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Environmental quality effects of income, energy prices and trade: The role of renewable energy consumption in G-7 countries

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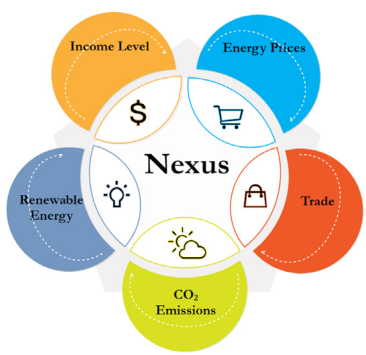
HIGHLIGHTS

- Assessment of renewable energy usage, energy prices and trade in G-7 countries.
- Renewable energy consumption and energy price exert negative pressure CO_2 emissions.
- The EKC hypothesis is validated in both panel and country-specific levels.
- Effects of renewable energy consumption and trade are disparate across countries.
- Renewable energy affects energy prices while energy prices affect CO_2 emissions.

GRAPHICAL ABSTRACT



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ABSTRACT

Renewable energy plays a vital role in achieving environmental sustainability, however, the mitigating effect varies across countries depending on the share of renewables in the energy mix. Herein, we analyze the effect of renewable energy consumption, energy prices, and trade on emissions in G-7 countries. The results demonstrate that renewable energy and energy prices exert negative pressure on CO_2 emissions while trade volume exerts a robust positive pressure on CO_2 emissions. The country-specific estimation results provide evidence of a negative effect of energy prices on CO_2 emissions. While the environmental Kuznets curve hypothesis is validated at the panel and country-specific levels, the effect of renewable energy consumption and trade, are disparate across countries. The panel Granger causality shows a mono-directional causality flowing from energy prices, GDP, the quadratic term of GDP and trade to CO_2 emissions. Renewable energy consumption, however, has no causal relationship with CO_2 emissions but indirectly affects CO_2 emissions through its direct effect on energy prices. Joint action on trade, energy prices, and country-specific renewable energy policies have implications for environmental sustainability and the attainment of the Sustainable Development Goals (SDGs).

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1. Introduction

The perspectives of policymakers on global energy-environment dynamics could be well-posited on two main paradigm shifts. The first perception is based on the argument that more implementation of energy diversification of the downstream sector could curb the incessant oil price fluctuations. From another perspective, these conjectures by most environmentalists have consistently been hinged on the need for a global drive towards a cleaner environment and sustainable economic development. Hence, mirroring from the environmental context and especially the conventional Environmental Kuznets Curve (EKC) hypothesis, the role of global energy price dynamics amidst the increasing use of low-carbon energy sources and energy technologies is worth further scientific examination. The dynamics in global energy prices are observed to cut across the myriad of energy use which includes unleaded premium; oil for industry, households and motor vehicles; natural gas for industry and households; steam coal for industry; and electricity for commercial and residential purposes (International Energy Agency, IEA, 2019a). For instance, the IEA reveals that the average price of gasoline in 2018 increased by 14% from the previous year (International Energy Agency, IEA, 2019b). The IEA further observes that the European consumers paid the highest gasoline price, thus, suggesting a reflection of the continent's high taxes on fuels as a measure to achieving the low carbon energy targets and Sustainable Development Goals (SDGs) target.

The use of renewable energy and clean energy technologies is one of the prominent mechanisms towards breaking the long-standing link between fuel pollution, carbon emissions (CO_2) and economic growth. This is because energy utilization is arguably linked with economic growth, thus indicating that energy consumption is responsible for determining the environmental quality (Rafindadi, 2016; Rafindadi and Usman, 2019; Usman et al., 2019a).

Consequently, in achieving global environmental sustainability, the United Nations Framework Convention on Climate Change (UNFCC),[1] and a growing number of states among other stakeholders have consistently urged for more commitment to the comprehensive 2015 Paris Agreement.[2] For instance, the share of renewables in total energy consumption is reported to increase in a five-year period to attain a 12.4% growth by 2023 (International Energy Agency, IEA, 2019c). With about 30% of power demand being met by 2023 through renewables, 70% of global growth in electricity generation from renewable energy through solar photovoltaic (PV), wind, hydropower and bioenergy, renewables are expected to be the fastest-growing energy technology in the electricity sector by 2023 (International Energy Agency, IEA, 2019c). However, the current global outlook suggests that energy generation from renewables is inadequate to meet the global demand — prominently from the heating, cooling, and transportation sectors (REN21, 2019). Implying that the heavy reliance on fossil fuels, which are mostly subsidized in many countries is persistent amidst the high cost of renewable energy generation and the use of energy technologies (Destek and Sarkodie, 2020).

Considering the role of the world-leading economies, such as the G-7 countries (Canada, France, Germany, Italy, the UK, the US, and Japan) in influencing the dynamics in energy prices and global environmental challenges through policy directions, this study examines the EKC hypothesis in the presence of renewable energy consumption, energy prices and trade volume in G-7 countries. While previous studies (Alola and Alola, 2018; Alola et al., 2019a; Alola et al., 2019b; Alola et al., 2019c; Bekun et al., 2019; Saint Akadiri et al., 2019) have considered the role of renewable energy consumption in mitigating environmental degradation as well as examining the link between energy prices and environmental degradation (Al-Mulali and Ozturk, 2016; Balaguer and Cantavella, 2016; Yilanci and Ozgur, 2019), the current study contributes to the existing literature in several ways: First, the study jointly investigates the role of energy prices, renewables and trade within the EKC framework in G-7 countries. Second, the study considers the nexus outlined in both panel and country-specific framework in order to unravel joint and country-specific effect of energy prices, renewables and trade on environmental quality. The findings of this paper will reveal whether these economies differ from other economies, particularly the developing and emerging economies regarding the role of renewable energy consumption, energy prices and trade volumes on environmental quality within the framework of the EKC hypothesis. In addition, by applying heterogeneous panel estimation methods of the mean group (group mean) variants, the effect of heterogeneity within the panel dataset is addressed. The group mean Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) estimation techniques applied in addition to mean group OLS estimator would help to eliminate serial correlation and endogeneity.

The succeeding sections of this study are arranged in the following order: a brief review of the extant literature underpinning renewable energy consumption and energy prices in the context of environmental degradation is highlighted in Section 2. Section 3 presents the data and the empirical methodologies employed, while Section 4 details and discusses the estimated results and findings. Section 5 concludes by presenting policy implications and the direction for future studies.

2. Literature review

While few studies (Al-Mulali and Ozturk, 2016; Balaguer and Cantavella, 2016) have both specifically examined the nexus of energy prices and the EKC hypothesis, the general concept of environmental degradation vis-à-vis CO_2 and energy consumption nexus has also been investigated in G-7 countries (Chang, 2015; Nabaee et al., 2015; Shahbaz et al., 2017a). For instance, the concept was examined across 27 advanced economies including the G-7 and found that CO_2 was cointegrated with real Gross Domestic Product (GDP), disaggregate energy consumption, trade openness, urbanization, and energy prices (Al-Mulali and Ozturk, 2016). The study showed that GDP increases CO_2 emissions and confirmed an inverted U-shaped relationship between the GDP and CO_2 emissions, whereas, Usman et al. (2019b) noted that stimulating environmental performance reduces growth in 28 European Union (EU) countries.

Adding to the evidence of the EKC hypothesis, Balaguer and Cantavella (2016) specifically investigated the EKC hypothesis for Spain (one of the 27 advanced economies) over the period 1874–2011. The study found that 1950 related emissions in Spain were 24 times more than in 1874; however, emissions generated in 2011 were 250 times higher compared with the 1874 CO_2 emissions. In the wake of the historical observations, the study also observed that the per capita income of Spain might have attained a certain level, thus causing a decline in CO_2 emissions since the per-capita income was observed to have experienced a 50% increase in growth rate in 1950 than in 1874. Importantly, the validity of the EKC hypothesis was confirmed for Spain when energy prices were incorporated in the estimation model of the Autoregressive Distributed Lag (ARDL) approach (Balaguer and Cantavella, 2016). The level of per capita income in Spain corresponded to the highest CO_2 emissions in 1980 before experiencing a decline in CO_2 emissions with increasing income growth. However, while Balaguer and Cantavella (2016) employed real oil prices as a proxy variable for energy price, Al-Mulali and Ozturk (2016) employed a weighted average of the index of gas prices, liquid fuel and energy heat prices.

