2018) examined the relationship between GDP per capita, renewable and non-renewable, R&D, and CO_2 emission in 28 OECD countries. The findings indicated that per-capita GDP and non-renewable energy increase CO_2 emission while R&D reduces emissions and promote quality environment. They concluded that innovation is a vital component in the mitigation of CO_2 emissions across these countries. In a similar study in OECD economies, Balsalobre et al. (2015) findings show that innovation in energy decreases CO_2 emissions and thus recommended a strong policy in energy RD&D to offset the negative effects of energy intensity. In another breath, Al-Mulali et al. (2015) examine the effect of internet retailing on pollution in 77 countries between 2000 and 2013. They proxy CO_2 emission for pollution and the results show that GDP growth, electricity consumption, and urbanization embolden CO_2 emissions for both developed and developing countries. However, the study noted that internet retailing reduces CO_2 emissions in developed countries but does not have significant impact on CO_2 emission in developing countries.

From theoretical and empirical perspective it can be deduced that the impact of FDI and trade openness on the environment is at best mixed and a cause for continue debate. For instance, Sun et al. (2017) found that FDI increases CO_2 emissions. In addition to aforementioned, Mihci et al. (2005) argument supports the opinion that strict environmental protection has a strong influence on FDI outflow from such countries, thus encourage FDI moving from home countries with restrict environment rules to weak environmental regulatory location. On the other hand, some studies established that FDI improves environmental quality (Zhu et al. 2016). Interestingly, Hanna (2010) argued that in countries with weak environmental rules, foreign firms appear to apply most efficient production method that consequently reduces pollution. This happens because the foreign firms use advanced technology which eventually benefit domestic firms through knowledge spillover. This implies that lax environmental regulations would not always be the reason for foreign firms to pollute host countries.

Similarly, Ertugrul et al. (2016), Ozturk and Acaravci (2013), and Sannassee and Seetanah (2016) found trade openness to increase CO_2 emissions and subsequently lead to deterioration of the environment. On the contrary, Managi et al. (2009) and Saud et al. (2018) indicated that trade openness reduces CO_2 emissions. However, the study of Le et al. (2016) on high-, middle-, and low-income countries revealed that trade openness has a benign effect on the environment in high-income countries, but a detrimental to the environments in the middle- and low-income countries. Hossain (2011) concluded that trade openness is fairly good for environment due to the varying findings in his study.

Studies have shown that both economic growth, energy, and urbanization impact the environmental quality. This is evident in the research of Liobikienė and Butkus (2019), who showed in their study for 147 countries that GDP and urbanization contributed to reducing CO_2 emissions only through energy efficiency. For this reason countries should pay close attention to technological development and energy efficiency as they seek sustainable economic growth. While Talbi (2017) also indicates that energy efficiency plays a dominant role in reducing CO_2 emissions, his findings contrast Liobikienė and Butkus (2019) on economic growth and urbanization in emission reduction observation. Moreover, Chen et al. (2018) indicated that energy intensity, economic growth, and urbanization are the main factors affecting CO_2 emissions in many developed and developing countries. According to Wang et al. (2016) urbanization increases CO_2 emissions in a panel of Southeast Asian countries. In contrast to above findings, Zhu et al. (2018) revealed that urbanization and income inequality reduce CO_2 emissions in BRICS economies but Bekhet and Othman (2017) concluded that there is an inverted *U*-shaped relationship between CO_2 emissions and urbanization.

The emergence of the EKC hypothesis investigates the long-run effects of economic growth on the environment. The EKC depicts an inverted-*U*-shaped relationship between per capita income and environmental problems. The EKC theory purports that at the beginning of development, economic growth leads to environmental pollution until it reaches a stabilization and then pollution starts to decline when per capita income rises and people demand for quality environment (Grossman and Krueger 1995). Since then numerous empirical studies found evidence of EKC hypothesis across different regions. For example, Omri et al. (2015), Saud et al. (2018), and Zhu et al. (2018) and among other researchers confirmed the EKC hypothesis. However, Balsalobre-Lorente et al. (2018a) found *N*-shaped relationship between economic growth and CO_2 emissions.

