



# Effects of energy consumption, economic growth, and financial development on carbon emissions: evidence from heterogeneous income groups

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Received: 27 December 2018 / Accepted: 26 April 2019 / Published online: 5 June 2019  
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## Abstract

This paper examines the effects of energy consumption, economic growth, and financial development on carbon emissions in a panel of 122 countries. We employ both first-generation and second-generation cointegration and estimation procedures in order to address diverse economic and econometric issues such as heterogeneity, endogeneity, and cross-sectional dependence. We find a cointegration relationship between the variables. Energy consumption, economic growth, and financial development have detrimental effects on carbon emissions in the full sample. When the sample is split into different income groups, we reveal that economic growth and financial development mitigate carbon emissions in high-income group but have the opposite effects in low-income and middle-income groups. The implication of the findings is that energy consumption increases carbon emissions. While high levels of income and financial development decrease carbon emissions, low levels of income and financial development intensify it. Based on the findings, the paper makes some policy recommendations.

**Keywords** Carbon emissions · Energy consumption · Financial development · Economic growth

**JEL classification** Q40 · G20 · O44

## Introduction

An insight into the relationship among carbon dioxide (CO<sub>2</sub>) emissions, energy consumption, economic growth, and financial development is fundamental for policy making in developed and developing countries. This is because policies that increase economic growth could raise energy consumption, and ultimately aggravate CO<sub>2</sub> emissions. Similarly, the promotion of financial development has the capacity to spur economic growth, which in turn increases energy consumption and CO<sub>2</sub> emissions. Therefore, the global increase in CO<sub>2</sub> emissions has remained a grave concern to policy-makers

especially due to the problems of climate change. For instance, global CO<sub>2</sub> emissions increased from 4.19 metric tons per capita in 1990 to 4.97 metric tons per capita in 2014. This could be due to the increase in global energy consumption from 1660.93 kg of oil equivalent per capita in 1990 to 1919.38 kg of oil equivalent per capita in 2014. During this period, global real GDP per capita and financial development have also increased from USD7164.75 and 99.60% in 1990 to USD10,121.93 and 122.95% in 2014, respectively.<sup>1</sup>

However, there is a wide variation in the level and growth rates of these variables among different income groups during the period. In 1990 for instance, CO<sub>2</sub> emissions were 0.27, 0.99, 3.46, and 11.46 metric tons per capita in low-income, lower-middle-income, upper-middle-income, and high-income countries, respectively, compared to 0.25, 1.47, 6.59, and 10.98 metric tons per capita in 2014. This indicates that CO<sub>2</sub> emissions experienced slight decline in low-income and high-income groups (but its level remains very high in the latter), while the middle-income groups recorded significant

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Responsible editor: Philippe Garrigues

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<sup>1</sup> All data are obtained from World Development Indicators (2018) of the World Bank.

increase during the period. Furthermore, the corresponding energy consumption in 1990 were 371.51, 554.76, 1373.07, and 4595.39 kg of oil equivalent per capita compared to 395.86, 647.12, 2192.10, and 4756.23 kg of oil equivalent per capita in 2014 in low-income, lower-middle-income, upper-middle-income, and high-income groups.<sup>2</sup> It is obvious though that all the income groups experienced increase in energy consumption during the period, but the middle-income groups have the highest growth rate while the high-income group has the lowest growth rate.

Moreover, the levels of real GDP per capita in 1990 were USD460.47, USD964.84, USD3197.79, and USD29,426.42 compared to USD579.06, USD1965.71, USD7575.90, and USD41,016.44 in 2014 in low-income, lower-middle-income, upper-middle-income, and high-income groups, respectively. The corresponding financial development in 1990 were 14.11%, 26.47%, 44.85%, and 108.98% compared to 17.84%, 41.33%, 98.29%, and 143.50% in 2014 in low-income, lower-middle-income, upper-middle-income, and high-income groups.<sup>3</sup> Again, the middle-income groups experienced the highest growth rates in both real GDP per capita and financial development while the low-income group had the lowest. The wide variations in the levels and growth rates of CO<sub>2</sub> emissions, energy consumption, real GDP per capita, and financial development among the different income groups could produce different relationships between the variables across the income groups.

Although the nexus between CO<sub>2</sub> emissions and energy consumption has attracted the attention of scholars in the past three decades, there is no general consensus among the researchers. A strand of literature posited that energy consumption has detrimental effect on CO<sub>2</sub> emissions (e.g., Alkhatlan and Javid 2013; Arouri et al. 2012; Mirza and Kanwal 2017; Omri 2013). They documented a positive impact of energy consumption on CO<sub>2</sub> emissions, suggesting that CO<sub>2</sub> emissions increase with a rise in energy consumption. Besides, a higher level of economic development can be achieved with higher level of energy consumption which in turn exacerbates CO<sub>2</sub> emissions. Nonetheless, a greater level of energy consumption may not aggravate CO<sub>2</sub> emissions if the fraction of clean and renewable energy in the energy mixture is large (see Hossain 2011).

Another strand of literature contended that CO<sub>2</sub> emissions and economic growth have association. They posited that CO<sub>2</sub> emissions rise as the country experiences economic growth at early stages of economic development but decline after a certain threshold level of economic growth is attained (see

Apergis and Payne 2010; Arouri et al. 2012; Chen et al. 2016; Lean and Smyth 2010). However, Narayan and Narayan (2010) showed that CO<sub>2</sub> emissions decline with a rise in economic growth in 15 countries, but the impact is heterogeneous in 28 countries. Similarly, Ozcan (2013) also found little support that CO<sub>2</sub> emissions decline with a rise in real GDP per capita, but Zhang and Cheng (2009) provided empirical evidence to show that an increase in economic growth<sup>4</sup> has the capacity to increase energy consumption and ultimately aggravates CO<sub>2</sub> emissions.

Theoretical literature posited that financial development could intensify or mitigate CO<sub>2</sub> emissions. The environmental effect of financial development stems from the fact that expansion in financial services, products, intermediaries, and institutions could engender higher energy demand, thereby increasing energy consumption which ultimately aggravates CO<sub>2</sub> emissions. Katircioglu and Taşpinar (2017) noted that as the financial sector develops, it will start to rely on energy which could intensify CO<sub>2</sub> emissions. Farhani and Solarin (2017) also noted that financial development stimulates energy use in the short run albeit it could reduce it in the long run. Besides, financial development causes higher economic activity (via credit expansion and investments) which in turn increases energy consumption (Shahbaz and Lean 2013). An efficient financial system may offer a conducive atmosphere for consumers to acquire greater loans that allow them to increase their demands for items that produce CO<sub>2</sub> emissions (e.g., automobiles, refrigerators, air conditioners, washing machines, etc.), thereby aggravating CO<sub>2</sub> emissions (Jalil and Feridun 2011). Moreover, Salahuddin et al. (2015) noted that an economy that has a well-developed financial system tends to attract greater investment, and thus enhances greater industrialization which engenders higher energy consumption, and ultimately leads to greater CO<sub>2</sub> emissions.