[1] "UNFCC is the section of the United Nations organization that is saddled with mitigating global climate change. Further information on UNFCCC is available at https://unfccc.int/."

[2] "The 2015 Paris Agreement by the UNFCC. More details relating to the 2015 Paris Agreement are available at: https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/Paris-agreement."

The findings from the drivers of renewable energy consumption in G7 countries showed that CO_2 emissions and income had a significant positive relationship with renewable energy at the panel level while the relationship with oil price was insignificantly negative with renewable energy at the panel level. However, country-level estimations showed that apart from income with a robust positive relationship across all countries, estimates for oil price and CO_2 emissions were disparate across countries (Sadorsky, 2009). In contrast to the theoretical framework of previous studies, we account for the reverse effects of renewable energy, energy prices and trade on CO_2 emissions within the EKC framework.

A recent study by Yilanci and Ozgur (2019) employed per-capita ecological footprint (EF) in lieu of the conventional CO_2 emissions as a proxy for environmental degradation to investigate the EKC hypothesis in G-7 countries. The study equally analyzed the income-pollution level nexus in the sub-group periods. The findings confirmed the validity of the EKC hypothesis for Japan and the US, whereas no evidence of the EKC hypothesis was found for the other five countries. On the contrary, the validity of the EKC hypothesis was found only for Canada, France, Germany, Italy, the UK, and the US in the empirical study conducted by Shahbaz et al. (2017a). The results of this study also validated the feedback effect between CO_2 and GDP for France and Italy; a neutral effect for Japan while CO_2 emission was observed to Granger-cause GDP in Canada, Germany, the UK, and the US. While investigating the EKC hypothesis in G-7 countries, Chang (2015) and Nabaee et al. (2015) compared their outcomes with the BRICS (Brazil, Russia, India, China, and South Africa) and selected developing countries and found that while G-7 countries are on the verge of decarbonizing their economy, BRICS and developing countries are still carbonizing and intensifying its energy-based economy.

The EKC hypothesis in a panel of G-7 countries over the period 1991–2008 was investigated by considering potential endogeneity biases (Chiang and Wu, 2017). With the implementation of the panel smooth transition regression approach, the study examined the changes in the elasticity of CO_2 emissions with country and time effects to underpin the elasticity of heterogeneous countries and possible structural breaks. The CO_2-real income per capita (GDP per capita) nexus in Japan, the UK, and the US favoured environmental quality while such relationship was not valid for the remaining G-7 countries. However, an inverted U-shaped relationship between CO_2 emissions and real income per capita was validated at a turning of US$ 20,488. Hence, affirmed the regime-switching impact of GDP per capita —the EKC hypothesis on environmental degradation vis-à-vis CO_2 emissions in the panel of G-7 countries.

The role of renewable energy consumption in the context of the EKC hypothesis was examined in a panel of G-7 countries over the period 1991–2016 (Raza and Shah, 2018). While investigating the EKC hypothesis, the study employed the dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and the fixed effects ordinary least squares regression (FE OLS) to establish evidence of cointegration. The study found economic growth to increase CO_2 emissions, thus, causing more environmental hazards, especially in the long-run. In the case of renewable energy consumption, the development of renewables in the panel of G7 countries was a significant factor for long-term decarbonization policy. While incorporating trade indicator together with renewable energy consumption and per capita GDP, the empirical results supported the validity of the EKC hypothesis in G-7 countries. Among other studies that have either examined the EKC hypothesis for the panel of G-7 countries or individual G-7 member countries in the framework of alternative energy sources include Sebri and Ben-Salha (2014); Shafiei and Salim (2014); Zoundi (2017); Ito (2017); Shahbaz et al. (2017b); Cetin (2018); Cai et al. (2018); Lau et al. (2019). The results of these studies largely support the CO_2-mitigating effect of renewable energy consumption. However, most of these studies failed to control for energy price effects, which may have far-reaching implications for environmental quality. In view of the few studies that incorporate energy prices, one major challenge stands out, the analysis of panel data covering larger geographical locations may not accurately depict the true relationship among the variables in the individual countries of the panel employed. Conversely, studies on a single country are geographically limited, hence, policy implications may be country-specific. In contrast, our study moves a step further by incorporating heterogeneous panel and country-specific cointegration estimation techniques in order to unravel the long-run relationship between renewable energy consumption, trade, income, energy prices and CO_2 emissions in the G-7 countries as a whole, as well as, for individual member countries.

3. Material and methods

3.1. Data

We used an unbalanced panel dataset sampled at different time periods for the United Kingdom (1970–2014) and Germany (1990–2014) due to data limitations in these countries. Data for the remaining 5 countries in the panel were sampled from 1960 to 2014. Variables such as CO_2 (measured in metric tons per capita), per-capita real GDP (measured in constant 2010 USD), renewable energy consumption (measured in kg of oil equivalent per capita), per capita trade volume (measured in constant 2010 USD) were obtained from the World Bank world development indicators.[3] The energy price index follows the United Nations classification of individual consumption by purpose which was adopted in the compilation of the Harmonized Index of Consumer Prices (HICP) of the EU, the Euro area, as well as, OECD countries. The index includes the COICOP 04.5 classification (Electricity, gas and other fuels) which incorporates the weighted index of the price of electricity, gas, natural gas and town gas, liquefied hydrocarbons, domestic heating and lighting oils, solid fuels and heat energy. It also includes the COICOP 07.2.2 classification which covers fuels (diesel and petrol) and lubricants for personal transport equipment. The energy price index was obtained from the OECD Statistics.[4]

3.2. Model estimation

In line with the purpose of this research, the conventional EKC model was augmented with renewable energy, energy prices and trade, specified as (Grossman and Krueger, 1991, 1995):

$$LCO2PK_{it} = \beta_0 + \beta_1 LRGDPK_{it} + \beta_2 LRGDPK2_{it} + \beta_3 LRENPK_{it} + \beta_4 LCPIE_{it} + \beta_5 LTRADPK_{it} + u_{it} \quad (1)$$

From Eq. (1), *LCO2PK*, *LRGDPK*, *LRGDPK2*, *LRENPK*, *LCPIE* and *LTRADPK* denotes real per-capita GDP, the square of real per capita GDP, per capita renewable energy consumption, energy prices and per capita trade volume respectively, of country i at time t. u denotes the stochastic white noise error term and β_1-β_5 indicate the slope coefficients of the variables while β_0 is a time-invariant country-specific effect. Except for energy prices, all quantitative variables are measured in per-capita terms in order to control for population effects. All variables including energy prices were log-transformed in order to reduce the incidence of heteroscedasticity. Consequently, the slope coefficients are interpreted as elasticities.

We used heterogeneous panel estimation methods of the mean group (group mean) variants because of the unbalanced nature of the dataset employed. Unlike conventional pooled panel estimation procedures, panel mean group estimation techniques employ full heterogeneity with the implication of both long-run and short-run heterogeneity. In the estimation of the mean group, N time series equations were estimated for each individual country in the panel. The

[3] https://databank.worldbank.org.

[4] http://www.oecd.org/sdd.

estimated coefficients were then averaged to represent the overall panel estimate. The estimation sequence of mean group techniques makes it ideal for unbalanced panel data type, a procedure applied in this present study. We used the group mean FMOLS (Pedroni, 2001a, 2001b), DOLS (Kao and Chiang, 2001; Pedroni, 2001b) and mean group estimator (Pesaran and Smith, 1995). While the the procedure for FMOLS eliminates serial correlation and endogeneity in OLS estimations through a semi-parametric correction, the DOLS procedure conversely applies a parametric correction to OLS estimators to eliminate endogeneity and serial correlation. The DOLS model is argued to exhibit the least bias in small samples when compared to FMOLS and OLS procedures (Kao and Chiang, 2001). An advantage of group mean estimators over the other pooled panel estimators is that their formulation is based on the "*between dimension*" of the panel rather than the "*within dimension*" of pooled estimators, as such, the t-statistic implies a more flexible alternative hypothesis (Pedroni, 2001a). Pesaran and Smith (1995) further argued within the perspective of OLS regression that when the true slope coefficients are heterogeneous, group mean estimators provide a consistent sample mean point estimates of the heterogeneous cointegrating vectors, a feat which cannot be replicated by traditional pooled estimators. All three estimation procedures are used to ascertain whether the model parameters are robust to different estimation techniques.