In addition to the foregoing, a leading study by Balsalobre-Lorente et al. (2018b) argued that the fall of EKC after income levels has increased is not static and if environmental regulations and technological innovation are not encouraged, society is bond to fall into a trap of "technological obsolescence effect" where society returns to increasing environmental pollution beyond the EKC. This further emphasizes the incorporation of energy innovation and strict environmental regulations into the development process at all stages to avoid the obsolescence technical effect. From the above studies, the common denominator of improving environmental quality is incorporating technological innovation into energy and production at all stages for sustainable economic growth and development. In that way, the negative effects of economic growth could be maintained.

Methodology and data

Empirical model

The following is our proposed model:

$$CO_2 = f(GDP, INOV, FDI, EC, TO, URB) \quad (1)$$

Equation (1) states that GDP (PPP constant 2011 international $) (as explained in the literature, we proxy for economic growth), foreign direct investment net inflow (FDI constant 2011 international $), energy consumption (EC in kilotons), innovation (INOV), trade openness (TO Mechandise trade ratio of GDP), urbanization (URB), and CO_2 emissions (CO_2 in kilotons) proxy for environmental quality. Following Flikkema et al. (2015), Gotsch and Hipp (2014), Potepa and Welch (2018), and Wang (2013) the study proxy trademark application for innovation. The innovation is efficient use of resources to reduce waste and pollution. Using a panel data for our study Eq. (1) can be written in panel form as

$$lnCO_{2it} = \alpha_0 + \beta_1 lnpgdp_{it} + \beta_2 (lnpgdp_{it})^2 + \beta_3\ lninov_{it} + \beta_4\ lnfdi_{it} + \beta_5 lnec_{it} + \beta_6 lnto_{it} + \beta_7 lnurb_{it} + \varepsilon_{it} \quad (2)$$

where i represents the country (in this study, we have 18 countries; t represents time (our time frame is 1980–2016). The study variables are GDP proxy for economic growth, trade openness (to), energy consumption (EC), urbanization (URB), and innovation (inov). To test for the environmental Kuznets curve, GDP squared is added to the independent variables. If gdp is significantly positive and the square of gdp is negatively significant then it confirms the presence of EKC hypothesis in the sampled countries. Thus, $\beta_1 > 0$ and $\beta_2 < 0$. Foreign direct investment and trade openness are interesting variables to be added to test for the pollution haven hypothesis and pollution halo effect in these countries.

Panel unit root and cointegration tests

In a panel data analysis, the unit root of the panel is taken to identify the stationary properties of the variables. However, we test for cross-section dependence (Pesaran 2004) in order to be able to select an approperiate unit root and cointegration tests that can eliminate cross-sectional dependence problems. In the presence of cross-section dependence, cross-sectional augmented Dickey-Fuller (CADF) panel unit root tests (Pesaran 2007) are suitable because they are robust in the presence of cross-section effects.

Westerlund panel cointegration

Cointegration tests are necessary to ascertain long-run relationship among variables. If the presence of cross-sectional dependency is confirmed in the series, ordinary cointegration tests (Johansen 1988; Kao 1999) have some biases which can give misleading results. To overcome such demerits, we applied (Westerlund 2007) cointegration test because it can eliminate cross-section dependence effects among the variables by the bootstrap technique than other cointegration such as Johansen (1988) and Kao (1999) with no such properties. The cointegration test statistics are G_t (between groups), G_a (among groups), P_t (between panels), and P_a (among panels). G_t, G_a statistics test null hypothesis of no cointegration in whole panel against existence of cointegration in one cross-sectional units at least. P_t, P_a test null of no cointegration in the whole panel, against evidence of cointegration in the whole panel.

Data

Table 1 reports summary of panel data. The data comprises GDP (PPP constant 2011 international $), FDI net inflows (PPP constant 2011 international $), urban population (person), trade openness (Mechandise trade ratio of GDP), and trademark application (total). Both CO_2 emissions and energy consumption are measured in kilotons. The panel data are from World Development Indicators (WDI). We employed the variables in their natural logarithms.