Conversely, financial development could mitigate CO<sub>2</sub> emissions if it encourages investment in environmental projects, and empowers firms to adopt and use advanced, energy-saving, and cleaner technologies or renewable energy projects which are environmentally friendly. It could boost the funding of environmental projects at reduced costs and increases foreign direct investment which in turn stimulates technological improvement and accentuates greater level of research and development that engender high environmental quality (see Tamazian et al. 2009). A well-developed and functioning financial system provides the mechanism for carbon trading which offers incentives for the mitigation of CO<sub>2</sub> emissions (Claessens and Feijen 2007). A more developed and sound financial system also helps economies to enforce

<sup>2</sup> All the data are obtained from World Development Indicators (2018) of the World Bank.

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<sup>4</sup> Economic growth and real GDP per capita are used interchangeably in this study.

**Table 1** Descriptive statistics

Variables		All income	High income	Upper middle income	Lower middle income	Low income
CO2	Mean	5.579	11.079	4.258	1.329	0.249
	Maximum	70.136	70.136	15.940	12.098	1.601
	Minimum	0.017	1.270	0.029	0.092	0.017
	Std. dev	7.176	8.892	2.976	1.551	0.279
ENC	Mean	2383.278	4750.384	1574.412	681.788	368.792
	Maximum	21,959.44	21,959.44	5928.661	4856.586	952.613
	Minimum	113.423	723.846	363.416	115.477	113.423
	Std. dev	2782.452	3280.326	981.025	583.040	158.134
GDP	Mean	14,408.06	33,061.32	5970.380	2221.186	607.252
	Maximum	111,968.3	111,968.3	14,652.18	14,778.91	1837.138
	Minimum	161.834	5132.953	698.564	193.245	161.834
	Std. dev	18,808.53	19,776.22	2782.228	2151.028	309.382
FDE	Mean	50.999	83.858	39.983	29.498	17.299
	Maximum	312.118	312.118	166.504	114.723	103.632
	Minimum	0.186	0.186	1.2669	1.385	0.198
	Std. dev	45.173	49.253	35.375	22.175	12.637

CO<sub>2</sub> carbon dioxide emissions, ENC energy consumption, GDP real GDP per capita, FDE financial development

environment-friendly regulations as well as influences firms and households’ economic activities thereby lessening CO<sub>2</sub> emissions (Omri et al. 2015; Yuxiang and Chen 2010).

Empirically, Farhani and Ozturk (2015) showed that financial development has a harmful effect on CO<sub>2</sub> emissions, implying that financial development takes place at the expense of environmental degradation in Tunisia. Although this viewpoint is consistent with some empirical studies (e.g., Al-mulali and Sab 2012b; Boutabba 2014; Yuxiang and Chen 2010), Ozturk and Acaravci (2013) reported that financial development has no significant long-run effect on CO<sub>2</sub> emissions in Turkey. Conversely, Salahuddin et al. (2015) documented that financial development reduces CO<sub>2</sub> emissions in GCC countries, and similar findings have been reported by Jalil and Feridun (2011) in China, Shahbaz et al. (2013c) for Malaysia, Al-Mulali et al. (2016a) for Kenya, and Tamazian et al. (2009) in BRIC countries. Moreover, Al-mulali et al. (2016b) showed that financial development has a mitigating effect on CO<sub>2</sub> emissions in Western Europe, but it aggravates CO<sub>2</sub> emissions in Central and Eastern Europe, East Asia and the Pacific, South Asia, and sub-Saharan Africa. However, the effect is insignificant in America and Middle East and North Africa.

Thus, the differences in the empirical outcomes in some previous studies on the impact of energy consumption, economic growth, and financial development on CO<sub>2</sub> emissions could be attributed to failure to account for differences in the level of income among the countries. It could also be due to differences in the methodologies employed as well as the inability to account for some economic and econometric issues

such as heterogeneity, endogeneity, and cross-sectional dependence.

The specific objective of this study is to examine the impact of energy consumption, economic growth, and financial development on CO<sub>2</sub> emissions in a panel of 122 countries. First, the study examines the impact of these variables on CO<sub>2</sub> emissions in the full panel of 122 countries regardless of their income group. Second, the study categorizes the countries into four income groups based on World Bank (2017) classification of countries according to their income levels, namely, low income (\$1005 and below), lower middle income (\$1006–\$3955), upper middle income (\$3956–\$12,235), and high income (\$12,236 and above). The classification enables us to determine whether the empirical outcomes differ among the various income groups.

This study differs from previous studies because it represents the first attempt to examine the impact of economic growth, energy consumption, and financial development on carbon emissions from a global perspective comprising a global panel of 122 countries. This is important because CO<sub>2</sub> emission is a global pollutant whose impact is uncertain, spatially and temporarily diverse. The growing CO<sub>2</sub> emissions and its concentration engender global warming which is deleterious to the global economy. This issue is accorded greater attention due to the potential dangers of such emissions on climate change and global warming which can disrupt the functioning of the ecosystems that may undermine the requisite conditions for human welfare. Hence, it may be necessary to analyze the causes of carbon emissions from a global perspective rather than individual-specific country or a small group of countries.

**Table 2** Correlation analysis

Variables	CO <sub>2</sub>	ENC	GDP	FDE
All income				
ENC	0.906***			
GDP	0.657***	0.735***		
FDE	0.299***	0.371***	0.602***	
High income				
ENC	0.839***			
GDP	0.387***	0.479***		
FDE	−0.152***	−0.050	0.382***	
Upper middle income				
ENC	0.939***			
GDP	0.370***	0.440***		
FDE	0.133***	0.081**	−0.019	
Lower middle income				
ENC	0.921***			
GDP	0.609***	0.574***		
FDE	0.457***	0.280***	0.454***	
Low income				
ENC	0.675***			
GDP	0.664***	0.313***		
FDE	0.452***	0.366***	0.198***	

CO<sub>2</sub> carbon dioxide emissions, ENC energy consumption, GDP real GDP per capita, FDE financial development

\*\*\*, \*\*, and \* indicate statistically significant at 1%, 5%, and 10%, respectively

Second, many previous studies (e.g., Alkhatlan and Javid 2013; Ezzo and Keho 2016; Mirza and Kanwal 2017) have examined the relationship between CO<sub>2</sub> emissions, energy consumption, and economic growth without incorporating financial development in a single framework. Even those studies that have attempted it focused on time series data of individual-specific countries, namely, Jalil and Feridun (2011) for China, Katircioglu and Taşpinar (2017) for Turkey, Shahbaz et al. (2013c) for Malaysia, Shahbaz et al. (2013a) for Indonesia. Some studies have also used panel data of a group of countries such as Hafeez et al. (2018) for Belt and Road Initiative countries; Salahuddin et al. (2015) for Gulf Cooperation Council countries; Al-mulali and Sab (2012a) for sub-Saharan African countries; and Al-mulali and Sab (2012a) for 19 selected countries. However, none of these panel data studies has considered differences in the income level of the countries. We fill this gap by categorizing the global panel into four panels, with each panel having countries of similar income level. This approach enables us to juxtapose the results of the global panel with those of the different income groups. This is important because some studies have argued that the pooling of countries with different income levels into the same panel could lead to

inappropriate estimation of the determinants of CO<sub>2</sub> emissions (Sirag et al. 2018).