The panel vector error correction model (VECM) is a suitable Granger causality testing approach to apply when the variables are integrated of order one, I(1) and long-run cointegration has been validated among the series. In the present study, the panel VECM was used to test both the long-run and short-run Granger causality relationship, specified as:

$$\Delta\begin{bmatrix} LCO2PK_{it} \\ LCPIE_{it} \\ LRENPK_{it} \\ LRGDPK_{it} \\ LRGDPK2_{it} \\ LTRADPK_{it}\end{bmatrix} = \begin{bmatrix}\beta_1\\ \beta_2\\ \beta_3\\ \beta_4\\ \beta_5\\ \beta_6\end{bmatrix} + \sum_{k=1}^{p}\Delta\begin{bmatrix}\Theta_{11ik}\,\Theta_{12ik}\,\Theta_{13ik}\,\Theta_{14ik}\,\Theta_{15ik}\,\Theta_{16ik}\\ \Theta_{21ik}\,\Theta_{22ik}\,\Theta_{23ik}\,\Theta_{24ik}\,\Theta_{25ik}\,\Theta_{26ik}\\ \Theta_{31ik}\,\Theta_{32ik}\,\Theta_{33ik}\,\Theta_{34ik}\,\Theta_{35ik}\,\Theta_{36ik}\\ \Theta_{41ik}\,\Theta_{42ik}\,\Theta_{43ik}\,\Theta_{44ik}\,\Theta_{45ik}\,\Theta_{46ik}\\ \Theta_{51ik}\,\Theta_{52ik}\,\Theta_{53ik}\,\Theta_{54ik}\,\Theta_{55ik}\,\Theta_{56ik}\\ \Theta_{61ik}\,\Theta_{62ik}\,\Theta_{63ik}\,\Theta_{64ik}\,\Theta_{65ik}\,\Theta_{66ik}\end{bmatrix} \quad (2)$$

$$\times\begin{vmatrix} LCO2PK_{it-k} \\ LCPIE_{it-k} \\ LRENPK_{it-k} \\ LRGDPK_{it-k} \\ LRGDPK2_{it-k} \\ LTRADPK_{it-k}\end{vmatrix} + \begin{bmatrix}\lambda_{1i}\\ \lambda_{2i}\\ \lambda_{3i}\\ \lambda_{4i}\\ \lambda_{5i}\\ \lambda_{6i}\end{bmatrix} ECT_{it-1} + \begin{bmatrix}u_{1it}\\ u_{2it}\\ u_{3it}\\ u_{4it}\\ u_{5it}\\ u_{6it}\end{bmatrix}$$

where ECT_{t-1} is the lagged residual from the long-run relationship, Δ is the difference operator and u_{xit} is the stochastic error term at time t in the x^{th} equation of the i^{th} country, which is independently and identically distributed (i.i.d). The significance of the estimated coefficient of the ECT_{t-1} in any equation indicates the validation of the long-run causality from the independent variables to the dependent variable of the specific equation. For instance, $\lambda_{1i} \neq 0$ implies that the long-run causality runs from the regressors to *LCO2PK*. The short-run causality is depicted by the joint statistical significance of the lagged differences of the explanatory variables. In addition, $\sum_{k=1}^{p}\Delta\Theta_{12ik}\neq 0$ implies that *LCPIE* has a short-run predictive content for *LCO2PK*.

3.3. Descriptive statistics

A cursory look at the summary statistics in Table 1 shows that while log-transformed real per-capita GDP (LRGDPK) has the lowest standard deviation and thus, the least volatile of all the variables, its squared counterpart (LRGDPK2), however, is the most volatile with the highest standard deviation. This implies that the EKC inflexion points would most likely be disparate across countries. Per-capita renewable energy consumption follows suit with the 2nd most volatile variable in the dataset signifying potential differences in the attitude of stakeholders towards the production and utilization of renewable energy in their respective economies. It can be observed from Fig. 1 that per capita CO_2 emissions for all countries is initially upward sloping from the beginning of the 1960s. The downward sloping of the trend occurs during the mid-part of the 2000s, a period which coincides with the institutionalization of the Kyoto protocol in February 2005. The time-series plot of energy prices shows a level convergence across the G-7 countries. A major reason for this may be attributed to the regional economic integration of the EU which was aided by the introduction of the Euro as a single currency for the EU member countries. In line with the law of one price, Euro area price convergence with other advanced economies such as the US has been validated in various studies (Sosvilla-Rivero and Gil-Pareja, 2004; Goldberg and Verboven, 2005; Rogers, 2007). The implication of this observation is that energy price effects across G-7 countries may not be too far apart.

Table 1
Summary statistics.
Source: Authors' computations.

Variable	Obs	Mean	Std. Dev.	Min	Max
LCO2PK	354	2.286567	0.4639481	0.7786112	3.113986
LCPIE	382	3.612786	0.8852169	1.460868	4.79814
LRECNPK	392	6.046653	1.13742	2.646366	7.715763
LRGDPK	382	10.28365	0.3676815	9.060408	10.85772
LRGDPK2	382	105.8882	7.466323	82.09099	117.89

4. Results and discussions

Prior to estimating the model coefficients, we employed several pretesting procedures to ascertain the time series properties of the variables as well as the status of cointegration. We used country-specific and panel unit root techniques, and country-specific and panel cointegration techniques. Detailed results are outlined in subsequent sub-sections.

4.1. Unit root and stationarity test results

We used the Dickey-Fuller generalized least squares (DFGLS) (Elliott et al., 1996) as well as the Kwaitkowski-Phillips-Schmidt-Shin (KPSS) (Kwaitkowski et al., 1992) stationarity test in order to ascertain the country-specific time series properties of the variables. A rejection of the null hypothesis of the DFGLS unit root test implies variable stationarity, however, a rejection of the null hypothesis of the KPSS stationarity test implies that the variable is non-stationary. Results of the unit root and stationarity tests are outlined in Table 2. From Table 2, the KPSS stationarity test rejects the null hypothesis of stationarity for all variables at levels in all 6 countries at all conventional significance levels. This is also corroborated by the DFGLS unit root test in which the null of a unit root cannot be rejected for all variables at levels in all 6 countries at the 1% significance levels. After first differencing the variables, the KPSS stationarity test fails to reject the null of stationarity at either the 1% or 5% significance levels for all variables in all countries. The DFGLS unit root test also rejects the null of a unit root at either 1%, 5% or 10% significance level for all variables in all countries. Going by the results obtained by the stationarity and unit root test, it is safe to infer that all the variables are I(1), thus, employing conventional panel estimation techniques may yield spurious results if the variables are not cointegrated. Against this backdrop, it was now appropriate to undertake panel and country-specific cointegration tests.

4.2. Cointegration test results

In order to ascertain the existence of a non-spurious long-run relationship between the variables, we used the Fisher and Johansen panel and country-specific cointegration test procedure. In this procedure, the *p*-values of the Johansen maximum likelihood cointegration test statistics (Johansen and Juselius, 1990) are aggregated via the Fisher test (see Maddala and Kim, 1998, p. 137). The test statistic can be computed as $-2\sum_{i=1}^{N} \; logp_i \sim \chi^2_{2N}$ where p_i indicates the p-value of the Johansen test statistic for the *ith* country. The test assumes heterogeneity of coefficients across countries. In Table 3, we fail to reject the hypothesis of at most 3 cointegrating relationships at 5% and 1% significance level of the whole panel. In Table 4 of the country-specific statistics, it is observed that the null hypothesis of no cointegration for each country is rejected at 5% significance level for Japan and the UK and rejected at 1% significance level for the remaining countries under the maximum Eigenvalue statistic. The hypothesis of at most 1 cointegrating relationship cannot be rejected for the US and Japan at

