Energy consumption, economic growth and CO_2 emissions: evidence from G7 countries

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Abstract

Purpose – The purpose of this paper is to find out the relationship between energy consumption, economic growth and CO_2 emissions for the G7 countries over the period 1971–2014. The second intent of the paper is to make a comparison whether it is renewable energy consumption, non-renewable energy consumption, or both that determine sustainable economic growth in G7 countries.

Design/methodology/approach – The authors testify the relationship among energy consumption, economic growth and CO_2 emissions using numerous econometric techniques. The authors have applied pooled mean group autoregressive distribution model (ARDL) for long-run and short-run relationships for individual countries. Finally, the authors have applied Granger causality testing based on Dumitrescu and Hurlin (2012) and Emirmahmutoglu and Kose's (2011) approach in order to check the causal relationship between energy consumption and economic growth, CO_2 emission and economic growth and vice versa.

Findings – However, energy usage is a greater concern due to the increase in imported energy prices. With this preposition, new thinking needs to be carried out for energy usage and sustainable economic growth. The authors consider cross-sectional reliance and cross-country heterogeneity for seven developed countries. The tests utilized in this investigation include the bootstrap causality approach of Dumitrescu and Hurlin (2012) and LA–VAR approach of Toda and Yamamoto (1995) that permits testing the causality for every individual panel individuals independently. However, not very many empirical works bring these two separate streams of writing together to analyze the causal connections between energy consumption, economic growth and CO_2 emission for G7 countries.

Originality/value – However, energy usage is a greater concern due to the increase in imported energy prices. Meanwhile, the exhaustive use of fossil fuels increases emission level which leads to climate change, global warming, reduction in agriculture productivity and danger to human life. With this preposition, new thinking needs to be carried out for energy usage and sustainable economic growth. There are limited number of studies addressing energy consumption, economic growth and CO_2 emission relationship. This study employs different methodology to find out the relationship among the variables.

Keywords Economic growth, ARDL, G7, Energy consumption, CO_2 emissions

Paper type Research paper

1. Introduction

Economic growth, energy consumption and increasing carbon emission are one of the most ongoing concerns in the world community. The growing concern of energy security and global warming has been researched intensively in many research works from the last two decades. It is a controversial topic with regard to the traditional neo-classical growth model, which treats land, labor and capital as major input sources for production (Ghali and El-Sakka, 2004; Soytas and Sari, 2006, 2007; Narayan and Smyth, 2009). Energy serves as a major element for economic growth in the era of liberalization, privatization and globalization, especially for developing countries (Cleveland *et al.*, 1984).

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The role of energy is important in generating income and employment, and thus economy heavily depends on it. The renewable sources of energy get attention due to a number of attributes. The rising level of carbon dioxide emissions (CO_2) and methane gas causes environmental degradation and global warming that are some factors which kindle interest in renewable sources of energy.

In the literature of energy consumption, economic growth and environment are getting attention from the past few decades. The Environmental Kuznets Theory (EKC) is the first theory which reveals a relationship between economic growth and environment. The theory postulates that with the increase in economic growth, the environmental degradation increases till it crosses the peak level (Ang, 2007; Banday *et al.*, 2014; Banday and Ismail, 2017; Saboori *et al.*, 2012). In the earlier stages of development of the country, the pollution level increases, but it starts decreasing as the level of income crosses the turning point of inverted Kuznets U-curve, as supported by Grossman and Krueger (1991). However, it is not important that with the increase in income, the CO_2 emissions level increases. It significantly depends upon the composition of the country and the use of natural resources like wind, solar, tide and wave, waste and biomass. Holtz-Eakin and Selden (1995) found non-increasing and non-decreasing curves, whereas Friedl and Getzner (2003) observed an N-shaped curve. Jaunky (2010) studied economic growth and CO_2 emissions relationship among 36 high-income countries over the period 1980–2005. He concluded that there is a unidirectional causality from gross domestic product (GDP) to CO_2 emissions in both short run and long run. However, Richmond and Kaufmann (2006) did not find any significant relationship between GDP growth and CO_2 emissions.

However, according the pioneering work of Kraft and Kraft (1978), higher economic growth can be achieved by the efficient use of energy consumption and efficient use of energy can be achieved by higher level of economic growth. Apergis and Payne (2011) determined the relationship between economic growth and renewable and non-renewable energy consumption for 80 countries within a dynamic panel framework which includes the variables like labor and gross capital formation over the period 1990–2007. They concluded that long-run elasticity for non-renewable energy consumption is higher than the other sources of energy, and it is both renewable and non-renewable energy consumption which matter to economic growth. They also found the long-run association between the variables, and causality shows the bidirectional results from renewable and non-renewable energy to economic growth for both the periods and validates the feedback hypothesis. Researchers like Stern (1993), Oztuk *et al.* (2010), Lee (2006) and Yuan *et al.* (2007) concluded that a relationship exists between energy consumption and economic growth. Aneja *et al.* (2017) and Oguz and Alper (2013) revealed that it is economic growth which leads to energy consumption. According to the results of Tugcu *et al.* (2012), Soytas and Sari (2007) and Menegaki (2011), no causality relationship exists between economic growth and energy consumption.

The G7 (Canada, France, Germany, Italy, Japan, UK, and USA) countries represent 50 percent of global GDP and 60 percent of global net wealth. The amount of carbon emissions has massively expanded over the previous years. The world CO_2 outflows increased from 19.35mn kilotons in 1980 to 35.84m kilotons in 2013, showing that it increased by around 84 percent along this period (WDI, 2017). G7 countries are the ones which account for 36.6 percent of total world energy production and 33.7 percent of the CO_2 emission over the period 2000–2008 (World Development Indicators, 2012). However, energy usage is a greater concern due to the increase in imported energy prices. Meanwhile, the exhaustive use of fossil fuels increases emission level which leads to climate change, global warming, reduction in agriculture productivity and danger to human life. With this preposition, new thinking needs to be carried out for energy usage and sustainable economic growth. We also intend to explore the aspect of sustainability of economic growth, rather than just economic growth in those economies. A large number of studies have used different variables like economic growth, total energy, non-renewable energy, renewable energy, CO_2 emission, industrial energy and nuclear energy but our study has used gross domestic product per capita, CO_2 emission, renewable energy and non-renewable energy. The reason for choosing G7 countries as a representative sample is because of divergent results. Apergis and Payne (2009a, b, c), Zhang and Cheng (2009) and Soytas *et al.* (2007) revealed increased energy consumption due to carbon emission in the considered countries. Chiu and Chang (2009), Sulaiman *et al.* (2013) and Shafiei and Salim (2014) revealed that renewable energy consumption is environmental friendly because it reduces carbon emission and non-renewable energy leads to environmental degradation. To investigate the impact of energy consumption, economic growth and environmental sustainability are important for policy implication. To accomplish the previously mentioned gaps in the literature, this study uses panel data analysis to find out the impact of CO_2 emissions on economic growth and energy consumption for G7 countries. This study uses panel unit root, pooled mean group (PMG) autoregressive distributed lag (ARDL) model and Dumitrescu and Hurlin (2012) and Emirmahmutoglu and Kose's (2011) approach for causality analysis. The aim of our study is to find out the long-run, short-run and causal relationship between energy consumption (i.e. renewable energy and non-renewable energy consumption) and economic growth, economic growth and CO_2 emissions and vice versa among G7 countries over the year 1971–2014. The second objective of the study is to make a comparison whether it is renewable energy, non-renewable energy consumption, or both that sustainable economic growth in G7 countries.

The paper is arranged as follows: in Section 2, brief reviews of the literature are provided, and Section 3 gives description of methodology, data and results. Finally, Section 4 provides a conclusion of the study.