Besides, the incorporation of financial development into the model provides useful insights and findings for policy-makers on how financial development is related to CO<sub>2</sub> emissions in different income groups. Therefore, these countries will be provided with policy options that suit their levels of income. Finally, unlike previous studies, this study controls for diverse economic and econometric issues (e.g., heterogeneity, endogeneity, cross-sectional dependence, etc.) using diverse empirical strategies, thereby producing reliable and robust results for policy formulations.

In doing the analysis, this study employs both the first- and second-generation panel unit root tests, cointegration tests, and estimation techniques in order to address diverse economic and econometric issues such as integration, cointegration, heterogeneity, endogeneity, and cross-sectional dependence. Besides the conventional cointegration and estimation procedures, we also employ the panel cointegration tests developed by Westerlund (2007), the common correlated effect (CCE) estimation procedure developed by Pesaran (2006), and the dynamic CCE estimator proposed by Chidik and Pesaran (2015). These diverse procedures enable us to examine the effects of the three variables on CO<sub>2</sub> emissions within static and dynamic specifications with a view to obtaining robust outcomes.

Interestingly, the paper finds that energy consumption, economic growth, and financial development have positive impact on CO<sub>2</sub> emissions in the full sample of countries regardless of income groups. But when the countries were split into various income groups, it shows that high levels of income and financial development reduce CO<sub>2</sub> emissions while low levels of income and financial development intensify it. This paper shows that energy consumption has taken place at the expense of CO<sub>2</sub> emissions in all the income groups. Hence, the adoption of energy consumption policies that do not exacerbate CO<sub>2</sub> emissions should be a fundamental agenda in the development policies of countries. Moreover, low-income countries should develop their financial system with a view to reducing CO<sub>2</sub> emissions.

Apart from this introduction, the paper is divided into three sections. “Methodology and data” section presents the methodology and data. “Empirical results” section contains the empirical results, while “Discussion and policy implications” section concludes the study with some policy recommendations.

## Methodology and data

### Empirical techniques

This study employs the following baseline model to determine the impact of energy consumption, economic growth, and



financial development on CO<sub>2</sub> emissions in panel data analysis<sup>5</sup> (see Bekhet et al. 2017; Salahuddin et al. 2015):

$$CO2_{i,t} = \alpha_0 + \alpha_1 ENC_{i,t} + \alpha_2 GDP_{i,t} + \alpha_3 FDE_{i,t} + \varepsilon_{i,t} \quad (1)$$

where CO<sub>2</sub> = carbon dioxide emissions (in metric ton per capita); ENC = energy consumption (in kg of oil equivalent per capita); GDP = real GDP per capita (at constant price 2010 = US\$100); FDE = financial development (proxy by domestic credit to private sector as a ratio of GDP),<sup>6</sup> and  $\varepsilon$  = error term. All the variables are transformed into natural logarithm before analysis.

The estimation techniques used in this study are as follows: first, the study examines the order of integration of the variables in the model using panel unit root tests developed by Breitung (2000), Levin et al. (2002), and Im et al. (2003). The use of these multiple tests enables us to account for individuals and common unit root processes as well as small sample size. However, these traditional panel unit root tests (Breitung, LLC and IPS) assume cross-sectional independence. To account for cross-sectional dependence, we employ Pesaran (2007) panel unit root test.

Second, the study determines the cointegration relationship of the variables using the cointegration tests developed by Pedroni (1999), Kao (1999), and Westerlund (2007). The Kao test imposes homogeneous cointegrating vectors and coefficients, while the Pedroni cointegration test enables us to account for country size and heterogeneity which permit multiple regressors of the cointegration vector to vary across various panel sections. We employ the four error-correction-based panel cointegration tests developed by Westerlund (2007) which accommodates unit-specific short-run dynamics, unit-specific trend, slope parameters, and cross-sectional dependence. It seeks to test the null hypothesis of no cointegration by determining

whether the error-correction term in a conditional panel error correction model is equal to zero. Two of the tests (i.e., panel tests) are made to test the alternative hypothesis that the whole panel is cointegrated, whereas the other two tests (i.e., group tests) are designed to test the alternative hypothesis that at least one unit is cointegrated (see Persyn and Westerlund 2008).<sup>7</sup>

Third, the study estimates the impact of energy consumption, economic growth, and financial development on CO<sub>2</sub> emissions using estimators that are appropriate for cointegrated panels, namely, dynamic ordinary least squares (DOLS) proposed by Stock and Watson (1993) and fully modified ordinary least squares (FMOLS) developed by Pedroni (2000). The DOLS is applied because the conventional OLS is inappropriate for cointegrated panels because it will produce spurious results. Hence, DOLS is considered to provide better results for panels that have cointegration relationships, albeit it does not account for cross sectional heterogeneity. The Stock–Watson DOLS model employed in this study is specified as follows:

$$CO2_{i,t} = \alpha_0 + \alpha_1 ENC_{i,t} + \alpha_2 GDP_{i,t} + \alpha_3 FDE_{i,t} + \sum_{i=-l}^{i=l} \beta_i \Delta ENC_{i,t} + \sum_{i=-m}^{i=m} \varphi_i \Delta GDP_{i,t} + \sum_{i=-n}^{i=n} \psi_i \Delta FDE_{i,t} + \varepsilon_{i,t} \quad (2)$$

where  $\alpha$  = cointegrating vectors (long-run cumulative multipliers) and  $l, m, n$  = the lengths of the lags and leads of the regressors.

The study also uses FMOLS to estimate the long-run parameters because it accounts for cross-sectional heterogeneity (heterogeneous long-run coefficients), serial correlation, and endogeneity problems. FMOLS estimator also provides consistent estimates even in small sample (see Pedroni 2000; Salahuddin et al. 2015). The panel FMOLS estimator employed to estimate the coefficients of the variables is given as follows:

$$\hat{a}_{NT^*} - a = \left( \sum_{i=1}^N \sum_{t=1}^{T-2} L_{22i}^{-2} \sum_{t=1}^T (x_{it} - \bar{x})^2 \right)^{-1} \sum_{i=1}^N \hat{L}_{11i}^{-1} \sum_{t=1}^{T-2} L_{22i}^{-2} \left( \sum_{t=1}^T (x_{it} - \bar{x}) \varepsilon_{it}^* - T \hat{\gamma}_i \right) \quad (3)$$

<sup>5</sup> Baltagi (2008) highlighted the motivation of using panel data as follows: first, panel data are better able to identify and measure effects that are simply not detectable in pure time series data. Second, panel data give more informative data, more variability, less collinearity among the variables, more degrees of freedom and more efficiency. With additional more informative data, one can produce more reliable parameter estimates. Third, panel data control for individual heterogeneity. Panel data can control for country- and time-invariant variables while time series study cannot. Fourth, panel data are better able to study the dynamics of adjustment, thereby shedding light on the speed of adjustments to economic policy changes. Finally, panel data models allow us to construct and test more complicated behavioral models compared to purely time series models.

<sup>6</sup> We proxy financial development with credit to private sector relative to GDP which is the most commonly used proxy that measure the credit that goes to the private sector (see Al-Mulali et al. 2016b; Jalil and Feridun 2011; Shahbaz et al., 2013a, b, c; Hafeez et al. 2018; Salahuddin et al. 2015). Although we attempted to use another proxy of financial development (e.g., liquid liabilities relative to GDP) that measures financial depth, or stock market development indicators (e.g., market capitalization relative to GDP), but we could not get complete data for the 122 countries for the 1990–2014 period. When data become readily available, we suggest that future research should consider this possibility for comparison.