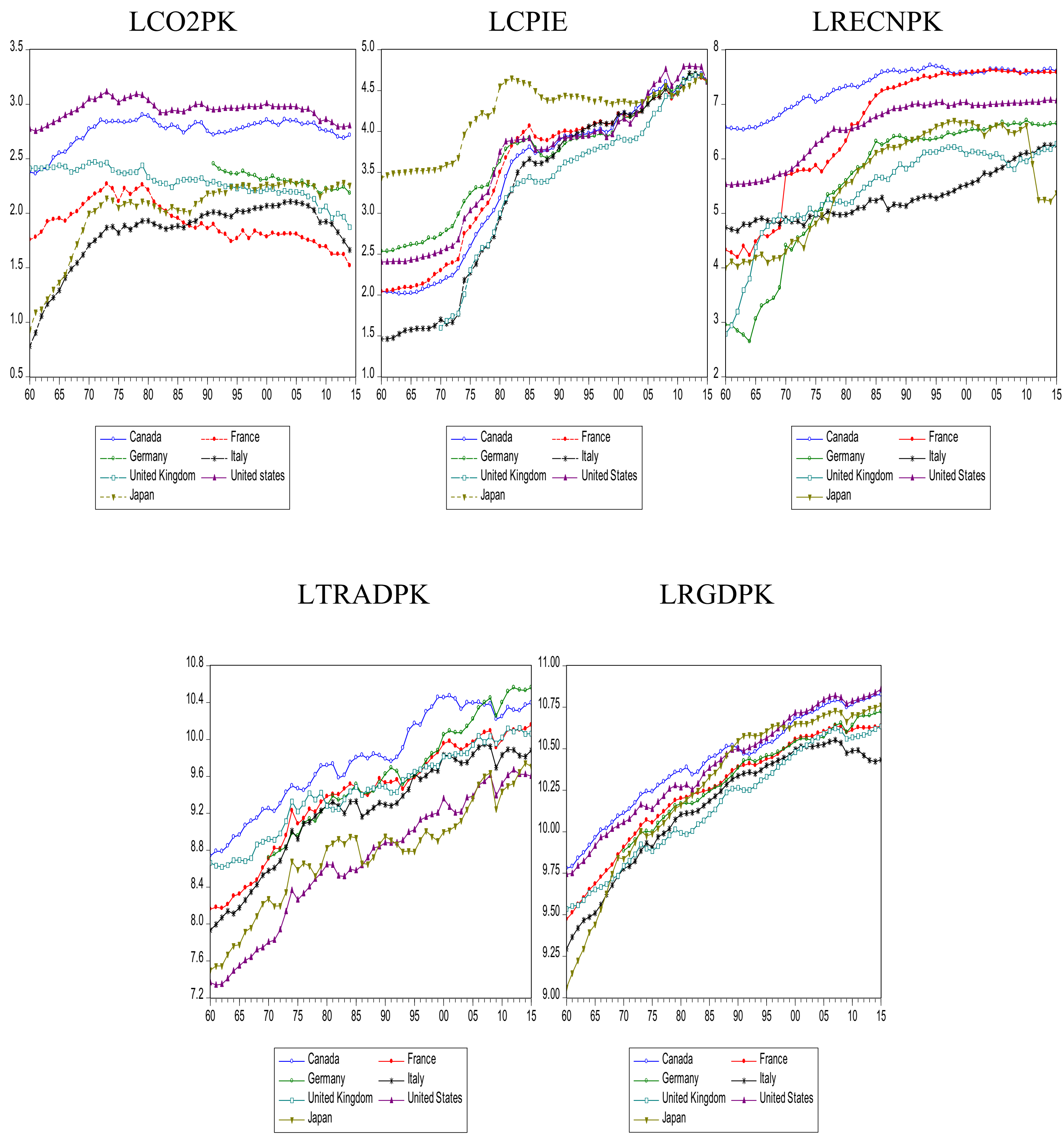

Fig. 1. Graphical plot of variables.

Table 2
Stationarity and unit root tests.

Countries	Panel A: variables at levels									
	LCO2PK		LCPIE		LRENPK		LRGDPK		LTRADPK	
	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS
Canada	0.423^{a}	−1.129	0.476^{a}	−1.223	0.687^{a}	−0.764	0.459^{a}	−1.207	0.364^{a}	−1.768
France	0.374^{a}	−0.901	0.559^{a}	−1.081	0.669^{a}	−0.786	0.607^{a}	−0.409	0.515^{a}	−1.347
Germany	1.66^{a}	−2.709	0.357^{a}	−2.098	0.681^{a}	−0.690	0.484^{a}	−1.639	0.291^{a}	−3.124^{c}
Italy	0.504^{a}	0.127	0.543^{a}	−1.068	0.596^{a}	−0.758	0.643^{a}	−0.048	0.495^{a}	−1.000
United Kingdom	0.285^{a}	−0.951	0.387^{a}	−1.624	0.478^{a}	−1.133	0.326^{a}	−2.057	0.280^{a}	−2.484
United States	0.367^{a}	−1.537	0.335^{a}	−1.754	0.683^{a}	−0.827	0.435^{a}	−1.502	0.486^{a}	−1.684
Japan	0.441^{a}	−0.979	0.532^{a}	−1.374	0.560^{a}	−0.808	0.628^{a}	−0.584	0.322^{a}	−2.263
Countries	Panel B: variables at first difference									
	D.LCO2PK		D.LCPIE		D.LRENPK		D.LRGDPK		D.LTRADPK	
	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS	KPSS	DFGLS
Canada	0.398^{c}	−4.811^{a}	0.149	−3.184^{a}	0.430^{c}	−3.981^{a}	0.418^{c}	−4.784^{a}	0.263	−5.152^{a}
France	0.415^{c}	−4.270^{a}	0.180	−3.355^{b}	0.408^{c}	−4.006^{a}	0.431^{c}	−4.812^{a}	0.309	−5.501^{a}
Germany	0.414^{c}	−3.365^{b}	0.101	−3.594^{b}	0.414^{c}	−4.063^{a}	0.417^{c}	−6.233^{a}	0.126	−5.841^{a}
Italy	0.634^{c}	−2.879^{b}	0.203	−3.502^{b}	0.461^{c}	−5.414^{a}	0.464^{c}	−5.837^{a}	0.431^{c}	−6.337^{a}
United Kingdom	0.431^{c}	−4.616^{a}	0.324	−2.964^{c}	0.402^{c}	−3.729^{b}	0.244	−4.645^{a}	0.117	−5.259^{a}
United States	0.343^{c}	−4.732^{a}	0.104	−3.735^{b}	0.347	−2.853	0.418^{c}	−4.829^{a}	0.330	−5.108^{a}
Japan	0.432^{c}	−2.627	0.168	−4.074^{a}	0.418^{c}	−4.956^{a}	0.426^{c}	−4.538^{a}	0.217	−5.112^{a}

Note: The table reports the Dickey-Fuller Generalized unit root test with the Elliot-Rothenberg-Stock(1996) interpolated critical values (DFGLS-ERS) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) Stationarity test results for each country-specific variable at levels. The null hypothesis for DFGLS is the existence of a unit root which implies non-stationarity. The null hypothesis for KPSS is that the series is stationary. "a", "b" and "c" denotes statistical significance at the 1%, 5% and 10% levels respectively.

1% and 5% significance levels, respectively under the maximum Eigenvalue statistic. However, the hypothesis of at most 2 cointegrating relationships cannot be rejected for the remaining countries under the maximum eigenvalue statistic. After validating panel and country-specific cointegration, we progressed to estimate the panel and country-specific long-run coefficients.

4.3. Estimation results

The results of the mean group OLS, group mean FMOLS and group mean DOLS estimators are outlined in Table 5. The EKC hypothesis is validated in all panel estimation specifications. Energy price has a robust negative relationship with CO_2 emissions in all the 3 panel estimators. In the mean group OLS specification, a 1% increase in energy prices reduces CO_2 emissions by ~0.23%, in the FMOLS specification, the same increment declines CO_2 emissions by 0.23%. However, in the group mean-DOLS specification, CO_2 emissions declines by 0.17%, which is not too far from the estimates of the other specifications. The outcome is consistent with Balaguer and Cantavella (2016) and Al-mulali and Ozturk (2016). We observe that the estimates for the mean group OLS as well as the group mean FMOLS specifications corresponding to the coefficients for renewable energy are quite close but quite different from that which is obtained from the group mean DOLS specification. A 1% increase in renewable energy consumption leads to 0.08% reduction in the mean group OLS specification and 0.09% reduction in the group mean FMOLS specification. The group mean DOLS, however, supports a reduction in CO_2 emissions by 0.26% for a 1% increase in renewable energy consumption, consistent with Ojonugwa et al. (2020) who found a negative effect of renewable energy on environmental degradation in the US. A significantly negative relationship between renewable electricity consumption and CO_2 emissions was uncovered in Al-mulali and Ozturk (2016). Going further, a 1% increase in international trade volumes triggers an increase in CO_2 emissions by 0.20% for the mean group OLS specification, 0.21% reduction for the group mean FMOLS and 0.19% reduction in the group mean DOLS specification. This outcome is inconsistent with Al-mulali and Ozturk (2016), where a negative relationship between trade openness and CO_2 emissions was found for 27 advanced economies.