2. Literature review

Natural resources are the major source of energy for economic growth. The exhaustive use of natural resources will increase the level of carbon dioxide (CO_2) emissions which depletes the environment. A large amount of theoretical work has been done on economic growth; most of them are based on Solow growth model. There are considerable number of studies that model the relationship between economic growth and environment, energy consumption and environment. Xepapadeas (2005) failed to consider the environment aspect of growth. He argued that it is a dire need for growth theories to consider environment impact and resource management variable which is important for growth theories.

Kolstad and Krautkraemer (1993) pointed out that energy resources are important for the economic growth, and negative impacts on the environment may be observed in the long run. Ricca (2007), in his study, found several transmission mechanisms through which environmental policy and growth may interact. This may be partly because some model considering pollution as an input to production and others as negative by products. In respect to policy effects, environmental policies are considered to have negative effects on growth. If environmental improvement results will be used as an increased factor of production, the growth will enhance (see Dudek *et al.*, 2003; Ricca, 2007).

Several studies have examined the relationship between economic growth and energy consumption. The reduction commitments of carbon dioxide by many countries across the globe have led to an increased focus on energy-related issues. It was Kraft and Kraft (1978) who lead a pioneering work to find out the relationship between energy consumption and economic growth, in which they found a unidirectional causality from economic growth to energy and no causality from energy to economic growth.

The economists got fascinated with the concept of Halicioglu (2009), who tried to explain the relationship between energy consumption and economic growth. Arouri *et al.* (2012)

studied 12 Middle East and North African countries over the time period 1981–2005. The results show a quadratic relationship with CO_2 emissions for the whole region.

Omri (2013) studied 14 MENA countries over the time period 1990–2011 to examine the relationship between CO_2 emissions, economic growth and energy consumption. The simulation equation model results conclude unidirectional causality from energy consumption to CO_2 emission and a bidirectional relationship between economic growth and CO_2 emission. The results find a bidirectional relationship between energy consumption and economic growth.

Sebri and Ben-Salha (2014) investigated the relationship among economic growth, renewable energy consumption and CO_2 emissions for BRICS countries over the period 1971–2010 by employing ARDL-bound testing approach and VECM model. The ARDL results find a long-run relationship between energy consumption, economic growth and carbon emission. VECM reveals bidirectional causality between economic growth and renewable energy consumption.

Halicioglu (2009) examined the relationship between energy consumption, income and CO_2 emission using time series data for Turkey over the period 1960–2005. The research uses bound testing approach and Granger causality testing. The results conclude a long-run relationship from energy consumption and foreign trade to carbon emission. The Granger causality reveals bidirectional causality between CO_2 emission and income in both short run and long run. There is an extensive literature which testifies the relationship between economic growth and carbon emissions followed by EKC (Shafik, 1994; Heil and Selden, 1999; Friedl and Getzner, 2003; Dinda and Coondoo, 2006; Coondoo and Dinda, 2008; Managi and Jena, 2008).

Bowden and Payne (2010) studied the sectorial relationship between renewable and non-renewable energy consumption and economic growth for USA over the period 1949–2006. They followed Toda–Yamamota causality procedure within the multivariate framework. The results do not support causality between renewable energy consumption and real GDP by taking industrial sector into consideration and support the neutrality hypothesis; the results show a unidirectional positive relationship between energy consumption and GDP, which indicates the possibility of the presence of growth hypothesis, whereas causality test shows bidirectional results from energy consumption to real GDP in commercial and residential sectors which supports feedback hypothesis, and a negative relationship between industrial non-renewable energy consumption to GDP, which gives evidence of growth hypothesis.

Apergis *et al.* (2010) employed panel error correction mechanism for the group of 19 developing and developed countries for the period 1984–2007. The results reveal that there is a long-run relationship among CO_2 emissions, energy consumption and economic growth. However, the short-run causality test supports the bidirectional causality between renewable energy consumption and economic growth, which validates the feedback hypothesis and in the long run, unidirectional causality running from nuclear renewable energy to economic growth supporting growth hypothesis. These findings exhibit that renewable energy consumption has a positive significant influence on economic growth, whereas negative with nuclear energy consumption.

Aslan and Ocal (2016) investigated the causality among economic growth, renewable energy consumption, capital and labor for new EU member countries for the period 1990–2009, by using asymmetric causality test approach and ARDL approach. The empirical results support that renewable energy consumption has a positive impact on economic growth for all countries. It also supports neutrality hypothesis for Cyprus, Estonia, Hungary, Poland and Slovenia, while the conservation hypothesis is present for Czech Republic. The fact is that there is a causal relationship from economic growth to renewable energy consumption and the growth hypothesis is supported for Bulgaria, referring to causality from energy consumption to economic growth (Table I).

Table I.
Summary of recent literature review on energy consumption, economic growth and CO_2 emissions

Study	Methodology/countries and period	Results
	Energy consumption, Economic growth and CO_2 Emissions	
Saboori *et al.* (2012)	EKC hypothesis, Malaysia (1980-2009)	Inverted-U shape curve both in long run and short run
Anis Omri (2013)	Simultaneous equations models, 14 MENA countries (1990–2011)	Unidirectional casuality from energy to CO_2 and bidirectional from GDP to CO_2
Apergis and Payne (2009a, b, c)	EKC hypothesis, panel VECM, 6 central American countries (1971–2004)	Unidirectional casuality from CO_2 to GDP and energy to CO_2
Halicioglu (2009)	ARDL bounds test, Johansen-Juselius, VECM, Turkey (1960–2005)	Unidirectional casuality from CO_2 to Income and CO_2 to Energy
Soytas and Sari (2007)	Granger causality test, Turkey (1960–2000)	Unidirectional casuality from CO_2 to energy
Sebri and Ben-Salha (2014)	ARDL-bound testing and VECM, BRICS (1971–2010)	Bidirectional casuality from GDP and energy
Ozturk and Acaravci (2010)	ARDL-bound test, VECM, Turkey (1968–2005)	Unidirectional casuality from CO_2 to GDP
Zhang and Cheng (2009)	Toda–Yamamoto procedure, China (1960–2007)	Unidirectional casuality from GDP to energy
	Economic growth and energy consumption	
Apergis and Payne (2010)	Granger causality and error correction model, 13 Eurasia countries (1992–2007)	Feedback hypothesis
Fuinhas and Marques (2012)	Autoregressive distributed lag (ARDL), Portugal, Italy, Greece, Spain and Turkey (1965-2009)	Feedback hypothesis
Aneja *et al.* (2017)	Pedroni co-integration and VECM, BRICS (1990–2012)	Unidirectional causality from economic growth to energy consumption
Apergis and Payne (2012)	Panel error correction model, 80 countries (1990–2007)	Feedback hypothesis in both short and long run
Eggoh *et al.* (2011)	Panel co-integration and panel causality tests, 21 African countries (1970–2006)	Feedback hypothesis
Kaplan *et al.* (2011)	Johansen and Juselius co-integration, Granger causality, Turkey (1971–2006)	Feedback hypothesis
Ocal and Aslan (2013)	ARDL approach and Toda–Yamamoto causality test, Turkey (1990–2010)	Conservation hypothesis
Apergis and Payne (2009a, b, c)	Panel co-integration and Granger causality, 11 Commonwealth of Independent States (1991–2005)	Growth and the feedback
Pao and Fu (2013)	Error correction model, Brazil (1980–2010)	Conservation hypothesis (EG and EC) Feedback hypothesis (EG and REC)

In the last couple of years, the increasing level of carbon emission in G7 countries becomes a cause of worry for future growth prospects. To get the momentum of economic growth, there is ample amount of scope for the policy makers to review the drivers of economic growth in G7 countries. It is evident from the above table that different researchers all over the world have studied different countries and some have clubbed different countries as a group and have employed different methodologies based on the qualities of data. The results of all the studies are different based on their sample size of the country and their methodologies. Some studies have developed a model based on the above studies like Apergis and Payne (2010), Tugcu *et al.* (2012) and Salim and Rafiq (2012). The study employs ARDL PMG model for long-run and short-run relationships and panel causality analysis to find out the cause-and-effects relationship between energy consumption (i.e. renewable energy consumption and non-renewable energy) and economic growth and economic growth and CO_2 emissions and vice versa by employing Dumitrescu and Hurlin (2012) and Emirmahmutoglu and Kose's (2011) approach over the time period 1971–2014.