<sup>7</sup> Our panel data of 122 countries covering 1990–2014 period are appropriate (not too small) for Westerlund’s (2007) error correction model-based panel cointegration test because this cointegration test produces reliable results even in small sample size. Westerlund (2007, p. 709) said “Our simulation results suggest that the tests have good small-sample properties with small size distortions and high-power relative to other popular residual-based panel cointegration tests.” In his empirical application, Westerlund (2007, p.733–736) presented empirical evidence to show that international healthcare expenditures and GDP are cointegrated in a small sample size using annual panel data of 20 OECD countries for 1970–2001 period. Moreover, some studies have also used the Westerlund’s (2007) error correction model-based panel cointegration test for similar sample size (e.g., Persyn and Westerlund 2008).

**Table 3** Panel unit root tests

Variables	LLC	IPS	Breitung	Pesaran
<b>All income</b>				
CO <sub>2</sub>	-1.293	2.669	5.879	0.917
ENC	-2.692***	1.033	7.240	-0.629
GDP	-2.604***	7.814	2.272	-1.053
FDE	-5.110***	-1.113	0.725	0.945
ΔCO <sub>2</sub>	-19.87***	-26.26***	-11.57***	-5.181***
ΔENC	-17.81***	-22.50***	-10.66***	-5.688***
ΔGDP	-19.28***	-19.09***	-11.40***	-3.648***
ΔFDE	-21.86***	-22.26***	-14.59***	-6.651***
<b>High income</b>				
CO <sub>2</sub>	0.838	2.589	6.685	1.071
ENC	-4.482***	-2.153	7.223	-0.825
GDP	-6.708***	0.879	0.543	0.584
FDE	-3.217***	-0.153	1.883	0.601
ΔCO <sub>2</sub>	-10.98***	-14.93***	-6.695***	-4.751***
ΔENC	-10.16***	-13.23***	-6.337***	-5.599***
ΔGDP	-10.09***	-10.94***	-7.169***	-1.458**
ΔFDE	-15.40***	-13.13***	-7.743***	-2.354***
<b>Upper middle income</b>				
CO <sub>2</sub>	-1.107	0.257	0.297	-1.884**
ENC	-0.559	1.455	0.782	-1.962**
GDP	-0.525	5.248	0.529	-0.897
FDE	-4.104***	-2.574	-1.929	-0.340
ΔCO <sub>2</sub>	-11.34***	-15.59***	-7.218***	-5.527***
ΔENC	-8.775***	-12.68***	-6.563***	-5.434***
ΔGDP	-9.251***	-10.85***	-5.973***	-3.111***
ΔFDE	-12.51***	-12.84***	-7.741***	-4.718***
<b>Lower middle income</b>				
CO <sub>2</sub>	-2.185**	-0.099	1.542	-0.080
ENC	-0.731	2.165	3.599	1.042
GDP	0.465	6.765	1.839	-1.691**
FDE	-1.995	0.224	0.434	-1.799**
ΔCO <sub>2</sub>	-11.17***	-14.05***	-6.433***	-3.575***
ΔENC	-8.226***	-10.1***	-4.690***	-2.293**
ΔGDP	-12.04***	-8.99***	-5.356***	-3.012***
ΔFDE	-7.27***	-10.5***	-7.451***	-5.749***
<b>Low income</b>				
CO <sub>2</sub>	1.579	3.112	2.277	2.408
ENC	0.974	1.493	1.821	2.494
GDP	2.729	3.455	2.687	3.259
FDE	0.059	0.560	0.103	-1.570
ΔCO <sub>2</sub>	-4.913***	-6.154***	-1.983**	-2.479***
ΔENC	-9.159***	-8.596***	-3.287***	-3.665***
ΔGDP	-6.451***	-6.988***	-4.007***	-1.870**
ΔFDE	-7.335***	-7.091***	-8.341***	-4.104***

Δ first differenced notation, *LLC* Levin et al. (2002) test, *IPS* Im et al. (2003) test, *Breitung* Breitung (2000) test, *Pesaran* Pesaran (2007) test, *CO<sub>2</sub>* carbon dioxide emissions, *ENC* energy consumption, *GDP* real GDP per capita, *FDE* financial development

\*\*\*, \*\*, and \* indicate statistically significant at 1%, 5%, and 10%, respectively

where  $\varepsilon_{it}^* = \varepsilon_{it} - \frac{\hat{L}_{22i}}{L_{22i}} \Delta x_{it}$ ;  $\hat{\gamma}_i = \hat{\Gamma}_{21i} + \hat{\Omega}_{22i}^o - \frac{\hat{L}_{22i}}{L_{22i}} (\hat{\Gamma}_{22i} + \hat{\Omega}_{22i}^o)$   
 $x$  = the independent variables (such as energy consumption, real GDP per capita and financial development) and  $\bar{x}$  = the individual specific means. And the t-statistic is computed using the following:

$$t_{\hat{\alpha}_{NT}^*} = \left( \hat{\alpha}_{NT}^* - \alpha \right) \left( \sum_{i=1}^N \hat{L}_{22i}^{-2} T \sum_{t=1}^T (x_{it} - \bar{x})^2 \right)^{1/2} \rightarrow N(0, 1) \tag{4}$$

To complement the static (model) specifications, we employ the dynamic panel generalized method of moments (GMM) estimator developed by Arellano and Bond (1991) to estimate the impact of energy consumption, economic growth, and financial development on CO<sub>2</sub> emissions in a dynamic framework. We use this estimation procedure since it can control for country-specific effect, endogeneity,<sup>8</sup> and autocorrelation because the addition of the lagged dependent variable in the model causes autocorrelation concerns. The GMM estimation procedure uses the difference equation as instruments in estimating the parameters. We verify the consistency of the GMM estimator with the Sargan test of overidentifying restriction (used to test the joint validity of the instruments) and the Arellano and Bond test for autocorrelation (used to test for the presence of first-order and second-order serial correlation). The dynamic model is given as follows:

$$CO_{2,i,t} - CO_{2,i,t-1} = (1-\lambda)CO_{2,i,t-1} + \alpha_1 ENC_{i,t} + \alpha_2 GDP_{i,t} + \alpha_3 FDE_{i,t} + \eta_i + \varepsilon_{i,t} \tag{5}$$

Furthermore, Pesaran (2006) posited that parameter estimates could be considerably bias, and their sizes distorted if cross-sectional dependence is overlooked. Consequently, we employ the common correlated coefficient (CCE) estimation procedure proposed by Pesaran (2006) and the dynamic common correlated coefficient (DCCE) estimator developed by Chidik and Pesaran (2015) which are capable of addressing cross-sectional dependence in the estimation. The CCE estimator can consistently estimate the parameters of a model with unobserved common factor and a heterogeneous factor loading. The heterogeneous coefficients are randomly distributed around a common mean with unobserved common factor and a heterogeneous factor loading. The CCE estimation procedure can also account for unobserved dependencies between countries in the panel. This is necessary since most economic models require heterogeneous coefficients, while most panel data are cross-sectionally dependent. According to Pesaran (2006), the model can be consistently estimated by approximating the unobserved common factor with cross-sectional means of the dependent and independent variables under strict exogeneity. The CCE estimated equation is given as follows:

$$y_{i,t} = \beta_i + \alpha_i x_{i,t} + \delta_i \bar{y}_{i,t} + \eta_i \bar{x}_{i,t} + \varepsilon_{i,t} \tag{6}$$

where  $y_{i,t}$  represents the dependent variable ( $CO_{2,i,t}$ ) and  $x_{i,t}$  represents the regressors ( $ENC_{i,t}$ ,  $GDP_{i,t}$ ,  $FDE_{i,t}$ ). The coefficients  $\delta_i$  and  $\eta_i$  represent the elasticity estimates of  $y_{i,t}$  with respect to the cross-sectional averages of the dependent variables and the observed regressors, respectively.