Based on the country-specific estimations, the results show that the EKC hypothesis is supported in all countries, for all specifications and that, energy prices have a significant negative effect on CO_2 emissions. The EKC turning points, the magnitude of the energy price effects, and

Table 3
Johansen and Fisher unrestricted cointegration rank test (H_0: No cointegration).

Panel	Fisher stat.		Fisher s tat.	
Hypothesized No. of CE(s)	Trace test	Prob.	Max-Eigen	Prob.
None	195.0***	0.0000	101.5***	0.0000
At most 1	107.0***	0.0000	56.98***	0.0000
At most 2	58.64***	0.0000	29.34***	0.0094
At most 3	38.70***	0.0004	21.35*	0.0929
At most 4	29.84***	0.0080	22.35*	0.0717
At most 5	29.25***	0.0097	29.25***	0.0097

Notes: '***'and '*' denotes statistical significance at the 1% and 10% levels respectively.

Table 4
Johansen and Fisher country specific statistics (H_0: No cointegration).

Country	Trace	Prob.	Max-Eigen	Prob.
Canada	183.6009***	0.0000	83.8097***	0.0000
France	155.4070***	0.0000	62.9737***	0.0000
Germany	144.9472***	0.0000	48.3776***	0.0047
Italy	143.9627***	0.0000	46.1954***	0.0091
United Kingdom	133.2015***	0.0000	42.9367**	0.0232
United States	124.6195***	0.0001	52.6724***	0.0012
Japan	126.8427***	0.0001	45.0071**	0.0129
Hypothesis of at most 1 cointegrating relationship				
Canada	99.7911***	0.0000	42.1215***	0.0042
France	92.4334***	0.0003	37.6373**	0.0169
Germany	96.5696***	0.0001	42.1582***	0.0041
Italy	97.7673***	0.0001	43.0538***	0.0031
United Kingdom	90.2648***	0.0005	37.2873**	0.0188
United States	71.9471**	0.0335	26.7706	0.2758
Japan	81.8356***	0.0041	31.5820*	0.0917
Hypothesis of at most 2 cointegrating relationships				
Canada	57.6696***	0.0046	23.1424	0.1675
France	54.7960***	0.0097	20.3003	0.3207
Germany	54.4114**	0.0107	25.3668*	0.0936
Italy	54.7135***	0.0099	26.0167*	0.0782
United Kingdom	52.9775**	0.0153	26.3967*	0.0703
United States	45.1765*	0.0874	23.8327	0.1407
Japan	50.2536**	0.0292	24.7966	0.1092

Notes: '***' and '*' denotes statistical significance at the 1% and 10% levels respectively.

Table 5
Panel and country-specific estimation results.

Variables	Mean group OLS	Group mean-FMOLS	Group mean-DOLS
Panel			
LCPIE	−0.225758***	−0.234366***	−0.169350***
LRENPK	−0.084570***	−0.093201***	−0.264111***
LRGDPK	16.46624***	8.156401***	26.98987***
LRGDPK2	−0.785871***	−0.397318***	−1.289601***
LTRADPK	0.199876*	0.205477***	0.193246***
Canada	OLS	FMOLS	DOLS
LCPIE	−0.165598***	−0.165073***	−0.18810***
LRENPK	−0.003313	−0.001461	0.145211
LRGDPK	17.05942***	17.27092***	15.79845***
LRGDPK2	−0.790878***	−0.805969***	−0.728383***
LTRADPK	0.053669	0.100522*	0.066165
France			
LCPIE	−0.2614522***	−0.306934***	−0.310585***
LRENPK	−0.0283194	−0.000760	0.034400
LRGDPK	22.949730***	21.07187***	19.75640***
LRGDPK2	−1.1651271***	−1.072235***	−0.994348***
LTRADPK	0.6500363***	0.654864***	0.546640***
Germany			
LCPIE	−0.242736***	−0.243457***	0.183390
LRENPK	−0.215821	−0.211918	−1.71519***
LRGDPK	−44.30459*	−48.65094**	94.84620**
LRGDPK2	2.046318*	2.249479**	−4.601248**
LTRADPK	0.371235	0.380486***	0.830798***
Italy			
LCPIE	−0.2722195***	−0.284322***	−0.273339***
LRENPK	−0.1249403***	−0.146004***	−0.121201**
LRGDPK	10.068650***	9.773414***	7.023427***
LRGDPK2	−0.4246356***	−0.408180***	−0.271091***
LTRADPK	0.0622173	0.070995	−0.006995
United Kingdom			
LCPIE	−0.1983623***	−0.212368***	−0.175060***
LRENPK	−0.1403334***	−0.203227***	−0.148706*
LRGDPK	23.738801***	32.47268***	28.75883***
LRGDPK2	−1.1350860***	−1.557730***	−1.375380***
LTRADPK	−0.113512	−0.065921	−0.168786
United States			
LCPIE	−0.222528***	−0.216244***	−0.194485***
LRENPK	−0.082263*	−0.068526	−0.015279
LRGDPK	14.28918***	14.88632***	13.63381***
LRGDPK2	−0.691411***	−0.713346***	−0.641208***
LTRADPK	0.312883***	0.223587**	0.058092
Japan			
LCPIE	−0.211497***	−0.212166***	−0.227266***
LRENPK	−0.013192	−0.020514	−0.028008
LRGDPK	11.25163***	10.27055***	9.111988***
LRGDPK2	−0.526431***	−0.473241***	−0.415546***
LTRADPK	0.141856**	0.073805	0.026806

Notes: '***', '**', and '*' denotes statistical significance at the 1%, 5% and 10% levels respectively.

the effect of renewable energy consumption and trade volumes are however disparate across countries. The subsequent sub-sections discuss the country-specific results in details.

4.3.1. Estimation results for Canada

For Canada, a 1% increase in energy prices leads to 0.166% and 0.165% reduction in CO_2 emissions in both OLS and FMOLS specifications as well as 0.188% reduction in the DOLS specification. This is consistent with He and Richard (2010), where a negative relationship between oil and CO_2 emissions was uncovered for Canada – though with a lot lesser magnitude of 0.28% reduction for a 10% increase in emissions. However, while He and Richard (2010) adopted oil prices, this study adopts a weighted index of energy prices. Renewable energy consumption, on the other hand, has an insignificant effect on CO_2 emissions, consistent with Bilgili et al. (2016), where an insignificant relationship between renewables and CO_2 emissions was found for Canada via a DOLS estimation. This may have arisen due to Canada's renewed dependence on fossil fuels, which necessitated the drop out from the Kyoto protocol. Trade volume effect is insignificant for both the OLS and DOLS models but is statistically significant in the FMOLS model where a 1% increase in trade volume increases CO_2 emissions by 0.101%.

4.3.2. Estimation results for France

In France, a different scenario is observed as energy prices seem to have a relatively larger effect on CO_2 emissions compared to Canada. A 1% rise in energy prices leads to 0.261%, 0.307% and 0.311% reduction in CO_2 emissions with the OLS, FMOLS and DOLS specifications, respectively. This relationship is novel in the literature for the French regarding the inclusion of energy prices. The effect of renewable energy on CO_2 emissions has no statistical evidence for all 3 specifications — an outcome consistent with Bilgili et al. (2016). This implies that the taxation of fossil fuels in France is a more viable method of mitigating CO_2 emissions. Trade volume has a statistically significant positive relationship with CO_2 emissions as evinced from all specifications. Specifically, a 1% increase in trade leads to a reduction in CO_2 emissions by 0.650% for both OLS and FMOLS specifications and a reduction of 0.547% in the DOLS specification.