3. Data, methodology and results

3.1 Data

The multivariate framework uses panel data for G7 countries (Canada, France, Germany, Italy, Japan, UK, and USA) for the period 1971–2014. The general framework includes GDP in constant 2010 US dollars, carbon dioxide emission (CO_2) metric tons/per capita, renewable energy (shows electricity generation from hydro, geothermal, solar, wind and tide/wave/ocean energy, as well as biofuels and renewable waste), renewable sources, electricity output (GWh) (IEA Headline Energy Data, 2016) and we have calculated non-renewable electricity consumption (total electricity consumption minus renewable electricity consumption) in billion kilowatt hours for each country. Electricity output (GWh) shows electricity generation from coal, peat, oil shale, oil and natural gas. Electricity output (GWh) shows the total number of GWh generated by power plants. Contrary to the Energy Statistics, electricity production for hydro pumped storage is excluded within the energy balances.

Pumped storage is excluded within the energy balances (IEA Headline Energy Data, 2016). Energy consumption is used as a proxy of electricity consumption. Data cover has been obtained from World Bank and energy data from US Energy Information Administration.

We try to explore the relationship among economic growth, energy consumption and CO_2 emission by using the method proposed by Ghali and El-Sakka (2004) and Soytas and Sari (2007) based on neo-classical production method where capital, CO_2 emissions, renewable energy and non-renewable are treated as inputs:

$$Y_t = a_0 + a_1\mathrm{RE} + a_2\mathrm{NRE} + a_3\mathrm{CO_2} + u_t, \quad (1)$$

where Y_t is the GDP per capita in constant 2010 US dollars, RE is the renewable electricity (shows electricity generation from hydro, geothermal, solar, wind and tide/wave/ocean energy, as well as from biofuels and renewable waste). Electricity output (GWh) data are taken from IEA Headline Global Energy Data (2016 edition). NRE is the non-renewable electricity consumption defined as Electricity output (GWh) shows electricity generation from coal, peat, oil shale, oil and natural gas. Electricity output (GWh) shows the total number of (GWh) generated by power plants. Contrary to the Energy Statistics, electricity production for hydro pumped storage is excluded within the energy balances. CO_2 is the carbon dioxide emission (Total CO_2 emissions – Fuel Combustion (Mt of CO_2)) that presents total CO_2 emissions from fuel combustion. This includes CO_2 emissions from fuel combustion reported in IPCC Source/Sink Category 1 A Fuel Combustion Activities and those which may be reallocated to IPCC Source/Sink Category 2 Industrial Processes and Product Use under the 2006 IPCC Guidelines from IEA Headline Global Energy Data (2016 edition).

3.2 Panel unit root test

In order to assess the integration and unit root among the variables for panel co-integration, numerous panel unit root tests have been performed. The panel unit root test is based on ADF proposed by Levin *et al.* (2002, hereafter LLC), who assumed homogeneity in the dynamic panel of auto regression in all panel units. Im *et al.* (2003) and the Fisher–ADF and PP test allow for individual unit root processes. The tests are all characterized by the combining of individual unit root tests to derive a panel-specific result and have the advantage of allowing much heterogeneity across all panel units. Levin *et al.* (2002), Breitung (2001) and Hadri (2000) tests suppose a common unit root process. However, both the tests are different on the basis of null hypothesis of unit root.

The panel unit root test is based on a heterogeneous model testing the significance of results based on N individual tests. For this model, IPS takes an average statistic. However, we can have an alternative model in which we can combine significant levels of the individual tests. This method is based on p-value which has a greater statistic power in terms of developing single conclusion. These tests are based on Fisher (1932), which was particularly used by Choi (2001) and Maddala and Wu (1999):

$$\Delta y_{i,t} = a_i + \rho_i y_{i,t-1} + \sum_{z=1}^{\rho_i} \left(\beta_{i,z} \Delta y_{i,t-z}\right) + \epsilon_{i,t}, \tag{2}$$

the above equation is based on IPS defined as H_0: $\rho_i = 0$ for all $i = 1, \ldots, N$ against the alternative hypothesis H_1: $\rho_i < 0$ for $i = 1, \ldots, N_1$ and $\rho_i = 0$ for $i = N_1 + 1, \ldots, N$, with $O < N_1 \leqslant N$. The alternative hypothesis does not have unit root test for all individuals' series. But, IPS is based on a separate unit root test of N cross-section units without pooling of data. The test takes averaged across groups which are based on augmented Dickey–Fuller test. The results of unit root test are given in Tables II and III.

To reduce the robustness in the series, we employed several unit root tests based on individual effects and combined effects. The results of unit root test based on intercept and trend conclude that some of the variables are I(0), such as renewable energy, non-renewable energy, CO_2 emission and GDP, in some countries and some are I(1) based on individual panel unit root test.

Table II. Panel unit root tests result (intercept and trend)

Variables	LLC	IPS	ADF – Fisher	PP – Fisher
GDP	0.49547 (0.6899)	1.78283 (0.9627)	8.96352 (0.8334)	4.84008 (0.9879)
ΔGDP	−11.1215 (0.0000)	−9.69814 (0.0000)	103.386 (0.0000)	112.174 (0.0000)
RENG	1.09712 (0.8637)	2.22924 (0.9871)	14.4834 (0.4144)	29.124 (0.0101)
ΔRENG	−8.06154 (0.0000)	−10.663 (0.0000)	115.533 (0.0000)	404.9 (0.0000)
CO_2	2.62394 (0.9957)	1.27368 (0.8986)	12.4717 (0.5685)	14.7506 (0.3954)
ΔCO_2	−8.6273 (0.0000)	−9.44405 (0.0000)	100.64 (0.0000)	171.603 (0.0000)
NRE	3.43307 (0.9997)	2.93722 (0.9983)	11.8894 (0.6152)	14.3780 (0.4219)
ΔNRE	−6.73969 (0.0000)	−8.20713 (0.0000)	88.4957 (0.0000)	211.512 (0.0000)

Notes: Exogenous variables: individual effects, individual linear trends (includes intercept and trend). User-specified lags: 1, Newey–West automatic bandwidth selection and Bartlett kernel

Table III. ADF Fisher individual unit root test (intercept and trend)

Country		GDP	RENG	CO2	NRE
Canada	Level	0.0473 (lag 0)[a]	0.0634 (lag 0)[a]	0.3295 (lag 0)	0.9490 (lag 0)
	First difference	–	–	0.0001 (lag 0)[b]	0.0000 (lag 0)[b]
France	Level	0.1934 (lag 0)	0.0123 (lag 0)[a]	0.7327 (lag 0)	0.7225 (lag 0)
	First difference	0.0000 (lag 0)[b]	–	0.0000 (lag 0)[b]	0.0001 (lag 0)[b]
Germany	Level	0.6137 (lag 0)	0.9860 (lag 0)	0.0223 (lag 0)[a]	0.0293 (lag 0)[a]
	First difference	0.0001 (lag 2)[b]	0.0001 (lag 0)[b]	–	–
İtaly	Level	0.9999 (lag 2)	0.9917 (lag 0)	0.9996 (lag 0)	0.9997 (lag 0)
	First difference	0.0000 (lag 1)[b]	–	0.0001 (lag 0)[b]	0.0000 (lag 0)[b]
Japan	Level	0.9381 (lag 0)	0.0074 (lag 0)[a]	0.3643 (lag 0)	0.0656 (lag 0)[a]
	First difference	0.0000 (lag 0)[b]	–	0.0002 (lag 0)[b]	–
UK	Level	0.2272 (lag 0)	0.9999 (lag 1)	0.5191 (lag 0)	0.9976 (lag 0)
	First difference	0.0000 (lag 0)	0.0000 (lag 0)	0.0000 (lag 0)	0.2220 (lag 1)
	Second difference	–	–	–	0.0000 (lag 2)
USA	Level	0.9567 (lag 1)	0.0945 (lag 0)[a]	0.7939 (lag 0)	0.8593 (lag 0)
	First difference	0.0000 (lag 0)	–	0.0001 (lag 0)	0.0000 (lag 0)