<sup>8</sup> This study controls for endogeneity by using the GMM developed by Arellano and Bond (1991) which is renowned for controlling for endogeneity and autocorrelation.

**Table 4** Results of Pedroni cointegration test

	All income	High income	Upper middle income	Lower middle income	Low income
Panel v-statistic	8.120***	0.496	9.811***	2.796***	0.745
Panel rho-statistic	− 7.955***	− 1.434*	− 9.450***	− 3.012***	− 0.174
Panel PP-statistic	− 22.048***	− 5.437***	− 23.607***	− 9.235***	− 1.789**
Panel ADF-statistic	− 10.185***	− 3.733***	− 9.915***	− 6.194***	− 1.031
Group rho-Statistic	− 0.022	1.204	− 1.192	− 1.063	1.230
Group PP-statistic	− 15.102***	− 4.943***	− 12.016***	− 10.769***	− 1.318*
Group ADF-statistic	− 9.681***	− 2.2129***	− 8.784***	− 6.459***	− 1.626**
Kao cointegration test	− 8.251***	− 7.251***	− 5.223***	− 8.347***	− 4.475***

\*\*\*, \*\*, and \* indicate statistically significant at 1%, 5%, and 10%, respectively, and a rejection of the null hypothesis of no cointegration

However, in dynamic specification, the lagged dependent variable is not strictly exogenous, and its inclusion in the model could make the CCE estimator to become inconsistent. Therefore, Chudik and Pesaran (2015) developed the DCCE estimator which is appropriate for dynamic models. They revealed that the estimator gains consistency provided the appropriate lag is selected for the cross-sectional means. The DCCE allows for slope heterogeneous coefficients. It also computes the cross-sectional dependence test (with the null hypothesis that the error terms are weakly cross-sectional dependent). It allows for endogenous regressors, supports both balanced and unbalanced panels, and can be used in small sample time series since it has small sample bias correction. The DCCE is based on autoregressive distributed lagged (ARDL) panel data model with cross-sectionally augmented unit-specific regressions as follows:

$$y_{i,t} = \beta_i + \phi_i y_{i,t-1} + \alpha_{0i} x_{i,t} + \alpha_{1i} x_{i,t-1} + \sum_{l=0}^{P_T} \delta_{i,l} \bar{z}_{i,t-1} + \varepsilon_{i,t} \quad (7)$$

where  $\bar{z}_t = \frac{1}{N} \sum_{i=1}^N z_{it} = (\bar{y}_t, \bar{x}_t, \bar{g}_t)$ . Thus,  $y_{i,t}$  represents the dependent variable ( $CO2_{i,t}$ ), while  $x_{i,t}$  represents the regressors ( $ENC_{i,t}$ ,  $GDP_{i,t}$ ,  $FDE_{i,t}$ ) and  $\bar{g}_t$  represents the covariates. Hence, the dynamic CCE mean group estimation of the coefficients  $\phi$  and  $\alpha_o$  can be obtained by taking the arithmetic averages of the least squares estimates of  $\phi_i$  and  $\alpha_{oi}$ .<sup>9</sup>

Finally, prior to using Westerlund cointegration tests, CEE and DCCE estimation techniques, we conducted cross-sectional dependence tests to ascertain the presence of cross-

sectional dependence using four tests, namely, Lagrange multiplier (LM) test developed by Breusch and Pagan (1980), the scaled  $CD_{LM}$  and general CD tests proposed by Pesaran (2004), and the bias-adjusted LM test proposed by Pesaran et al. (2008). After estimation, we conduct postestimation test using Pesaran (2015) test to ascertain whether the errors are weakly cross-sectional dependent.

**Data**

This study uses panel data of 122 countries for the 1990–2014 period<sup>10</sup> obtained from World Development Indicators (2017) of the World Bank. The countries are grouped into four categories based on World Bank (2017) classification of countries according to their income levels, namely, low income (\$1005 and below), lower middle income (\$1006–\$3955), upper middle income (\$3956–\$12,235), and high income (\$12,236 and above). The study comprises 45 high-income countries, 32 upper-middle-income countries, 32 lower-middle-income countries, and 13 low-income countries. Unavailability of data on energy consumption limited the number of low-income countries included in the study. The countries included in the study are listed in Appendix Table 11.

**Empirical results**

**Descriptive statistics and correlation analysis**

Table 1 presents the descriptive statistics of the variables included in the model. It shows wide variations among the variables in the different income groups. It also reveals that  $CO_2$  emissions and energy consumption are larger in high-income countries compared to low-income countries. It is

<sup>9</sup> Our data characteristics determine the panel estimation techniques we employ in this study. First, since our variables are integrated of order one and cointegrated, we employ the estimation techniques which are appropriate for cointegrated panels such as DOLS and FMOLS. Thereafter, we test for cross-sectional dependence, and the results show the existence of cross-sectional dependence. To account for this, we employ the estimation techniques that can account for cross-sectional dependence, and also appropriate for cointegrated panels such as CCE and DCCE. Moreover, autocorrelation is potentially common to all time series or long span panel data (such as our 25-year data span). Similarly, endogeneity is a potential common concern in many economic variables. Thus, we employ GMM to control for potential autocorrelation and endogeneity in the model.

<sup>10</sup> Our original intention was to include all countries in the world that have data on carbon emissions, economic growth, energy consumption, and financial development for a minimum of three decades. Unfortunately, after intensive search, we only able to find data for 122 countries for 1990–2014 period. Hence, unavailability of data limited the scope of this study.

**Table 5** Results of dynamic ordinary least squares (DOLS) estimation

Variables	All income	High income	Upper middle income	Lower middle income	Low income
ENC	0.767*** (16.299)	0.915*** (17.083)	0.462*** (7.151)	0.881*** (8.964)	1.300*** (8.836)
GDP	0.165*** (4.196)	−0.183*** (−3.939)	0.408*** (6.956)	0.238*** (3.488)	0.826*** (6.542)
FDE	0.053*** (3.052)	−0.032* (−1.501)	−0.056*** (−2.019)	0.119*** (4.227)	0.196*** (4.331)
R-squared	0.995	0.986	0.985	0.989	0.983
Adj. R-squared	0.991	0.974	0.972	0.979	0.968

$CO_2$  carbon dioxide emissions, *ENC* energy consumption, *GDP* real GDP per capita, *FDE* financial development

\*\*\*, \*\*, and \* indicate statistically significant at 1%, 5%, and 10%, respectively; T-statistic in parenthesis

also obvious that the level of financial development is higher in high-income countries relative to low-income countries. Hence, as countries move from low-income to high-income group, there is a rise in  $CO_2$  emissions, energy consumption, and financial development.