4.3.3. Estimation results for Germany

For Germany, renewable energy consumption has a negative relationship with CO_2 emissions in all 3 specifications but only significant in the DOLS specification. A 1% rise in renewable energy consumption leads to 1.715% reduction in CO_2 emissions based on the DOLS specification. Energy prices are significantly negative and near-identical relationship in both FMOLS and DOLS specifications, reducing CO_2 emissions by ~0.243% at a 1% rise in energy prices in both specifications. This gives credence to the viability of taxing fossil fuels as a means of mitigating CO_2 emissions in Germany. Trade volume has a significant positive impact on CO_2 emissions in both the FMOLS and DOLS specifications, increasing CO_2 emissions by 0.380% and 0.831% at 1% increase in trade volume for both the FMOLS and DOLS models respectively. The EKC hypothesis is validated in only the DOLS specification unlike the observed outcome in other countries validating the EKC hypothesis in all model specifications. A cautious interpretation is required in this situation because of the shorter time series (1991–2014) employed for the German case estimation, which may have influenced the sensitivity of coefficients using different estimation techniques. A significant negative relationship between energy prices and carbon emissions in Germany shows the importance of fossil fuel taxation in mitigating carbon emissions, constituting a new finding in the literature.

4.3.4. Estimation results for Italy

In the Italian model, there is a significant negative relationship between energy prices and CO_2 emissions in all 3 specifications. A 1% rise in energy prices lead to 0.272% reduction in CO_2 emissions for both OLS and DOLS specification and 0.284% reduction in CO_2 emissions for the FMOLS specification. Renewable energy consumption has a significant negative relationship with CO_2 emissions in all 3 specifications. A 1% increase in renewable energy consumption leads to 0.125%, 0.146% and 0.121% reduction in CO_2 emissions in the OLS, FMOLS and DOLS specifications respectively. This outcome is inconsistent with Bilgili et al. (2016), where an insignificant relationship was found between renewable energy consumption and CO_2 emissions. But consistent with Bento and Moutinho (2016) wherein a significant negative relationship was found between renewable electricity consumption and CO_2 emissions in Italy. This new finding shows that Italy is quite advanced in the deployment of alternative cleaner energy sources and shows a clearer and more definitive detail on the effectiveness of both renewable energy and increased energy prices in mitigating carbon emissions in Italy. Trade volume, however, has no significant relationship with CO_2 emissions in all specifications — an outcome that is inconsistent with

Bento and Moutinho (2016), in which a significantly positive relationship was established between international trade and CO_2 emissions.

4.3.5. Estimation results for the United Kingdom

The results for the United Kingdom are a bit similar to what has previously been obtained in Italy — as energy prices and renewable energy consumption both significantly decline CO_2 emissions. A 1% rise in energy prices causes 0.198%, 0.212% and 0.175% decline in CO_2 emissions for the OLS, FMOLS and DOLS specifications respectively. In addition, a 1% rise in renewable energy consumption leads to 0.140%, 0.203% and 0.149% reduction in CO_2 emissions for the OLS, FMOLS and DOLS specifications whereas the effect of trade volume, on the other hand, is negative in all the specifications but statistically insignificant. This shows that just like Italy, the UK's attitude towards deploying alternative energy sources seems quite uncompromising.

4.3.6. Estimation results for the United States

Going by its status as the world's biggest economy, the energy demand of the US would be enormous, which may lead to difficulties in sustaining lower CO_2 emissions. It can, however, be observed from the estimated coefficients that increasing energy prices are more effective in reducing CO_2 emissions than increasing renewable energy consumption. Particularly, a 1% increase in energy prices declines CO_2 emissions by 0.225%, 0.216% and 0.194% in the OLS, FMOLS and DOLS specifications respectively. The effect of renewable energy consumption is negative in all specifications but significant only for the OLS specification at 10% level. A 1% rise in renewable energy consumption leads to 0.082% reduction in CO_2 emissions as evinced from the OLS specification. Trade volume shows a significantly positive relationship with CO_2 emissions for both the OLS and FMOLS specifications. Thus, a 1% rise in trade volume leads to 0.313% and 0.224% reduction in CO_2 emissions in both the OLS and FMOLS specifications, contrary to a statistically insignificant positive coefficient with the DOLS specification.

4.3.7. Estimation results for Japan

The estimated results for Japan show that energy prices are more effective in reducing CO_2 emissions, evidenced in a significant negative coefficient of energy prices compared to an insignificant negative coefficient of renewable energy consumption in all 3 specifications. A 1% increase in energy prices leads to 0.211%, 0.212% and 0.227% decline in CO_2 emissions for the OLS, FMOLS and DOLS specifications. Trade has a significantly positive relationship with CO_2 emissions only in the OLS specification, reducing CO_2 emissions by 0.142% at 1% increase in trade volume. The effect of trade volume on CO_2 emissions is however positive but insignificant for FMOLS and DOLS models.

4.4. Panel granger causality test results

From the results of the long-run segment of the panel Granger causality tests outlined in Table 6, it can be observed that the long-run causality is validated for all the variables, with LRGDP and its quadratic counterpart having the fastest speed of adjustment. About 99% deviation of GDP from its equilibrium values are corrected yearly. Energy prices have the slowest speed of adjustment, a 20% deviation from its equilibrium values is corrected yearly, attributable to nominal price rigidities. Renewable energy consumption has a modest speed of adjustment compared to other adjustment speeds in the model, with 24% deviation from its equilibrium path adjusted yearly. This implies that renewable energy consumption and energy prices are the most exogenous variables in the model. The adjustment parameter for trade volume and CO_2 emissions are quite sizable — 62.20% and 57.20% respectively. From the results of the short-run causality, we observe a causality flowing from energy prices, GDP, quadratic GDP and trade to CO_2 emissions. Renewable energy consumption, however, has no short-run predictive content for CO_2 emissions. It can be observed that trade volume, renewable energy consumption and GDP has short-run predictive content for energy prices. However, CO_2 emissions have no short-run predictive content for energy prices, implying that energy prices are affected by economic shocks rather than environmental shocks. In summary, a unidirectional causality is observed flowing from energy prices to CO_2 emissions, from GDP and quadratic GDP to CO_2 emissions and from trade volume to CO_2 emissions. A unidirectional causality is similarly observed from GDP and quadratic GDP to energy prices and from renewable energy to energy prices with the implication that renewable energy consumption has no direct impact on CO_2 emissions through its direct effect on energy prices. Bidirectional causality is observed between energy prices and trade volume with the implication that energy price convergence across the G-7 countries is as a result of trade instigated economic integration within the region. Bidirectional causality is likewise found between trade volume and GDP which shows a strong interdependence between trade and output in the G-7 economies. GDP and its quadratic counterpart have a unidirectional causal flow towards renewable energy consumption, implying that economic growth exacts pressure on renewable energy consumption due to the environmental consequences of growth instigated high energy needs. This consequently leads to the need to seek out alternative cleaner energy sources.

4.5. Discussion of major findings

As reported in Section 4.3, while trade volumes spur CO_2 emissions, renewable energy consumption and energy prices tend to dampen it. This finding is consistent with Dogan and Seker (2016) who established that renewable energy mitigates environmental pollution in the EU but disagreed with the notion that trade increases emissions. Our finding on the negative effect of renewables and energy prices on CO_2 emissions is corroborated by Al-mulali and Ozturk (2016) while the insignificant effect of renewables on CO_2 emissions is line with Bilgili et al. (2016) who found a negative and insignificant impact of renewable energy on CO_2 emissions in Canada. The results further revealed that the effect of energy prices in reducing CO_2 emissions is stronger relative to renewable energy, which is relatively disparate across countries. This could be

Table 6
Panel Granger causality analysis (vector error-correction framework).