Notes: Automatic lag length selection based on AIC, panel results are calculated by ADF – Fisher χ^2 statistic. Probabilities for Fisher tests are computed using an asymptotic χ^2 distribution. All other tests assume normality

3.3 ARDL pooled mean group (PMG) model

ARDL model combines both dependent and independent variables as regressors. The panel individual effect in the regression model is difficult and bias, because of correlation between differenced mean regressors and error term. The biasness gets away for large number of observation T, not by increasing cross-sections, N. The dynamic panel of GMM estimators have been developed to address the small T and large N problem. Even GMM estimators are inappropriate in the large T data sets and estimators breakdown.

To overcome this problem, alternative PMG estimators of Pesaran *et al.* (1999) (PSS) is employed. The model takes simple form of ARDL and advanced panel settings include intercept, short-run coefficients and co-integration term. PSS model derives long-run coefficients, θ, and adjustment coefficients, $\emptyset_i$. It is been assumed that both dependent variables and regressor have same number of lags in each cross-sections. The PMG model is a more efficient model which provides more variability, less collinearity, more degree of freedom and more efficiency (Baltagi, 1995).

PMG ARDL model can be written as:

$$\Delta Y_{i,t} = \emptyset_i \mathrm{EC}_{i,t} + \sum_{j=0}^{q-1} + \Delta X_{i,t-j}{}' \beta_{i,j} + \sum_{j=1}^{\rho-1} \lambda_{i,j} \times \Delta Y_{i,t-j} + \epsilon_{i,t}, \quad (3)$$

$$\mathrm{lnGDP}_{it} = \alpha_i + \sum_{j=1}^{p} \lambda_{ij}\, \mathrm{lnCO2}_{it-j} + \sum_{j=0}^{q} \delta_{1ij}\, \mathrm{lnRENG}_{it-j} + \sum_{j=0}^{q} \delta_{2ij}\, \mathrm{lnNRE}_{it-j} + u_{it}. \quad (4)$$

The results of the unit root test showed that some variables are I(1) and some are I(0) at level. When variables have different order of integration, we have decided to apply PMG ARDL. The results of Equation (4) are given in Table IV.

Before moving to results, we have imposed maximum two lags for dependent variable and three lags for independent variables, and the model selection is based on Akaike information criterion (AIC) to select the maximum lags.

	Coefficient	*t*-statistic	Prob
Long run			
LNCO2	−0.0002	−2.03	0.043
LNRENG	0.1416	0.984	0.325
LNNRE	1.7898	7.317	0.000
Short run			
COINTEQ(01)	−0.0029	0.915	0.361
D(LNGDP(1))	0.1136	4.258	0
D(CO2)	0.0003	3.974	0.001
D(LNCO2(1))	0.0001	1.957	0.051
D(LNCO2(2))	5.0501	0.562	0.574
D(LRENG)	0.0355	1.696	0.091
D(LNRENG(1))	−0.0163	−1.377	0.169
D(LNRENG(2))	0.011	0.62	0.535
D(LNRE)	0.1145	2.525	0.012
D(LNRE(1))	0.0006	0.02	0.983
D(LNRE(2))	−0.0956	−1.753	0.08
C	0.0147	0.225	0.822

Note: Dependent variable (LNGDP)

Table IV. Results from pooled mean group ARDL model

Table IV gives the results of PMG ARDL. The results are based on t-value and corresponding p-values of the respective variables, CO_2 emission, renewable energy, non-renewable energy and dependent variables: economic growth (GDP). The results confirm that non-renewable energy and CO_2 emissions have a positive long-run relationship with economic growth in all the countries, but renewable energy does not have a significant impact on economic growth, that may be due to the availability, usage of natural resources and the size of country.

Table V shows the cross-sectional short-run coefficients of individual country. Based on estimation, economic growth, CO_2 emissions, renewable energy and non-renewable energy consumption have a positive short-run relationship in all the G7 countries (Canada, France, Germany, Italy, Japan, the UK and USA). To sum up all the findings, we find all the countries have a short-run relationship among CO_2 emission, renewable energy, non-renewable energy and economic growth (GDP). The policy measures should be that all the countries should use more renewable source of energy because of the growing concerns of CO_2 emission in those countries see Kolstad and Krautkraemer (1993).

3.4 Panel causality test

In this study, we consider two models of Granger causality testing based on Dumitrescu and Hurlin (2012) and Emirmahmutoglu and Kose's (2011) approach. Both the models are different from each other as according to their methodology. The Dumitrescu and Hurlin granger causality testing is based on non-causality test in heterogeneous panel data having fixed coefficients. The model is based on the relationship of one individual to another, whether there is a causal relationship from x to y for all series. The first one is based on non-homogenous causality testing (NHC) which means there is no causal effect from x to y. The second one is based on homogenous causality (HC) which means when N number of causality exists and when y is predicted on the past information of y and x, then y is alike to all individuals in the sample. Finally, we assume there is a causal relationship from x to y for all individuals. Another model is based on Emirmahmutoglu and Kose Granger causality based on LA–VAR approach of Toda and Yamamoto (1995) which has asymptotic χ^2 distribution by using meta-analysis. This approach considers both cross-sectional independency and cross-section dependency which is more powerful method even if N and T are small. The LA–VAR approach only needs maximum order of integration because this approach does not need pre testing (like unit root and co-integration tests).

The VAR model is based on k_i+$dmax_i$ lags in heterogeneous mixed panels:

$$x_{i,t} = \mu_i^X + \sum_{j=1}^{k_i + dmax_i} A_{11,ij} X_{i,t-j} + \sum_{j=1}^{k_i + dmax_i} A_{12,ij} Y_{i,t-j} + u_{i,t}^X,$$

$$y_{i,t} = \mu_i^y + \sum_{j=1}^{k_i + dmax_i} A_{21,ij} X_{i,t-j} + \sum_{j=1}^{k_i + dmax_i} A_{22,ij} Y_{i,t-j} + u_{i,t}^y,$$

in which we consider $dmax_i$ is maximal order of integration, for each i. We check the causality from x to y in Equation (11), and vice versa from y to x in Equation (10) (for similar bootstrap approaches, see Konya, 2006; Destek and Aslan, 2017; Ucar and Omay, 2009).

The panel causality results are based on two types of causality tests one is Dumitrescu and Hurlin (2012) and second one is Emirmahmutoglu and Kose's (2011) approach. The panel results are based on individual countries given in Tables VI–X. Table VI gives causality relationship between economic growth (GDP) and renewable energy (RENG).