The correlation analysis presented in Table 2 reveals that  $CO_2$  emissions and energy consumption, as well as  $CO_2$  emissions and economic growth are positively and significantly correlated. Moreover,  $CO_2$  emissions and financial development as well as energy consumption and financial development have negative correlation in high-income group, but positive relationship in other income groups. Finally, the analysis shows that energy consumption and economic growth as well as financial development and economic growth have positive correlations.

### Panel unit root tests

The results presented in Table 3 show that all the variables are integrated of order one at 1% significant level in the whole panel as well as in different income groups. Hence, it is necessary to determine the cointegration between the variables using different cointegration tests.

### Panel cointegration tests

Table 4 shows the outcomes of Pedroni cointegration tests (individual intercept, no trend). The variables have cointegration relationship in all income groups, albeit that of

low-income group is relatively weak. We also estimate with individual intercept and individual trends (results available upon request), and found similar results. In order to further check the robustness of the cointegration test results, the study employs Kao cointegration test, and the results reported in the lower panel of Table 4 indicate that the variables are cointegrated in all the income groups.

### Long-run estimation using DOLS and FMOLS

The DOLS results presented in Table 5 reveal that energy consumption has a positive and significant impact on  $CO_2$  emissions in all income groups. This implies that an increase in energy consumption would increase  $CO_2$  emissions regardless of the income group. We also find that economic growth has positive impact on  $CO_2$  emissions in low-income and middle-income countries but negative impact in high-income countries. This suggests that an increase in economic growth increases  $CO_2$  emissions in low-income and middle-income countries but reduces  $CO_2$  emissions in high-income countries. In other words, at lower level of income, an increase in income increases  $CO_2$  emissions, but at higher level of income, a rise in income reduces  $CO_2$  emissions. Furthermore, the study shows that financial development has negative impact on  $CO_2$  emissions in high-income and upper-middle-income countries, whereas the impact is positive in low-income and lower-middle-income countries. This implies that high level of financial development reduces  $CO_2$  emissions,

**Table 6** Results of fully modified ordinary least squares (FMOLS) estimation

Variables	All income	High income	Upper middle income	Lower middle income	Low income
ENC	0.716*** (47.504)	0.859*** (44.469)	0.593*** (23.784)	0.612*** (19.235)	1.222*** (14.842)
GDP	0.268*** (21.860)	−0.140*** (−7.849)	0.337*** (16.942)	0.415*** (17.029)	0.909*** (16.081)
FDE	0.039*** (7.012)	−0.029*** (−3.897)	−0.0211*** (−2.138)	0.097*** (8.980)	0.147*** (6.298)
R-squared	0.989	0.970	0.970	0.969	0.958
Adj. R-squared	0.988	0.969	0.968	0.968	0.955

$CO_2$  carbon dioxide emissions, *ENC* energy consumption, *GDP* real GDP per capita, *FDE* financial development

\*\*\*, \*\*, and \* indicate statistically significant at 1%, 5%, and 10%, respectively; T-statistic in parenthesis



**Table 7** Results of dynamic panel GMM estimation

Variables	All income	High income	Upper middle income	Lower middle income	Low income
Lagged dependent variable	0.658*** (207.58)	0.341*** (67.68)	0.246*** (10.00)	0.559*** (14.33)	0.509*** (10.95)
ENC	0.684*** (211.19)	0.699*** (66.94)	0.733*** (13.04)	0.456*** (9.42)	0.593*** (7.19)
GDP	0.011* (1.93)	0.008 (0.55)	0.210*** (13.04)	0.081* (1.95)	0.478*** (4.63)
FDE	0.011*** (4.87)	−0.003*** (−4.20)	−0.032*** (−8.31)	0.038** (2.00)	0.112*** (6.08)
Constant	2.379*** (14.47)	−1.506*** (−10.66)	−3.794*** (−15.43)	−5.121*** (−18.65)	−7.481*** (−9.46)
Sargan Test ( <i>p</i> value)	120.772 (1.000)	42.619 (1.000)	24.496 (1.000)	30.861 (1.000)	240.539 (0.163)
First-order serial correlation test ( <i>p</i> value)	−4.961 (0.000)	−3.244 (0.001)	−3.090 (0.002)	−2.835 (0.004)	−2.482 (0.013)
Second-order serial correlation test ( <i>p</i> value)	−0.805 (0.421)	−1.443 (0.149)	−1.242 (0.214)	−0.339 (0.734)	0.039 (0.969)

The regressions are estimated using two-step dynamic GMM estimator (Arellano and Bond 1991). Significant time dummies are included in all regressions

CO<sub>2</sub> carbon dioxide emissions, *ENC* energy consumption, *GDP* real GDP per capita, *FDE* financial development

\*\*\*, \*\*, and \* indicate statistically significant at 1%, 5%, and 10%, respectively; T-statistic in parenthesis

whereas low level of financial development aggravates it. Put differently, at lower level of financial development, an increase in financial development increases CO<sub>2</sub> emissions, but at higher level of financial development, an increase in financial development decreases CO<sub>2</sub> emissions.

The results of FMOLS reported in Table 6 find similar outcomes as DOLS in terms of signs and statistical significance of the coefficients (except the magnitudes that slightly differ). Thus, energy consumption has positive impact on CO<sub>2</sub> emissions in all the panels. Similarly, economic growth has positive impact on CO<sub>2</sub> emissions in all the income groups except high-income groups (where the impact is negative). Moreover, financial development has negative impact on CO<sub>2</sub> emissions in high-income groups whereas the impact is positive in lower-middle-income and low-income groups. In both DOLS and FMOLS, changes in the regressors explain reasonable proportion of changes in the dependent variables as indicated by the coefficient of determination (R-squared).

Furthermore, Table 7 shows the results of the dynamic specification of the impact of energy consumption, economic growth, and financial development on CO<sub>2</sub> emissions using the two-step GMM estimation procedure. The GMM estimation results corroborated the earlier results obtained with DOLS and FMOLS. Expectedly, the lagged dependent variable enters with a positive and significant coefficient in all the income groups, an indication of persistence in CO<sub>2</sub> emissions.

**The issue of cross-sectional dependence and robustness test**

In order to address the issue of cross-sectional dependence and robustness check of our estimation results, we employ estimation procedures that are capable of addressing cross-sectional dependence (e.g., CCEMG, dynamic CCEMG). Before

estimation, we confirm the existence of cross-sectional dependence in the panels by conducting cross-sectional dependence tests. The results reported in Table 8 confirmed the presence of cross-sectional dependence in all the panels.