The data covers the period 1990 to 2016 for 18 developed and developing countries. The countries are grouped into three subpanels or regions. It includes **Group of 6** (Canada, France, Germany, Italy, Japan, United Kingdom), **MENA** (Bahrain, Egypt, Morocco, Tunisia, Algeria, Israel, United Arab Emirates), and **BRICS** (Brazil, Russia, India, China, and South Africa).

Results

Cross-section dependence test

The results in Table 2 indicate that the cross-section dependence test (Pesaran 2004) strongly supports the presence cross-section dependence in the variables in all the four panel levels. The study rejected the null hypothesis at 1% significance level, and accepted the

Table 1 Summary of data

	Statistics Unit	CO_2 Kiloton	GDP PPP Constant 2011 international $	Trademark application Total	FDI Constant 2011 international $	Energy consumption Kiloton	Trade openness Mechandise trade ratio of GDP	Urban population Person
Main	Mean	716,191.3	1.90e+12	72,793.18	2.74E+12	263,821.1	51.24705	8.68e+07
	Standard deviation	1,350,254	2.45e+12	185,739	4.83E+12	415,821.4	29.12318	1.36E+08
	Min	10,901.99	1.74e+10	854	− 2.33E+12	4899.073	9.051853	437,114
	Max	1.03e+07	1.99e+13	2,104,409	4.04E+13	3,051,504	176.6756	7.82e+08
	Observation	479	487	476	487	485	483	504
G6 (Group of 6)	Mean	632,208	35,776.78	69,247.27	4.15e+12	272,190.5	42.02617	5.48e+07
	Standard deviation	287,620.1	3416.574	39,762.59	5.17e+12	116,547	14.00218	2.59e+07
	Min	303,275.6	29,514.85	23,513	− 2.33e+12	146,556.2	13.55744	2.13e+07
	Max	1,266,010	44,431.82	211,011	4.04e+13	521,036.3	72.62037	1.16e+08
	Observation	159	162	162	162	162	162	162
MENA	Mean	68,607.48	26,953.8	68,603.51	2.76E+11	24,023.43	69.27373	1.24e+07
	Standard deviation	51,744.23	28,275.85	39,146.55	4.02e+11	20,493.64	36.28399	1.08e+07
	Min	10,901.99	3863.408	854	− 2.31E+11	4899.073	18.6419	437,114
	Max	217,163.4	110,432.5	211,011	1.99E+12	86,634.98	176.6756	4.09e+07
	Observation	189	189	183	189	189	189	189
BRICS	Mean	1,752,397	3.48e+12	169,752	4.49e+12	591,925	35.09746	2.25E+08
	Standard deviation	2,213,370	3.68e+12	329,470.4	6.15e+12	649,560.7	14.58818	1.92e+08
	Min	208,887	3.53e+11	10,600	− 3.48E+10	88,586.05	9.051853	1.95e+07
	Max	1.03e+ 07	1.99e+13	2,104,409	2.67E+13	3,051,504	63.96638	7.82e+08
	Observation	131	136	131	136	134	132	136

alternative of cross-sectional dependence in the series. Based on the evidence of cross-section dependence in the series, we applied CADF panel unit root test (Pesaran 2007), which is robust in the presence of cross-section dependence.

CADF panel unit root tests

As already mentioned, an important step for testing long-run relationship among CO_2 emissions, economic growth, innovation, FDI, energy consumption, trade openness, and

Table 2 Cross-section dependence test

Variable	Main panel		G6		MENA		BRICS	
	CD test	*p* value	CD test	*p* value	CD test	*p* value	CD test	*p* value
lnco2	55.800***	0.000	16.222***	0.000	7.072***	0.000	10.648***	0.000
lngdp	40.893***	0.000	17.679***	0.000	7.263***	0.000	15.118***	0.000
lninov	51.218***	0.000	20.364***	0.000	6.892***	0.000	10.720***	0.000
lnfdi	16.690***	0.000	2.248**	0.025	5.585***	0.000	13.133***	0.000
lnec	58.770***	0.000	20.489***	0.000	22.545***	0.000	15.394***	0.000
lnto	27.233***	0.000	10.395***	0.000	6.881***	0.000	6.666***	0.000
lnurb	50.794***	0.000	18.843***	0.000	23.938***	0.000	4.797***	0.000