Canada	Coefficient	*t*-statistic	Prob	France	Coefficient	*t*-statistic	Prob
COINTEQ(01)	−0.0056	−47.25	0.000	COINTEQ(01)	−0.0046	−757.07	0.000
D(LGDP(1))	0.0704	2.715	0.720	D(LGDP(1))	0.1746	7.34	0.000
D(CO2)	0.0006	13,653.57	0.000	D(CO2)	0.0004	10,274.22	0.000
D(LCO2(1))	0.0002	4,436.14	0.000	D(LCO2(1))	0.0003	8,329.71	0.000
D(LCO2(2))	−0.0003	−5,529.03	0.000	D(LCO2(2))	−2.0642	−537.27	0.000
D(LNRE)	0.0141	7.673	0.000	D(LNRE)	−0.0053	−12.17	0.000
D(LNRE(1))	0.0313	16.49	0.000	D(LNRE(1))	−0.0253	−63.08	0.000
D(LNRE(2))	0.0398	20.93	0.000	D(LNRE(2))	−0.0156	−36.12	0.000
D(LRENG)	0.1393	29.52	0.000	D(LRENG)	−0.0118	−47.65	0.000
D(LNRENG(1))	−0.022	−3.784	0.030	D(LNRENG(1))	−0.0146	−49.99	0.000
D(LNRENG(2))	0.1107	24.66	0.000	D(LNRENG(2))	−0.006	−23.33	0.000
C	0.0442	13.29	0.000	*C*	0.0519	94.29	0.000
Germany	Coefficient	*t*-statistic	Prob	Italy	Coefficient	*t*-statistic	Prob
COINTEQ(01)	−0.0037	−14.63	0.000	COINTEQ(01)	0.0266	302.45	0.000
D(LGDP(1))	0.2176	9.87	0.000	D(LGDP(1))	−0.0369	−1.21	0.310
D(CO2)	0.0001	9,196.14	0.000	D(CO2)	0.0005	6,916.1	0.000
D(LCO2(1))	−8.6124	−6,879.24	0.000	D(LCO2(1))	6.5432	694.38	0.000
D(LCO2(2))	5.7125	4,392.14	0.000	D(LCO2(2))	0.0001	2,178.97	0.000
D(LNRE)	0.2534	31.24	0.000	D(LNRE)	0.2135	46.38	0.000
D(LNRE(1))	0.0884	8.989	0.000	D(LNRE(1))	0.0678	10.759	0.000
D(LNRE(2))	−0.1588	−17.39	0.000	D(LNRE(2))	−0.0926	−17.149	0.000
D(LRENG)	−0.0029	−4.785	0.000	D(LRENG)	0.0475	62.599	0.000
D(LNRENG(1))	−0.0674	−104.88	0.000	D(LNRENG(1))	0.0249	33.88	0.000
D(LNRENG(2))	−0.0232	−33.71	0.000	D(LNRENG(2))	−0.0019	−3.024	0.05
C	0.0366	7.443	0.000	*C*	−0.1247	−12.75	0.000
Japan	Coefficient	*t*-statistic	Prob	UK	Coefficient	*t*-statistic	Prob
COINTEQ(01)	0.0486	121.76	0.000	COINTEQ(01)	0.0199	64.322	0.000
D(LGDP(1))	0.12	3.954	0.020	D(LGDP(1))	0.1625	8.1982	0.000
D(CO2)	0.0001	4,950.5	0.000	D(CO2)	0.0004	18,595.34	0.000
D(LCO2(1))	−1.7247	−620.3	0.000	D(LCO2(1))	0.0003	−12,729.49	0.000
D(LCO2(2))	−9.0432	−4,137.97	0.000	D(LCO2(2))	0.0004	16,155.88	0.000
D(LNRE)	0.1917	14.18	0.000	D(LNRE)	0.1725	29.71	0.000
D(LNRE(1))	0.032	2.184	0.110	D(LNRE(1))	−0.1458	−22.41	0.000
D(LNRE(2))	0.0939	8.463	0.000	D(LNRE(2))	−0.2888	−46.26	0.000
D(LRENG)	0.072	60.74	0.000	D(LRENG)	0.0133	33.99	0.000
D(LNRENG(1))	0.0172	10.05	0.000	D(LNRENG(1))	−0.0216	−94.63	0.000
D(LNRENG(2))	−0.0285	21.69	0.050	D(LNRENG(2))	−0.0216	−59.48	0.000
C	−0.1845	−5.93	0.000	*C*	−0.0682	−6.91	0.000
USA	Coefficient	*t*-statistic	Prob				
COINTEQ(01)	−0.1018	−43.76	0.000				
D(LGDP(1))	0.087	4.197	0.020				
D(CO2)	0.0001	251,656.8	0.000				
D(LCO2(1))	2.0534	40,021.99	0.000				
D(LCO2(2))	6.8463	161,441.7	0.000				
D(LNRE)	−0.0385	−3.802	0.030				
D(LNRE(1))	−0.0441	−4.839	0.010				
D(LNRE(2))	−0.2476	−32.26	0.000				
D(LRENG)	−0.0086	−26.43	0.000				
D(LNRENG(1))	−0.0148	−58.32	0.000				
D(LNRENG(2))	−0.0089	−39.32	0.000				
C	0.3476	−2.886	0.060				

Note: Authors' compilation

Table V.
Cross section short-run coefficient

The results find positive causality from economic growth to renewable energy for France, Germany and UK, supporting the acceptance of conservation hypothesis. For other countries like Canada, Italy, Japan and USA, the findings show the absence of causality from economic growth to renewable energy and the acceptance of neutrality hypothesis. We do

Country	Dimitrescu Hurlin GDP→RENG Wald stat.	*p*-value	RENG→GDP Wald stat.	*p*-value	Emirmahmutoglu and Kose GDP→RENG Wald stat.	*p*-value	RENG→GDP Wald stat.	*p*-value
Canada	2.2782	0.1312	0.1827	0.6691	0.931	0.335	0.082	0.775
France	4.6799	0.0305**	0.6566	0.4178	0.285	0.593	0.455	0.500
Germany	3.9421	0.0471**	0.2267	0.6340	2.598	0.107	2.224	0.136
İtaly	1.5494	0.2132	1.9529	0.1623	0.966	0.326	0.309	0.578
Japan	1.0183	0.3129	2.0246	0.1548	0.827	0.363	0.042	0.837
UK	11.1173	0.0009***	0.7399	0.3897	0.542	0.462	1.520	0.218
USA	0.5719	0.4495	0.3134	0.5756	0.049	0.824	0.798	0.372

Notes: Dimitrescu–Hurlin: GDP→RENG: Wbar statistic = 3.5939; Zbar statistic = 4.8527, p-value = 0.0000, Zbar tild statistic (standardized for fixed T-value) = 4.3393, p-value = 0.0000; Dimitrescu–Hurlin: RENG→GDP: Wbar statistic = 0.8709; Zbar statistic = −0.2414, p-value = 0.8092, Zbar tild statistic (standardized for fixed T-value) = −0.3102, p-value = 0.7564; Emirmahmutoglu and Kose: GDP→RENG: Fisher test value: 13.907, bootstrap critical values: 1 percent: 31.747; 5 percent: 25.463; 10 percent: 22.329 (the number of bootstrap replication: 10,000, lag criteria: AIC); Emirmahmutoglu and Kose: RENG→GDP: Fisher test value: 12.369, bootstrap critical values: 1 percent: 33.256; 5 percent: 26.067; 10 percent: 22.551 (the number of bootstrap replication: 10,000, lag criteria: AIC). **,***Significant at 5 and 1 percent levels, respectively

Table VI.
Results for causality analysis (economic growth and renewable energy)