Endogenous variables	← Causal flow (Causing variables)						
	Short-run						Long-run
	ΔLCO2PK	ΔLCPIE	ΔLRGDPK	ΔLRGDPK2	ΔLRENPK	ΔLTRADPK	ECT_{t-1}
ΔLCO2PK	__	8.80**	6.48**	7.30**	4.40	5.13*	−0.572**
ΔLCPIE	4.46	__	5.01*	4.86*	6.16**	13.33***	−0.200**
ΔLRGDP	1.35	1.82	__	0.14	0.34	12.67***	−0.989***
ΔLRGDP2	1.33	1.23	0.39	__	0.52	13.22***	−0.992***
ΔLRENPK	1.80	0.68	5.41*	5.65*	__	0.8348	−0.246***
ΔLTRADPK	3.25	32.44***	44.74***	46.63***	4.35	__	−0.622***

Notes: ECT represents the coefficient of the error-correction term. Significance at the 1%, 5% and 10% levels are denoted by "***", "**" and "*" respectively. Numbers in the short-run cells indicate the χ^2 statistics for the Wald tests of the null H_0: $\sum_{k=1}^{p}\theta_{jik}= 0$. Numbers in the long-run cells indicate the estimated adjustment parameter λ_j under homogeneity assumption $\lambda = \lambda_i$. 2 lags were employed for the estimation based on the AIC and SBIC criterion.

occasioned by the different attitudes of country-specific stakeholders in harnessing and distributing renewable energy in the various countries. For instance, due to high energy demand and renewed fossil fuel dependence traceable to oil sands and shale oil boom in Canada and the US, phasing out fossil fuel energy sources may not be in the best economic interest of these countries. Therefore, the United States had to pull out of the Kyoto protocol in 2001 while Canada dropped out in December 2012. Out of the remaining countries which ratified the Kyoto protocol on climate change in the G-7, only Italy, the UK and Germany which apart from France constitutes the European bloc of the G-7, have renewable energy consumption evidently providing pollution abatement effects. However, the pollution abatement effect of energy prices is robust across all countries regardless of the estimation techniques. This further reveals that the attitude of different countries in the utilization of renewable energy is quite different depending on the political climate. In the US, renewable energy has been quite politicized because of the notion that renewable energy curtails economic growth. In contrast, the more liberal segment perceives the utilization of renewable energy as a way to protect the environment and foster sustainable economic growth regardless of the trade-off. Countries like the US and Canada are both oil-producing and both make up the North American bloc of the G-7. This shows a significant difference in perspective on the issue of climate change mitigation moving from the Europe to North America. The different perspectives appear both politically and economically motivated. The negative effect of renewable energy on CO_2 emissions in both Italy and the UK and to a lesser extent in Germany speaks volumes of the significant difference across countries in the climate change debate and the need to search for reasonable ways to bridge this gap.

The positive effect of trade on CO_2 emissions can be traced to the measurement of trade used in this study which is trade volume (export+import). Our finding is supported by Farhani and Ozturk (2015), Dogan and Turkekul (2016) and Ozatac et al. (2017). The validity of the EKC hypothesis is not entirely in line with extant literature. For example, Shahbaz et al. (2017a) confirmed evidence of the EKC hypothesis for six countries excluding Japan. In a recent study, Yilanci and Ozgur (2019) confirmed the validity of the EKC hypothesis for Japan and the US while no evidence of EKC was found in the remaining five countries of the G-7 bloc. Regarding the findings of the panel Granger causality test, renewable energy Granger-cause energy prices, while energy prices Granger-cause CO_2 emissions. By implication, the synergy between harnessing renewable energy sources and the imposition of fossil fuel taxes in order to forestall climate change and further environmental degradation exists in some members of the G-7 countries. Therefore, the result is not supported by the earlier empirical result outlined in Dogan and Seker (2016) who confirmed a bidirectional causality between renewable energy consumption and CO_2 emissions, and causality running from economic growth to CO_2 emissions. The inconsistency between existing studies can be traced to the inability to control for the effect of full heterogeneity in the estimation procedures. Our dataset was able to maintain its unique characteristics because of the unbalanced nature, hence, there was no need to symmetrically adjust the dataset into a more uniform quality, an act that would further constitute the loss of valuable data. The effect of full heterogeneity in the panel and time series data of our study was captured through the mean group and group mean methods of the panel, as well as, time series estimation.

5. Conclusion and policy implications

We employed a fully heterogeneous panel and country-specific estimation techniques in order to unravel the long-run equilibrium and the causal relationship among energy prices, renewable energy consumption, CO_2 emissions, trade volume. The study likewise tested the validity of the environmental Kuznets curve hypothesis in G-7 countries. The empirical results showed that renewable energy consumption and energy prices dampen the pressure on CO_2 emissions, but trade volumes positively exert pressure on CO_2 emissions. Based on the country-specific estimation results, a negative effect of energy prices on CO_2 emissions was found while the validity of the environmental Kuznets curve hypothesis was confirmed at both panel and country-specific levels. Conclusively, energy prices had a stronger effect on the reduction of CO_2 emissions compared to renewable energy consumption. While the pollution abatement effect of renewable energy consumption was observed for the whole panel, individual estimations showed that the effect of renewable energy consumption was quite disparate across the G-7 countries. The results based on a Panel Granger causality test showed a uni-directional causality running from energy prices, GDP, the quadratic term of GDP and trade to CO_2 emissions. The results further revealed no evidence to support the causal relationship between renewable energy consumption and CO_2 emissions, however, renewable energy consumption was found to indirectly affect CO_2 emissions through its direct effect on energy prices.

On policy directive, the synergy can be enhanced by formulating a tax program, wherein the tax on fossil fuels would be directly proportional to the availability of renewable energy sources, as renewable energy rises steadily, taxes on conventional energy sources increases until renewable energy becomes economically viable compared to fossil fuels. An application of this synergy in all countries would greatly reduce the pressure on the environment and significantly improve worldwide environmental sustainability in both short- and long- run. This is a clear pathway towards the attainment of the United Nations Sustainable Development Goals (SDGs). Considering the commitment of the EU countries within the G-7 to set-up active renewable energy policies such as the revised renewable energy directive 2018/2001/EU,[5] the commitments of the G-7 member countries could be harmonized towards attaining feasible and collective targets without undermining country-specific potentials. It can be observed that the policy implication of this study cannot follow a one-size-fit all approach due to the disparate distribution of inferences across the G7 countries regarding renewable energy consumption. Employing full heterogeneity, as well as, individual time series estimations has succinctly shown that things are not very rosy in the renewable energy department of the US and Canada. As the US happens to be the second-highest polluting economy after China, there is the need to de-politicize climate change and adopt renewable energy in the two North American countries. More effort should be put in place to educate the populace on the dangers of climate change. The strides taken by the EU countries should not be dampened by political rhetoric, as the consequence may constitute a significant danger for future generations.

Future studies should aim at country-specific causal relationships between renewable energy, energy prices and CO_2 emissions in order to ascertain the existence of synergy at the country level.

CRediT authorship contribution statement

George N. Ike: Data curation, Writing - original draft. **Ojonugwa Usman:** Conceptualization, Formal analysis, Investigation, Methodology, Supervision. **Andrew Adewale Alola:** Writing - original draft, Writing - review & editing. **Samuel Asumadu Sarkodie:** Writing - review & editing, Funding acquisition, Validation, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG&toc=OJ:L:2018:328:TOC.

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References

Al-Mulali, U., Ozturk, I., 2016. The investigation of environmental Kuznets curve hypothesis in the advanced economies: the role of energy prices. Renew. Sust. Energ. Rev. 54, 1622–1631.

Alola, A.A., Alola, U.V., 2018. Agricultural land usage and tourism impact on renewable energy consumption among Coastline Mediterranean Countries. Energy Environ. 29 (8), 1438–1454.

Alola, A.A., Alola, U.V., Saint Akadiri, S., 2019a. Renewable energy consumption in Coastline Mediterranean Countries: impact of environmental degradation and housing policy. Environ. Sci. Pollut. Res. 1–13.

Alola, A.A., Bekun, F.V., Sarkodie, S.A., 2019b. Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Sci. Total Environ. 685, 702–709.

Alola, A.A., Yalçiner, K., Alola, U.V., Saint Akadiri, S., 2019c. The role of renewable energy, immigration and real income in environmental sustainability target. Evidence from Europe largest states. Sci. Total Environ. 674, 307–315.

Balaguer, J., Cantavella, M., 2016. Estimating the environmental Kuznets curve for Spain by considering fuel oil prices (1874–2011). Ecol. Indic. 60, 853–859.

Bekun, F.V., Alola, A.A., Sarkodie, S.A., 2019. Toward a sustainable environment: Nexus between CO2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. Sci. Total Environ. 657, 1023–1029.

Bento, J.P.C., Moutinho, V., 2016. CO2 emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy. Renew. Sust. Energ. Rev. 55, 142–155.