Next, we employ Westerlund (2007) error-correction-based panel cointegration tests. The results presented in Table 9 reject the null hypothesis of no cointegration, implying the existence of cointegration in the panels.<sup>11</sup>

Since, cointegration exists in the panels, we estimate the long-run coefficients using both CCE mean group and dynamic CCEMG. First, the results of CCEMG presented in Table 10 show that energy consumption enters with a positive and significant coefficient in all the income groups, suggesting its detrimental impact on CO<sub>2</sub> emissions. The impact of GDP on CO<sub>2</sub> emissions is also positive and significant in low- and lower-middle-income groups but insignificant in upper-middle-income and high-income groups. Financial development intensifies CO<sub>2</sub> emissions in low-income and lower-middle-income countries, whereas the impact is insignificant in high-income and upper-middle-income countries.<sup>12</sup> These results are similar to the DOLS and FMOLS estimation results.

<sup>11</sup> We also conducted another cointegration test using the Lagrange multiplier-based cointegration tests proposed by Westerlund and Edgerton (2007) that allow for heteroskedastic and serially correlated errors as well as structural breaks in the intercept and slope. The results (not reported for want of space, but available upon request) reject the null hypothesis of no cointegration, implying that cointegration relationship exists among the variables in all the panels.

<sup>12</sup> We thank the anonymous reviewer for this comment. Although the focus of this study is panel data analysis rather than time series analysis, our empirical strategy enables us to obtain the estimation results of individual-specific country through the CCE estimator. The results are not reported for lack of space, but available upon request. A summary of the results shows that economic growth, energy consumption and financial development are significant determinants of CO<sub>2</sub> emissions in most of the countries. However, we do not give much attention to the individual-specific country estimation results because the sample size is too short for time series analysis.

**Table 8** Results of cross-sectional dependence tests

Tests statistics	All income	High income	Upper middle income	Lower middle income	Low Income
Breusch–Pagan LM	47,991.2***	4908.31***	1784.37***	2254.13***	247.870***
Pesaran scaled LM	333.239***	87.046***	39.889***	54.804***	12.559***
Pesaran CD	26.556***	13.667***	2.651***	7.669***	0.259
Bias-corrected scaled LM	330.697***	86.108***	39.223***	54.138***	12.288***

\*\*\*Statistical significance at 1% level, and a rejection of the null hypothesis of no cross-sectional dependence (correlations) in residuals

Second, the results of the dynamic specification of the impact of energy consumption, economic growth, and financial development on CO<sub>2</sub> emissions using dynamic CCEMG are shown in the lower part of Table 10. Expectedly, the lagged dependent variable enters with a positive and significant coefficient, suggesting that past CO<sub>2</sub> emissions aggravates current CO<sub>2</sub> emissions. Energy consumption continues to enter with a

positive and significant coefficient in all the income groups, while the coefficient of financial development is positive and significant in low-income countries, but insignificant in high-income countries. This corroborates earlier results that financial development has harmful effect on CO<sub>2</sub> emissions in low-income countries. The Jackknife bias correction procedure<sup>13</sup> was used to correct for small sample time series bias in dynamic CCEMG estimator. Finally, the postestimation test using Pesaran (2015) test rejects the null hypothesis that the errors are weakly cross-sectional dependent in most of the panels.

**Table 9** Results of Westerlund (2007) panel cointegration test

Test	Value	Asymptotic <i>p</i> value	Bootstrap <i>p</i> value
All income			
Group- $\tau$	-2.002	0.997	0.025**
Group- $\alpha$	-4.362	1.000	0.077*
Panel- $\tau$	-12.984	1.000	0.000***
Panel- $\alpha$	-3.194	1.000	0.083*
High income			
Group- $\tau$	-1.752	1.000	0.430
Group- $\alpha$	-3.995	1.000	0.927
Panel- $\tau$	-16.077	0.001	0.033***
Panel- $\alpha$	-3.758	1.000	0.378
Upper middle income			
Group- $\tau$	-2.170	0.649	0.070*
Group- $\alpha$	-4.438	1.000	0.950
Panel- $\tau$	-10.035	0.784	0.025**
Panel- $\alpha$	-3.453	1.000	0.428
Lower middle income			
Group- $\tau$	-2.192	0.598	0.037**
Group- $\alpha$	-4.697	1.000	0.385
Panel- $\tau$	-3.199	1.000	0.953
Panel- $\alpha$	-2.075	1.000	0.783
Low income			
Group- $\tau$	-1.988	0.826	0.077**
Group- $\alpha$	-4.626	0.999	0.068*
Panel- $\tau$	-5.951	0.822	0.000***
Panel- $\alpha$	-4.054	0.969	0.077*

The tests are estimated using lags (2), leads (0), constant, bootstrap (400) replications. The Group mean tests do not require the cointegrating vector to be equal for all the cross-sections while the Panel tests assume equal cointegrating vector for all the cross sections

\*\*\*, \*\*, and \* indicate statistically significant at 1%, 5%, and 10%, respectively, and a rejection of the null hypothesis of no cointegration

## Discussion and policy implications

The positive impact of energy consumption on CO<sub>2</sub> emissions in all the income groups found in this study is consistent with Alkhatlan and Javid (2013), Arouri et al. (2012), Esso and Keho (2016), and Mirza and Kanwal (2017) who reported a detrimental effect of energy consumption on CO<sub>2</sub> emissions. This implies that energy consumption has taken place at the expense of CO<sub>2</sub> emissions in all the income groups. The harmful effect of energy consumption on CO<sub>2</sub> emissions in all the income groups is not surprising because all the income groups experienced remarkable increase in energy consumption during the period under review. In this regard, it might be necessary to adopt energy consumption policies that do not exacerbate CO<sub>2</sub> emissions. Therefore, the government of most countries should pay attention to building resources that would guarantee sufficient supply of energy by steadily increasing the proportion of renewable energy resources in the entire energy supplies. This is because an increase in energy production from renewable resources is considered to diminish CO<sub>2</sub> emissions. Moreover, policies and activities that reduce CO<sub>2</sub> emission should be vigorously pursued, and made a fundamental agenda in energy and environmental policies of countries with a view to lessening the harms connected with CO<sub>2</sub> emissions.

Moreover, the positive effects of economic growth on CO<sub>2</sub> emissions found mostly in full sample and low-income groups of this study agreed with some studies (see Lean and Smyth 2010; Narayan and Smyth 2008; Salahuddin and Gow 2014;

<sup>13</sup> For more information, see Dhaene and Jochmans (2015); Chudik and Pesaran (2015).