Country	Dimitrescu Hurlin GDP→CO_2 Wald stat.	*p*-value	CO_2→GDP Wald stat.	*p*-value	Emirmahmutoglu and Kose GDP→CO_2 Wald stat.	*p*-value	CO_2→GDP Wald stat.	*p*-value
Canada	2.2782	0.1312	0.0072	0.9323	0.697	0.404	2.277	0.131
France	1.8799	0.1703	0.5225	0.4698	0.686	0.407	0.027	0.869
Germany	2.8939	0.0889*	0.7097	0.3995	0.925	0.336	0.844	0.358
İtaly	11.7196	0.0006***	0.7113	0.3990	3.217	0.073*	1.64	0.200
Japan	2.4668	0.1163	7.3947	0.0065**	0.023	0.879	0.027	0.869
UK	4.3267	0.0375**	2.7344	0.0982	1.783	0.410	1.56	0.458
USA	2.8708	0.0902*	0.7454	0.3879	0.003	0.953	0.623	0.430

Notes: Panel data model results: Dimitrescu–Hurlin: GDP→CO_2: Wbar statistic = 4.0623, Zbar statistic = 5.7290, p-value = 0.0000, Zbar tild statistic (standardized for fixed T value) = 5.1391, p-value = 0.0000; Dimitrescu–Hurlin: CO_2→GDP: Wbar statistic = 1.8322, Zbar statistic = 1.5568, p-value = 0.1195; Zbar tild statistic (standardized for fixed T-value) = 1.3311, p-value = 0.1832; Emirmahmutoglu and Kose: GDP→CO_2: Fisher test value: 13.164, bootstrap critical values: 1 percent: 35.369; 5 percent: 26.710; 10 percent: 22.935 (the number of bootstrap replication: 10,000, lag criteria: AIC); Emirmahmutoglu and Kose: CO_2→GDP: Fisher test value: 13.140, bootstrap critical values: 1 percent: 37.242; 5 percent: 27.734; 10 percent: 23.651 (the number of bootstrap replication: 10,000, lag criteria AIC). **,***Significant at 5 and 1 percent levels, respectively

Table VII.
Results for causality analysis (economic growth and CO_2)

not find causality from renewable energy to economic growth for all countries and the acceptance of neutrality hypothesis.

Table VII presents the causal relationship between economic growth and CO_2. The results accept the conservation hypothesis in Germany, Italy, UK and USA, and neutrality hypothesis for Canada, France, and Japan.

Table VIII exhibits the causal relationship between renewable energy (RENG) and CO_2. Results find causality from renewable energy to CO_2 for France, Italy, Japan and UK and bidirectional causality for Italy and UK and accepting Feedback hypothesis and neutrality hypothesis for Canada, Germany and USA.

Table IX shows the causality relationship between economic growth (GDP) and non-renewable energy (NRE). Results accept the conservation hypothesis for USA and growth hypothesis for Japan and UK. There is no causal relationship for Canada, France, Germany and Italy and accepts the neutrality hypothesis.

	Dimitrescu Hurlin				Emirmahmutoglu and Kose			
	RENG→CO_2		CO_2→RENG		RENG→CO_2		CO_2→RENG	
Country	Wald stat.	*p*-value	Wald stat.	*p*-value	Wald stat.	*p*-value	Wald stat.	*p*-value
Canada	0.3249	0.5687	0.5729	0.4491	0.098	0.754	0.020	0.887
France	3.2504	0.0714**	0.5578	0.4551	0.072	0.788	1.003	0.317
Germany	1.29	0.2561	2.6995	0.1004	0.538	0.463	1.088	0.297
İtaly	10.2503	0.0014***	3.5541	0.0594**	0.002	0.963	0.913	0.339
Japan	6.203	0.0128**	1.9891	0.1584	0.627	0.428	3.778	0.052
UK	11.1992	0.0008***	14.5267	0.0001***	5.359	0.021**	1.080	0.299
USA	0.3072	0.5794	0.8075	0.3689	0.005	0.943	0.004	0.952

Notes: Dimitrescu–Hurlin: RENG→CO_2: Wbar statistic = 4.6893, Zbar statistic = 6.9020, p-value = 0.0000, Zbar tild statistic (standardized for fixed T value) = 6.2098, p-value = 0.0000; Dimitrescu–Hurlin: CO_2→RENG: Wbar statistic = 3.5297, Zbar statistic = 4.7325, p-value = 0.0000, Zbar tild statistic (standardized for fixed T value) = 4.2297, p-value = 0.0000; Emirmahmutoglu and Kose; RENG→CO_2: Fisher test value: 12.232, bootstrap critical values: 1 percent: 32.065; 5 percent: 25.434; 10 percent: 22.338; Emirmahmutoglu and Kose: CO_2→RENG: Fisher test value: 15.561, bootstrap critical values: 1 percent: 31.396; 5 percent: 25.023; 10 percent: 22.007 (the number of bootstrap replication: 10,000, lag criteria: AIC). **,***Significant at 5 and 1 percent levels, respectively

Table VIII. Results for causality analysis from (renewable energy to CO_2)

	Dimitrescu Hurlin				Emirmahmutoglu and Kose			
	GDP→NRE		NRE→GDP		GDP→NRE		NRE→GDP	
Country	Wald stat.	*p*-value	Wald stat.	*p*-value	Wald stat.	*p*-value	Wald stat.	*p*-value
Canada	0.0052	0.9423	0.1359	0.7124	1.334	0.248	0.027	0.868
France	2.3875	0.1223	2.5823	0.1081	0.155	0.694	0.142	0.707
Germany	0.2655	0.6064	1.2060	0.2721	0.222	0.638	0.445	0.505
İtaly	0.3505	0.5538	0.0208	0.8852	1.457	0.227	0.063	0.802
Japan	1.5864	0.2078	3.7332	0.0533**	0.230	0.631	0.280	0.597
UK	1.3531	0.2447	6.1492	0.0131**	2.756	0.097**	0.003	0.954
USA	3.4132	0.0647**	0.8283	0.3628	0.173	0.677	1.302	0.254

Notes: Dimitrescu–Hurlin: GDP→NRE: Wbar statistic = 1.4388, Zbar statistic = −0.7424, p-value = 0.4578, Zbar tild statistic (standardized for fixed T value) = −0.7983, p-value = 0.4247; Dimitrescu–Hurlin: CO_2→RENG: Wbar statistic = 3.4379; Zbar statistic = 1.9022 p-value = 0.0571; Zbar tild statistic (standardized for fixed T value) = 1.5643, p-value = 0.1177; Emirmahmutoglu and Kose: GDP→NRE, Fisher test value: 13.748, bootstrap critical values: 1 percent: 33.510, 5 percent: 26.297; 10 percent: 22.719; Emirmahmutoglu and Kose: CO_2→RENG: Fisher test value: 6.656, bootstrap critical values: 1 percent: 35.388; 5 percent: 26.878; 10 percent: 23.229 (the number of bootstrap replication: 10,000, lag criteria: AIC). **Significance at 5 percent levels

Table IX. Results for causality analysis (economic growth and non-renewable energy)

Finally, Table X reveals the causality relationship between non-renewable energy (NRE) and CO_2. The results show there is no causal relationship between non-renewable energy consumption and CO_2 for Canada, France, Japan and USA, but we find causal relationship for Germany, UK and Italy. We also find causality from CO_2 to non-renewable energy for France, Italy and Japan.