***, **, * denote significance level of 1%, 5% and 10%, respectively

Table 3 Cross-sectional augmented Dickey-Fuller (CADF) panel unit root tests

Variable	Main panel		G6		MENA		BRICS	
	Level	First difference	Level	First difference	Level	First difference	Level	First difference
lnco2	− 1.421	− 2.560***	− 1.757	− 3.22***	− 1.421	− 3.216***	− 1.265	− 3.103***
lngdp	− 2.590	− 2.799**	− 1.799	− 2.736**	− 1.855	− 2.44**	− 2.856*	− 3.084**
lninov	− 2.510	− 2.251**	− 0.904	− 3.642***	− 0.27	− 3.99***	− 2.498	− 3.276***
lnfdi	− 0.456	− 3.499***	− 1.707	− 2.725**	− 2.528	− 4.379***	− 3.377***	− 4.476***
lnec	− 1.54	− 3.522***	− 1.473	− 4.455***	− 2.053	− 2.785***	− 0.527	− 2.0837**
lnto	− 1.745	− 3.24***	− 2.086	− 2.886***	− 1.222	− 3.672***	− 2.042	− 4.493***
lnurb	− 1.802	− 2.471***	− 1.657	− 2.3838***	− 1.392	− 2.653**	− 2.04	− 2.852**

***, **, * denote significance level of 1%, 5% and 10%, respectively

urbanization is that the variables should be integrated at first order I(0) or second order I(1). We employed Pesaran (2007) CADF panel unit root test which is desirable in cross-sectional dependence cases. In Table 3, null hypothesis of unit root is accepted for all variables at level with the exception of per-capita GDP for BRICS panel. However, when we applied the panel unit root tests at the first difference, the null hypothesis is rejected. We therefore concluded that all the series are stationary at first difference.

Westerlund panel cointegration tests

We employed Westerlund (2007) cointegration tests due to the existence of cross-sectional dependence in the series (Pesaran 2007). The results in Table 4 confirmed cointegration in the variables, which implies that long-run relationship exists. Westerlund (2007) cointegration account for cross-sectional dependence because it contains a bootstrap properties that eliminate such problems as correlation among the units. The G_t, G_a (between- and among-group cross-sectional units) and P_t, P_a (between and among whole panel) statistics with *p* values and robust *p* values show a rejection of null hypothesis of no cointegration. This means that there is cointegration, an evidence of a long-run relationship among the series.

Fully modified ordinary least square regression

The results in Table 5 show that economic growth increases CO_2 emissions at the main and BRICS panel levels. However, economic growth depresses emissions in G6 and MENA countries. A unit increase in economic growth decreases emissions about 108.4% in G6 and 4.388% in MENA while a 1% increase in economic growth escalates emission of 9.014% in the main and 18.03% for BRICS, respectively.

Also, innovation at the main, MENA, and BRICS panel levels increase CO_2 emissions but only significant for the main and BRICS panels. A 1% increase innovation will increase emissions about 0.549% and 7.386%, respectively, in the main panel and

Table 4 Westerlund panel cointegration tests

Statistic	Main panel			G6 panel		
	G6 panel	G6 panel	G6 panel	G6 panel	G6 panel	G6 panel
Gt	− 2.682	0.144	0.173	− 3.753	0.001***	0.007**
Ga	− 9.704	0.983	0.008**	− 2.652	1.000	0.667
Pt	− 10.926	0.055*	0.210	− 6.848	0.085*	0.193
Pa	− 12.916	0.079*	0.040**	− 1.972	0.988	0.620
Statistic	MENA			BRICS		
	Value	*p* value	Robust *p*	Value	*p* value	Robust *p*
Gt	− 2.946	0.089*	0.090*	− 2.761	0.231 **	0.200**
Ga	− 13.278	0.573	0.010***	− 14.425	0.440	0.020***
Pt	− 3.665	0.950	0.595	− 13.140	0.000***	0.020***
Pa	− 3.665	0.029 **	0.030**	− 61.966	0.000***	0.000***