Bilgili, F., Koçak, E., Bulut, Ü., 2016. The dynamic impact of renewable energy consumption on CO2 emissions: a revisited Environmental Kuznets Curve approach. Renew. Sust. Energ. Rev. 54, 838–845.

Cai, Y., Sam, C.Y., Chang, T., 2018. Nexus between clean energy consumption, economic growth and CO2 emissions. J. Clean. Prod. 182, 1001–1011.

Cetin, M.A., 2018. Investigating the environmental Kuznets Curve and the role of green energy: emerging and developed markets. Int. J. Green Energy 15 (1), 37–44.

Chang, M.C., 2015. Room for improvement in low carbon economies of G7 and BRICS countries based on the analysis of energy efficiency and environmental Kuznets curves. J. Clean. Prod. 99, 140–151.

Chiang, G., Wu, M.Y., 2017. The richer the greener: evidence from G7 countries. Int. J. Econ. Financ. 9 (10), 11–20.

Destek, M.A., Sarkodie, S.A., 2020. Are fluctuations in coal, oil and natural gas consumption permanent or transitory? Evidence from OECD countries. Heliyon 6 (2), e03391. https://doi.org/10.1016/j.heliyon.2020.e03391.

Dogan, E., Seker, F., 2016. The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. Renew. Sust. Energ. Rev. 60, 1074–1085.

Dogan, E., Turkekul, B., 2016. CO2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ. Sci. Pollut. Res. 23 (2), 1203–1213.

Elliott, G., Rothenberg, T., Stock, J., 1996. Efficient tests for an autoregressive unit root. Econometrica 64 (4), 813–836.

Farhani, S., Ozturk, I., 2015. Causal relationship between CO2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. Environ. Sci. Pollut. Res. 22 (20), 15663–15676.

Goldberg, P.K., Verboven, F., 2005. Market integration and convergence to the Law of One Price: evidence from the European car market. J. Int. Econ. 65 (1), 49–73.

Grossman, G.M., Krueger, A.B., 1991. Environmental impacts of a North American free trade agreement (No. w3914). National Bureau of Economic Research.

Grossman, G.M., Krueger, A.B., 1995. Economic growth and the environment. Q. J. Econ. 110 (2), 353–377.

He, J., Richard, P., 2010. Environmental Kuznets curve for CO2 in Canada. Ecol. Indic. 69 (5), 1083–1093.

International Energy Agency, IEA, 2019a. Key world energy statistics. https://www.iea.org/statistics/kwes/prices/.

International Energy Agency, IEA, 2019b. World Energy Prices. https://www.iea.org/statistics/prices/.

International Energy Agency, IEA, 2019c. Renewables 2018. https://www.iea.org/renewables2018/.

Ito, K., 2017. CO2 emissions, renewable and non-renewable energy consumption, and economic growth: evidence from panel data for developing countries. Int. Econ. 151, 1–6.

Johansen K., S.Juselius, 1990. Maximum likelihood estimation and inference on cointegration—with applications to the demand for money. Oxf. Bull. Econ. Stat. 52.2, 169–210.

Kao, C., Chiang, M.H., 2001. On the estimation and inference of a cointegrated regression in panel data. Nonstationary Panels, Panel Cointegration, and Dynamic Panels. Emerald Group Publishing Limited, pp. 179–222.

Kwaitkowski, D., Phillips, P.C., Schmidt, P., Shin, Y., 1992. Testing the null hypothesis of stationarity against the alternative of a unit root. J. Econ. 54 (1), 159–178.

Lau, L.S., Choong, C.K., Ng, C.F., Liew, F.M., Ching, S.L., 2019. Is nuclear energy clean? Revisit of Environmental Kuznets Curve hypothesis in OECD countries. Econ. Model. 77, 12–20.

Maddala, G.S., Kim, I.M., 1998. Unit Roots, Cointegration, and Structural Change (No. 4). Cambridge university press.

Nabaee, M., Shakouri, G.H., Tavakoli, O., 2015. Comparison of the relationship between CO 2, energy USE, and GDP in G7 and developing countries: Is there environmental Kuznets curve for those? Energy Sys. Manage. Springer, Cham, pp. 229–239

Ojonugwa, U., Alola, A.A., Sarkodie, S.A., 2020. Assessment of the role of renewable energy consumption and trade policy on environmental degradation using innovation accounting: evidence from the US. Renew. Energy 150, 266–277.

Ozatac, N., Gokmenoglu, K.K., Taspinar, N., 2017. Testing the EKC hypothesis by considering trade openness, urbanization, and financial development: the case of Turkey. Environ. Sci. Pollut. Res. 24 (20), 16690–16701.

Pedroni, P., 2001a. Fully modified OLS for heterogeneous cointegrated panels. Nonstationary Panels, Panel Cointegration, and Dynamic Panels. Emerald Group Publishing Limited, pp. 93–130.

Pedroni, P., 2001b. Purchasing power parity tests in cointegrated panels. Rev. Econ. Stat. 83 (4), 727–731.

Pesaran, M.H., Smith, R., 1995. Estimating long-run relationships from dynamic heterogeneous panels. J. Econ. 68 (1), 79–113.

Rafindadi, A.A., 2016. Revisiting the concept of environmental Kuznets curve in period of energy disaster and deteriorating income: empirical evidence from Japan. Energy Policy 94, 274–284.

Rafindadi, A.A., Usman, O., 2019. Globalization, energy use, and environmental degradation in South Africa: startling empirical evidence from the Maki-cointegration test. J. Environ. Manag. 244, 265–275.

Raza, S.A., Shah, N., 2018. Testing environmental Kuznets curve hypothesis in G7 countries: the role of renewable energy consumption and trade. Environ. Sci. Pollut. Res. 25 (27), 26965–26977.

REN21, 2019. Renewables Now. http://www.ren21.net/gsr-2019/pages/foreword/foreword/ Retrieved 18 July 2019.

Rogers, J.H., 2007. Monetary union, price level convergence, and inflation: how close is Europe to the USA? J. Monet. Econ. 54 (3), 785–796.

Sadorsky, P., 2009. Renewable energy consumption, CO2 emissions and oil prices in the G7 countries. Energy Econ. 31 (3), 456–462.

Saint Akadiri, S., Alola, A.A., Akadiri, A.C., Alola, U.V., 2019. Renewable energy consumption in EU-28 countries: policy toward pollution mitigation and economic sustainability. Energy Policy 132, 803–810.

Sebri, M., Ben-Salha, O., 2014. On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions and trade openness: fresh evidence from BRICS countries. Renew. Sust. Energ. Rev. 39, 14–23.

Shafiei, S., Salim, R.A., 2014. Non-renewable and renewable energy consumption and CO2 emissions in OECD countries: a comparative analysis. Energy Policy 66, 547–556.

Shahbaz, M., Shafiullah, M., Papavassiliou, V.G., Hammoudeh, S., 2017a. The CO2–growth nexus revisited: a nonparametric analysis for the G7 economies over nearly two centuries. Energy Econ. 65, 183–193.

Shahbaz, M., Solarin, S.A., Hammoudeh, S., Shahzad, S.J.H., 2017b. Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: the role of biomass energy consumption in the United States. Energy Econ. 68, 548–565.

Sosvilla-Rivero, S., Gil-Pareja, S., 2004. Price convergence in the European Union. Appl. Econ. Lett. 11 (1), 39–47.

Usman, O., Iorember, P.T., Olanipekun, I.O., 2019a. Revisiting the environmental Kuznets curve (EKC) hypothesis in India: the effects of energy consumption and democracy. Environ. Sci. Pollut. Res. 26 (13), 13390–13400.

Usman, O., Elsalih, O., Koshadh, O., 2019b. Environmental performance and tourism development in EU-28 countries: the role of institutional quality. Curr. Issue Tour. https://doi.org/10.1080/13683500.2019.1635092.

Yilanci, V., Ozgur, O., 2019. Testing the environmental Kuznets curve for G7 countries: evidence from a bootstrap panel causality test in rolling windows. Environ. Sci. Pollut. Res. 1–11.

Zoundi, Z., 2017. CO2 emissions, renewable energy and the Environmental Kuznets Curve, a panel cointegration approach. Renew. Sust. Energ. Rev. 72, 1067–1075.