The causal relationships between economic growth and renewable energy consumption, non-renewable energy consumption and CO_2 emissions have been studied by various researchers for many countries. Results reveal there is a positive relationship between economic growth and CO_2 emissions for Germany, Italy, UK and USA and no causal relationship for Canada, France and Japan. Causal relationship from renewable energy to CO_2 emission is significant for France, Italy, Japan and UK, whereas no causal relationship for Canada, Germany and USA. However, there is a positive causal relationship between non-renewable energy to economic growth for Japan and UK, whereas no causal effects in Canada, France, Germany, Italy and USA. Moreover, there is a significant causal

Country	Dimitrescu Hurlin NRE→CO_2 Wald stat.	*p*-value	CO_2→NRE Wald stat.	*p*-value	Emirmahmutoglu and Kose NRE→CO_2 Wald stat.	*p*-value	CO_2→NRE Wald stat.	*p*-value
Canada	0.3225	0.5701	0.6330	0.4262	0.654	0.419	0.007	0.932
France	2.5140	0.1128	5.9073	0.0151**	0.813	0.367	0.004	0.948
Germany	7.6014	0.0058***	0.0001	0.9909	0.407	0.523	0.893	0.345
İtaly	6.3308	0.0119**	7.9263	0.0049***	2.382	0.123	0.164	0.685
Japan	2.0079	0.1565	0.8961	0.3438	0.735	0.391	4.762	0.029**
UK	1.2243	0.2685	1.8755	0.1708	4.349	0.037**	1.493	0.222
USA	0.2202	0.6389	0.0581	0.8096	1.374	0.241	0.026	0.872

Notes: Dimitrescu–Hurlin: GDP→NRE: Wbar statistic = 1.4388, Zbar statistic = −0.7424, *p*-value = 0.4578, Zbar tild statistic (standardized for fixed *T* value) = −0.7983, *p*-value = 0.4247; Dimitrescu–Hurlin: CO_2→RENG, Wbar statistic = 3.4379; Zbar statistic = 1.9022, *p*-value = 0.0571; Zbar tild statistic (standardized for fixed *T* value) = 1.5643, *p*-value = 0.1177; Emirmahmutoglu and Kose: GDP→NRE, Fisher test value: 13.748, bootstrap critical values: 1 percent: 33.510, 5 percent: 26.297; 10 percent: 22.719; Emirmahmutoglu and Kose: CO_2→RENG: Fisher test value: 6.656, bootstrap critical values: 1 percent: 35.388; 5 percent: 26.878; 10 percent: 23.229 (the number of bootstrap replication: 10,000, lag criteria: AIC). **,***Significant at 5 and 1 percent levels, respectively

Table X.
Results for causality analysis (non-renewable energy and CO_2)

relationship from non-renewable energy to CO_2 emissions for Germany, Italy and UK and no causal relationship for Canada, France, Japan, and USA. The results are consistent with the findings of Bowden and Payne (2010) for USA, Soytas *et al.* (2007) for the USA, Zhang and Cheng (2009) for China, Aslan and Ocal (2016) for EU member countries, Tugcu *et al.* (2012) for G7 countries and Apergis and Payne (2009a, b, c) for 11 Commonwealth countries and Aneja *et al.* (2017) for BRICS countries. All the G7 countries have potential for renewable energy sources, which can be a stimulus to economic growth. It is the dire need for G7 countries to take lead with respect to the design and implementation of policies to move toward the greater use of renewable source of energy with less dependence on non-renewable sources of energy.

4. Conclusion

The paper aims to investigate the three-way relationship among economic growth, energy consumption (renewable energy and non-renewable energy) and CO_2 emissions by employing PMG ARDL for long-run and short-run relationship and Dumitrescu and Hurlin (2012) and Emirmahmutoglu and Kose (2011) for causal relationship in G7 countries over the period 1971–2014.

This investigation offers multiple contributions. The study employs a bootstrap panel causality to check the causal connection among energy consumption, economic growth and carbon emissions among G7 countries. Second, we consider cross-sectional reliance and cross-country heterogeneity for seven developed countries. Finally, the tests utilized in this investigation include the bootstrap causality approach of Dumitrescu and Hurlin (2012) based on non-causality approach and LA–VAR approach of Toda and Yamamoto (1995) that permits testing the causality for every individual panel individuals independently which can be more reliable source for policy implications (see Konya, 2006; Destek and Aslan, 2017). The investigation uses bootstrap panel causality test which permits cross section reliance and country-specific heterogeneity crosswise over developed countries. In the literature, there are heaps of papers that look at the linkage among energy consumption and economic growth, talking both form of energy and economic growth and CO_2 emissions. Then again, there are two fundamental econometric issues: cross-country heteroskedasticity and cross-sectional reliance, since any shock in one developed country is transmitted to other country.

The results of PMG ARDL approach find evidence of long-run relationship among energy consumption, economic growth and CO_2 emissions. However, cross-sectional short-run results find a positive short-run relationship among energy consumption, CO_2 emissions and economic growth in all the countries.

Results based on Dumitrescu and Hurlin and Toda Yamamato causality approach give divergent results for all the individual countries. Causality between non-renewable energy and economic growth was found significant for Japan and UK and accepts growth hypothesis, and no causal relationship for other countries. However, results are significant between non-renewable energy consumption and CO_2 emissions for Germany, Italy and UK, and no causality for other countries. Moreover, a unidirectional causal relationship was found between economic growth and CO_2 for Germany, Italy, UK and USA.

Based on results obtained, it looks non-renewable energy consumption has a positive and significant long-run relationship with economic growth, that may be due to the fact that the share of non-renewable source of energy in total energy consumption is greater in developed countries. Moreover, we should use more of renewable source of energy instead of non-renewable source of energy that would be better policy for developed countries like France, Italy and Germany.

Our study rejects neo-classical hypothesis that energy is neutral for growth. Our findings are similar to Tugcu *et al.* (2012), Apergis and Payne (2009a, b, c), Zhang and Cheng (2009) and Soytas *et al.* (2007) that energy is a positive and significant variable for economic growth and higher level of economic growth creates more demand for energy consumption. It is critical to consider their conceivable negative impacts on economic growth in setting up energy preservation strategies. We found mixed results for causality which are similar to earlier studies (Soytas and Sari, 2003, 2006; Zachariadis, 2007; Narayan *et al.*, 2007; Omay *et al.*, 2014; Narayan and Smyth, 2008; Lee and Chien, 2010) for energy consumption and economic growth for G7 countries.

However, our results have several policy implications for policy makers. Our outcomes infer that conceivable negative impacts of the energy transformation approaches are constrained to just short run and therefore, policy makers may execute environment friendly strategies under every financial condition without dread of hurting long-run development of the economy. It is important to apply some sort of pollution controlling measure such as tax credits on renewable energy production and renewable energy portfolio standards in all the countries regarding energy consumption (Apergis and Payne, 2011). It is found that unidirectional causality from economic growth to CO_2 emissions will cause a decline in environment quality in the form of negative externalities through human health. In the present era, all the countries are in the pace of development whether it is infrastructure, market size or investments all are dependent on the energy sector. Insufficiency in non-renewable source of energy like oil supply and electricity will hamper the pace in economic growth. So it is important to put efforts from both the sides for energy productive enhancement in the form of renewable energy sector (Hirschi, 2010) which will reduce pollutant level and structural development in those countries.

References

Aneja, R., Banday, U.J., Hasnat, T. and Koçoglu, M. (2017), "Renewable and non-renewable energy consumption and economic growth: empirical evidence from panel error correction model", *Jindal Journal of Business Research*, Vol. 6 No. 1, pp. 76-85.

Ang, J.B. (2007), "CO_2 emissions, energy consumption, and output in France", *Energy Policy*, Vol. 35, pp. 4772-4778.

Apergis, N. and Payne, J.E. (2009a), "CO_2 emissions, energy usage, and output in Central America", *Energy Policy*, Vol. 37 No. 8, pp. 3282-3286.

Apergis, N. and Payne, J.E. (2009b), "Energy consumption and economic growth in Central America: evidence from a panel cointegration and error correction model", *Energy Economics*, Vol. 31 No. 2, pp. 211-216.

Apergis, N. and Payne, J.E. (2009c), "Energy consumption and economic growth: evidence from the Commonwealth of independent states", *Energy Economics*, Vol. 31 No. 5, pp. 641-647.

Apergis, N. and Payne, J.E. (2010), "Renewable energy consumption and growth in Eurasia", *Energy Economics*, Vol. 32 No. 6, pp. 1392-1397.