***,**,* denote significance level of 1%, 5% and 10% respectively

Table 5 Fully modified ordinary least square regression (FMOLS)

Dependent variable = CO_2 emission

Variable	Main panel	G6	MENA	BRICS
lngdp	9.014***	− 108.4**	− 4.388**	18.03***
	(0.734)	(44.57)	(2.072)	(2.539)
lngdp2	− 0.135***	2.043**	0.101**	− 0.414***
	(0.0136)	(0.795)	(0.04)	(0.0444)
lninov	0.549***	− 1.521***	0.0215	7.386***
	(0.0239)	(0.513)	(0.027)	(0.0309)
lnec	1.677***	1.794***	0.0747***	0.516***
	(0.012)	(0.0663)	(0.016)	(0.0154)
lnfdi	0.109***	1.064***	0.0115	− 0.856***
	(0.00939)	(0.125)	(0.00828)	(0.0164)
lnto	1.027***	− 2.865***	0.202*	4.991***
	(0.0833)	(0.671)	(0.119)	(0.114)
lnurb	0.480***	− 9.429***	0.0233	− 1.790***
	(0.0542)	(1.732)	(0.0671)	(0.126)
Constant	− 135.5***	155**	54.13**	− 210.4***
	(10.06)	(63.9)	(26.64)	(36.05)
Observation	485	161	188	134
R^2	0.784	0.842	0.936	0.973

Note. Standard errors are in parentheses. ***, **, * denote significance level of 1%, 5%, and 10%, respectively

BRICS countries. However, innovation decreases CO_2 emissions and a unit increase in innovation leads to about 1.521% reduction in emissions in G6 economies. More so, energy consumption stimulates CO_2 emissions in all the four panels in the study. A unit increase in energy consumption causes an increase in emissions in the main panel, G6, MENA, and BRICS economies for about 1.677%, 1.794%, 0.0747%, and 0.516%, respectively.

Furthermore, FDI is significantly positively related to emissions. FDI escalates emissions in the main and G6 panel levels while it is positive but insignificant in MENA countries. A unit increase in FDI increases emissions about 0.109% and 1.064% in the main panel and G6 countries. On one hand, FDI decreases CO_2 emissions and 1% increase in FDI results in emission reduction of about 0.856% in BRICS economies. Trade openness is statistically positive and induces emissions at all panel levels except G6 where it reduces CO_2 emissions. A unit increase in trade openness increases CO_2 emissions about 1.027%, 0.202%, and 4.991% for the main panel, MENA, and BRICS countries, while it reduces about 2.865% in G6. Urbanization upsurges CO_2 emissions in the main panel while it reduces emissions in G6 and BRICS. This implies that a 1% increase in urbanization rises emission levels in the main panel but at the same time reduces CO_2 emissions in G6 and BRICS countries.

Dynamic ordinary least square regression

The results in Table 6 show that economic growth reduces CO_2 emissions in MENA and G6. The signs of the coefficients are consistent with the fully modified ordinary least square regression (FMOLS) outcome. Similarly, innovation depresses CO_2 emissions at G6 panel which is consistent with the results in Table 5. However, innovation is positive at the main panel level, MENA, and BRICS but statistically significant for the MENA countries only. Also, FDI escalates the level of CO_2 emissions in all panel levels except MENA which is positive but statistically insignificant. Again, the results for energy consumption are positive and statistically significant at all panel levels. This is also consistent with the results in Table 5. Furthermore, trade openness is positive for the main panel, MENA, and BRICS but statistically significant only for BRICS economies; however, it decreases CO_2 emissions in G6 countries. Furthermore, urbanization increases emissions at the main panel, G6, and MENA while is declining emissions for the BRICS.