**Table 10** Results of CCEMG and dynamic CCEMG estimations

Estimator	Variables	All income	High income	Upper middle income	Lower middle income	Low Income
CCEMG	ENC	1.132*** (5.160)	1.016*** (12.930)	0.950*** (8.180)	0.828*** (3.240)	2.012** (1.870)
	GDP	0.307*** (3.190)	0.200 (2.730)	0.259 (1.190)	0.378* (1.700)	1.375*** (3.060)
	FDE	0.055*** (2.960)	0.006 (0.190)	−0.029 (−1.170)	0.121*** (2.870)	0.240*** (3.840)
Dynamic CCEMG	ENC	0.998*** (6.390)	1.042*** (11.890)	0.949*** (7.880)	0.738*** (2.940)	3.243** (1.690)
	GDP	0.252** (1.960)	0.161 (1.880)	−0.085 (−0.400)	0.515 (1.060)	0.529 (1.260)
	FDE	0.024* (1.710)	0.005 (0.120)	0.023 (0.270)	0.003 (0.007)	0.204** (2.140)
	CO <sub>2t-1</sub>	0.074*** (2.420)	0.078*** (2.570)	0.052 (0.870)	0.201** (2.20)	0.280*** (3.950)
	Pesaran CD test	0.878	2.062**	0.741	−1.828**	−2.310**

CCEMG = common correlated effects mean group (Pesaran 2006), Dynamic CCEMG (Chudik and Pesaran 2015). We use Jackknife bias correction procedure to correct for small sample time series bias in dynamic CCEMG estimator. Pesaran CD test is the postestimation cross-sectional dependence test (Pesaran 2015) with the null hypothesis of weak cross-sectional dependent errors

CO<sub>2</sub> carbon dioxide emissions, ENC energy consumption, GDP real GDP per capita, FDE financial development

\*\*\*, \*\*, and \* indicate statistically significant at 1%, 5%, and 10%, respectively; T-statistic in parenthesis

Tamazian and Rao 2010) who documented a significant positive effects of economic growth on CO<sub>2</sub> emissions. This implies that economic growth has taken place to the detriment of CO<sub>2</sub> emissions. Nevertheless, there is evidence that economic growth could reduce CO<sub>2</sub> emissions in high-income group in this study. This is consistent with the postulation that CO<sub>2</sub> emissions rise as the country experiences economic growth at early stages of economic development, but decline after a certain threshold level of economic growth is attained. Perhaps, the high-income group has reached income level where further increase in economic growth does not aggravate CO<sub>2</sub> emissions, whereas the low-income group is yet to attain such threshold level. This is consistent with Narayan and Narayan (2010) and Jaunky (2011). As countries move from low-income to high-income group, the repugnant effects of economic growth on CO<sub>2</sub> emissions decline. The policy implication of these findings is that low-income groups should prioritize policies and programs that would accelerate their level of income with a view to moving them to high-income groups if they desire to reduce CO<sub>2</sub> emissions and its obnoxious effects.

Furthermore, the finding of this study regarding the positive impact of financial development on CO<sub>2</sub> emissions in the full sample and low-income groups are consistent with some empirical studies (e.g., Al-mulali and Sab 2012b; Boutabba 2014; Farhani and Ozturk 2015; Zhang 2011). They argued that financial development increases CO<sub>2</sub> emissions. However, the negative impact of financial development on CO<sub>2</sub> emissions unveiled in high-income groups in this study is consistent with some studies (e.g., Jalil and Feridun 2011; Salahuddin et al. 2015; Shahbaz et al. 2013b). The differences in the impact of financial development on CO<sub>2</sub> emissions across the income groups could be attributed to the differences in their levels of financial development. Thus, Yuxiang and Chen (2010) also posited that a country with more developed

and sound financial system provides opportunity to industries for the adoption and utilization of advanced state-of-the-art technologies which produces less CO<sub>2</sub> emissions. They also contended that the development of the financial sector enhances the enforcement of regulations that are environmentally friendly. The policy implication is that low-income countries should strive to develop their financial sector in order to mitigate CO<sub>2</sub> emissions.

### Conclusion

This paper examines the effects of energy consumption, economic growth, and financial development on CO<sub>2</sub> emissions in heterogeneous panels of 122 countries divided into high-income, upper-middle-income, lower-middle-income, and low-income countries. We employ both first-generation and second-generation panel unit root tests, panel cointegration tests, and panel estimation procedures in order to address the issue of cross-sectional dependence. The study finds that cointegration exists between the variables regardless of income group. Energy consumption has positive impact on CO<sub>2</sub> emissions in all the income groups. However, the impact of economic growth and financial development on CO<sub>2</sub> emissions differ among the income groups. Specifically, there are evidences that economic growth and financial development mitigate CO<sub>2</sub> emissions in high-income countries, while their effects are detrimental in middle-income and low-income countries.

The implication of this paper is that energy consumption increases CO<sub>2</sub> emissions. But high levels of income and financial development decrease CO<sub>2</sub> emissions, while low levels of income and financial development increase it. This implies that energy consumption has taken place at the expense of CO<sub>2</sub>emissions in all the income groups. Hence, the

adoption of energy consumption policies that do not exacerbate CO<sub>2</sub> emissions is fundamental. Therefore, the countries should increase the proportion of renewable energy resources in the entire energy supplies in order to diminish CO<sub>2</sub> emissions. Additionally, the countries should formulate policies and activities that reduce CO<sub>2</sub> emission, and make them fundamental agenda in their energy and environmental policies in order to lessen CO<sub>2</sub> emissions and its detrimental effects.

Moreover, as countries move from low-income to high-income group, the adverse effects of economic growth on CO<sub>2</sub> emissions declines. Therefore, low-income groups should prioritize policies and programs that would move them to high-income groups if they desire to reduce CO<sub>2</sub> emissions. Since high level of financial development has the capacity to

reduce CO<sub>2</sub> emissions, the development of financial system should be prioritized by low-income countries. It appears that a sound financial system provides opportunity for the industries to adopt and use advanced state-of-the-art technologies which produces less CO<sub>2</sub> emissions, as well as enhances the enforcement of environmentally friendly regulations.

This paper has succeeded in unfolding the differential impact of energy consumption, economic growth, and financial development on CO<sub>2</sub> emissions in different income groups. Nevertheless, it is recommended that future researches should examine the threshold levels beyond which economic growth and financial development begin to reduce CO<sub>2</sub> emissions because this would be fundamental for policy formulations.

## Appendix

**Table 11** List of countries included in the study

High income			
Australia	Greece	Luxembourg	Slovenia
Austria	Hong Kong	Malta	Spain
Belgium	Hungary	Netherlands	Sweden
Canada	Iceland	New Zealand	Switzerland
Chile	Ireland	Norway	Trinidad and Tobago
Cyprus	Israel	Oman	United Arab Emirates
Czech Republic	Italy	Poland	UK
Denmark	Japan	Portugal	USA
Estonia	Korea, Rep.	Qatar	Uruguay
Finland	Kuwait	Saudi Arabia	
France	Latvia	Singapore	
Germany	Lithuania	Slovak Republic	
Upper middle income			
Albania	Colombia	Libya	Peru
Algeria	Costa Rica	Macedonia	Romania
Argentina	Ecuador	Malaysia	Russia
Bosnia and Herzegovina	Gabon	Mauritius	Serbia
Botswana	Iran	Mexico	South Africa
Brazil	Iraq	Namibia	Thailand
Bulgaria	Jamaica	Panama	Turkey
China	Kazakhstan	Paraguay	Venezuela
Lower middle income			
Angola	Croatia	Indonesia	Pakistan
Armenia	Egypt	Jordan	Philippines
Bangladesh	El Salvador	Kenya	Sri Lanka
Bolivia	Georgia	Lebanon	Tunisia
Cambodia	Ghana	Morocco	Ukraine
Cameroon	Guatemala	Myanmar	Vietnam
Congo, Rep.	Honduras	Nicaragua	Yemen
Côte d'Ivoire	India	Nigeria	Zambia
Low income			
Benin	Haiti	Senegal	Zimbabwe
Congo DR	Mozambique	Sudan	
Eritrea	Nepal	Tanzania	
Ethiopia	Niger	Togo	



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