Table 6 Dynamic ordinary least square regression (DOLS)

Dependent variable = CO_2 emission

Variable	Main panel	G6	MENA	BRICS
lngdp	2.334	− 91.63***	− 3.677*	− 8.045
	(3.144)	(63.650)	(1.919)	(11.350)
lngdp2	− 0.041	1.639	0.0856**	0.126
	(0.059)	(1.127)	(0.037)	(0.202)
lninov	0.233	− 0.130**	0.0754**	0.184
	(0.153)	(0.642)	(0.037)	(0.400)
lnec	0.247**	0.871***	0.0561*	0.413***
	(0.115)	(0.298)	(0.033)	(0.151)
lnfdi	0.182***	0.355*	0.023	0.335**
	(0.067)	(0.200)	(0.017)	(0.147)
lnto	0.591	− 1.583*	0.000	1.237***
	(0.39)	(0.935)	(0.115)	(0.363)
lnurb	0.375*	− 2.163	− 0.104*	1.106***
	(0.228)	(2.261)	(0.062)	(0.294)
Constant	− 39.400	131.000	48.41*	102.900
	(42.950)	(90.300)	(24.720)	(58.100)
Observation	483	159	186	132
R^2	0.659	0.509	0.862	0.969

Note. Standard errors are in parentheses. ***, **, * denote significance level of 1%, 5%, and 10%, respectively

Discussions

Our results revealed that economic growth increases CO_2 emissions and deteriorates the environment in the main panel and BRICS countries. The BRICS economies are known as a major manufacturing hub of commodities for export to the rest of the world, and these productions are engineered mostly by fossil fuel energy, a major contributor to CO_2 emissions. For instance, China and India are among the major emitters of global CO_2 emissions due to reasons mentioned. In contrast, economic growth reduces emissions and improves environmental quality in G6 and MENA economies. Similar results were found by Acheampong (2018) for MENA countries. In the MENA countries, growth reduces emission possibly because much production activities does not take place within the countries and multinational companies do not undertake major manufacturing activities in there; hence, no major or high polluting manufacturing plants are found in these countries. For this reason, these economies do not largely depend on production activities for growth as compared to the BRICS. The G6 countries that are well advanced in technology rely on renewable energy for industrial and domestic activities and environmental protection laws are strictly enforced as compared to the other blocs. The findings here is therefore an indication that energy policies and environmental protection regulations are yielding positive outcomes.

Also, the environmental Kuznets curve is validated at the main and BRICS panel levels. The implication is that some of these countries are still developing and mostly rely on fossil fuels for all their activities. Now the focus is on how to develop their economies rather than protecting their environment, hence the consequences of growth on their environmental quality. The outcome contradicts the findings of Abdouli and Hammami (2017) for the MENA countries and Shahbaz et al. (2018) for G7 but validates the findings of Dong et al. (2017) for BRICS. However, our study finds no evidence of EKC in MENA and G6 countries.

Furthermore, innovation induces CO_2 emissions in the main, MENA, and BRICS countries, and the possible reasons are most of the countries in these two blocs are developing and transition economies where the overhead cost of technology innovation make it difficult to incorporate into the manufacturing processes at early stage of development for clean production. Raiser et al. (2017) most inventors strictly protect their technological ideas spreading to third parties. Based on this contraction of global access to available technologies could be the reason for our findings. It is also believed that transitioning to technology innovation is a long-term process. Albino et al. (2014) noted that some of the global advanced countries in innovations do not always reduce emission as they progress in development.

Innovation reduces emissions in G6 countries and thus promote quality environment. The G6 countries are the world-developed and advance technological economies. Therefore, they have transitioned over the years to innovative clean production technologies to reduce environmental degradations. Although the study does not specifically use green innovation, cleaner production and clean energy consumption could lead to emission reduction. Assessment of innovation in these three economies indicate that G6 countries should help promote innovation in BRICS and MENA as developing economies (Liobikienė and Butkus 2018) due to different stages of development in these countries.

Energy consumption has been identified by numerous studies as the major cause of CO_2 emissions. This supports the fact that fossil fuel energy dominates primary energy consumption in most economies even the developed countries such as the G6. It is therefore not strange that energy consumption promotes CO_2 emissions in all panels because we considered the aggregate energy consumption which includes both renewable and non-renewable energy consumption.

Foreign direct investment and trade openness provide tremendous contribution to economic growth and development both developed and developing countries. However, these low-cost capital contribution flows into countries provide benefits and challenges. When the host economies benefit from knowledge spillovers from FDI and trade openness to promote clean production techniques and enhance environmental quality it is known as halo effect. Our findings is an evidence of halo effect and corroborates (Shahbaz et al. 2018) for G7. Nonetheless, when trade and FDI are carried out by pollution intensive industries the host experiences increase in CO_2 emissions. This phenomenon is an evidence of pollution haven hypothesis (PHH). Our findings confirmed both halo effect (Rafindadi et al. 2018; Zhu et al. 2016) and PHH at different panel levels (Sun et al. 2017).

Urbanization can contribute to economic development but stands as a threat to the environment due to the high energy consumption associated with urbanization which consequently upsurges emissions (Wang et al. 2014). Our results established that urbanization increases emissions at the main panel, MENA panels. As noted, the challenge with urbanization is that it increases energy demand and energy consumption; therefore, depending on the lifestyle of urban dwellers the impact of urbanization on the environment is determined. The result is similar to Salahuddin et al. (2018) for sub-Saharan Africa. Interestingly, our study finds that in G6 and BRICS economies, urbanization reduces emissions, consistent with Zhu et al. (2018) for BRICS.

Conclusion and policy implications

The study explores the effects of innovation and economic growth on CO_2 emissions for 18 developed and developing countries over the period of 1990 to 2016. The study used panel technique: panel unit root to determine the order of integration, Westerlund cointegration to assess cointegration relationship between the variables, and panel FMOLS and panel dynamic ordinary least square regression (DOLS) to estimate the long-run relationship. In the environmental economics literature, there are many research on innovation and its impact on emission. However, literature on regional differences is very scanty as there is no study that considered all the blocks in a single analysis. Therefore, this study adopts a holistic approach by incorporating all the blocks so as to assess how innovation contributes to emission reduction at various blocks. Also, the study compares the effects of innovation on CO_2 emissions in three regions. This is necessary because it will afford countries or blocs that are performing poorly in terms of reducing CO_2 emissions to learn best practices that are carried out in other blocs. Although, not directly comparing but the study highlighted on the regions that are doing well in terms of mitigating emissions through the use of innovation.

The findings of the study show that energy consumption increases CO_2 emissions at all panel levels. Moreover, economic growth reduces emissions in G6 and MENA countries while it increases emissions in the BRICS. FDI escalates CO_2 emissions in the main and G6 panels; however, it improves environment in BRICS. Trade openness harms the environment in all panel levels except G6 where the quality of the environment is improved with trade openness. In addition, innovation escalates CO_2 emissions in the main panel level, MENA, and BRICS countries while it improves environmental quality in G6 economies. EKC hypothesis is valid for the BRICS. The PHH and pollution halo effect were confirmed at different panel levels.

Based on the findings, the following policy implication is recommended.

First, economic growth increases CO_2 emissions and aggravates the environmental pollution due to energy consumption. Therefore, governments should take into consideration renewable energy-related sources such as solar energy, wind energy, and hydroelectric power that are environmentally friendly as they transition to green economy. Also, the economic structure of both developed and developing countries must be improved to benefit from efficient and low-carbon energy sources that protect the environment.

Second, policy makers should integrate technological innovation into CO_2 emission mitigation which can allow waste recycling in the process of production to reduce pollution. More resources should be allocated for research and development into energy efficiency and sustainable production that are technology intensive. This can be done by encouraging public and private investment into indigenous innovation for both energy efficiency and clean production process. Also, research cooperation between developed and developing countries will foster collaboration for the fight against CO_2 emission because some of the developed countries have progress in environmental pollution reduction.

Third, countries should make an effort to assess the effects of the environmental consequences of FDI before allowing it into their economy. This is necessary to allow for integration and absorption of advanced technology from FDI that has the potential of depressing CO_2 emission. Also, governments should offer tax incentives to national and foreign firms to encourage research and development into renewable and energy efficiency technologies toward low-carbon productions. To rectify problems associated with trade openness, used products especially electronic gadget importation should be discouraged through imposition of high tariffs.

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