Apergis, N. and Payne, J.E. (2011), "Renewable and non-renewable electricity consumption–growth nexus: evidence from emerging market economies", *Applied Energy*, Vol. 88 No. 12, pp. 5226-5230.

Apergis, N. and Payne, J.E. (2012), "Renewable and non-renewable energy consumption-growth nexus: evidence from a panel error correction model", *Energy Economics*, Vol. 34 No. 3, pp. 733-738.

Arouri, M.H., Ben Youssef, A., M'henni, H. and Rault, C. (2012), "Energy consumption, economic growth and CO_2 emissions in Middle East and North African countries", *Energy Policy*, Vol. 45, pp. 342-349.

Baltagi, B. (1995), *Econometric Analysis of Panel Data*, Wiley, New York, NY.

Banday, U.J. and Ismail, S. (2017), "Does tourism development lead positive or negative impact on economic growth and environment in BRICS countries? A panel data analysis", *Economics Bulletin*, Vol. 37 No. 1, pp. 553-567.

Banday, U.J., Assawa, A. and Kaushik, G. (2014), "Tourism and its impact on economic growth and environment", *Asian Economic Review*, Vol. 56 No. 3, pp. 147-162.

Bowden, N. and Payne, J.E. (2010), "Sectoral analysis of the causal relationship between renewable and non-renewable energy consumption and real output in the US", *Energy Sources, Part B: Economics, Planning, and Policy*, Vol. 5 No. 4, pp. 400-408.

Breitung, J. (2001), "The local power of some unit root tests for panel data", *Nonstationary Panels, Panel Co-integration, and Dynamic Panels*, Emerald Group Publishing Limited, pp. 161-177.

Chiu, C.L. and Chang, T.H. (2009), "What proportion of renewable energy supplies is needed to initially mitigate CO_2 emissions in OECD member countries?", *Renewable and Sustainable Energy Reviews*, Vol. 13 Nos 6/7, pp. 1669-1674.

Choi, I. (2001), "Unit root test for panel data", *Journal of International Money and Banking*, Vol. 20, pp. 249-272.

Cleveland, C.J., Costanza, R., Hall, C.A. and Kaufmann, R. (1984), "Energy and the US economy: a biophysical perspective", *International Library of Critical Writings in Economics*, Vol. 75, pp. 295-302.

Coondoo, D. and Dinda, S. (2008), "The carbon dioxide emission and income: a temporal analysis of cross-country distributional patterns", *Ecological Economics*, Vol. 65, pp. 375-385.

Destek, M.A. and Aslan, A. (2017), "Renewable and non-renewable energy consumption and economic growth in emerging economies: evidence from bootstrap panel causality", *Renewable Energy*, Vol. 111, pp. 757-763.

Dinda, S. and Coondoo, D. (2006), "Income and emission: a panel data-based cointegration analysis", *Ecological Economics*, Vol. 57, pp. 167-181.

Dudek, D., Golub, A. and Strukova, E. (2003), "Ancillary benefits of reducing greenhouse gas emissions in transitional economies", *World Development*, Vol. 31 No. 10, pp. 1759-1769.

Dumitrescu, E.I. and Hurlin, C. (2012), "Testing for Granger non-causality in heterogeneous panels", *Economic Modelling*, Vol. 29 No. 4, pp. 1450-1460.

Eggoh, J.C., Bangaké, C. and Rault, C. (2011), "Energy consumption and economic growth revisited in African countries", *Energy Policy*, Vol. 39 No. 11, pp. 7408-7421.

Emirmahmutoglu, F. and Kose, N. (2011), "Testing for Granger causality in heterogeneous mixed panels", *Economic Modelling*, Vol. 28 No. 3, pp. 870-876.

Fisher, R.A. (1932), *Statistical Methods for Research Workers*, Oliver and Boyd, Edinburgh.

Friedl, B. and Getzner, M. (2003), "Determinants of CO_2 emissions in a small open economy", *Ecological Economics*, Vol. 45, pp. 133-148.

Fuinhas, J.A. and Marques, A.C. (2012), "Energy consumption and economic growth nexus in Portugal, Italy, Greece, Spain and Turkey: an ARDL bounds test approach (1965–2009)", *Energy Economics*, Vol. 34 No. 2, pp. 511-517.

Ghali, K.H. and El-Sakka, M.I. (2004), "Energy use and output growth in Canada: a multivariate cointegration analysis", *Energy Economics*, Vol. 26, No. 2, pp. 225-238.

Grossman, G. and Krueger, A. (1991), "Environmental impacts of a North American free trade agreement", National Bureau of Economics Research Working Paper No. 3194, NBER, Cambridge, MA.

Hadri, K. (2000), "Testing for stationarity in heterogeneous panel data", *The Econometrics Journal*, Vol. 3 No. 2, pp. 148-161.

Halicioglu, F. (2009), "An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey", *Energy Policy*, Vol. 37 No. 3, pp. 1156-1164.

Heil, M.T. and Selden, T.M. (1999), "Panel stationarity with structural breaks: carbon emissions and GDP", *Applied Economic Letters*, Vol. 6, pp. 223-225.

Hirschi, C. (2010), "Strengthening regional cohesion: collaborative networks and sustainable development in Swiss rural areas", *Ecology and Society*, Vol. 15 No. 4.

Holtz-Eakin, D. and Selden, T.M. (1995), "Stoking the fires?: CO_2 emissions and economic growth", *Journal of Public Economics*, Vol. 57, pp. 85-101.

Im, K.S., Pesaran, M.H. and Shin, Y. (2003), "Testing for unit roots in heterogeneous panels", *Journal of Econometrics*, Vol. 115 No. 1, pp. 53-74.

Jaunky, V.C. (2010), "The CO_2 emissions–income nexus: evidence from rich countries", *Energy Policy*, Vol. 39, pp. 1228-1240.

Kaplan, M., Ozturk, I. and Kalyoncu, H. (2011), "Energy consumption and economic growth in Turkey: cointegration and causality analysis", *Romanian Journal of Economic Forecasting*, Vol. 2 No. 31, pp. 31-41.

Kolstad, C.D. and Krautkraemer, J.A. (1993), "Natural resource use and the environment", in Kneese, A. V. and Sweeney, J.L. (Eds), *Handbook of Natural Resource and Energy Economics*, Vol. 3, pp. 1219-1265.

Konya, L. (2006), "Exports and growth: Granger causality analysis on OECD countries with a panel data approach", *Economic Modeling*, Vol. 23, pp. 978-992.

Kraft, J. and Kraft, A. (1978), "On the relationship between energy and GNP", *Journal of Energy and Development*, Vol. 3, pp. 401-403.

Lee, C.C. (2006), "The causality relationship between energy consumption and GDP in G-11 countries revisited", *Energy Policy*, Vol. 34 No. 9, pp. 1086-1093.

Lee, C.C. and Chien, M.S. (2010), "Dynamic modelling of energy consumption, capital stock, and real income in G-7 countries", *Energy Economics*, Vol. 32 No. 3, pp. 564-581.

Levin, A., Lin, C.F. and Chu, C.S.J. (2002), "Unit root tests in panel data: asymptotic and finite-sample properties", *Journal of Econometrics*, Vol. 108 No. 1, pp. 1-24.

Maddala, G.S. and Wu, S. (1999), "A comparative study of unit root tests with panel data and a new simple test", *Oxford Bulletin of Economics and statistics*, Vol. 61 No. S1, pp. 631-652.

Managi, S. and Jena, P.R. (2008), "Environmental productivity and Kuznets curve in India", *Ecological Economics*, Vol. 65, pp. 432-440.

Menegaki, A.N. (2011), "Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis", *Energy Economics*, Vol. 33 No. 2, pp. 257-263.

Narayan, P.K. and Smyth, R. (2008), "Energy consumption and real GDP in G7 countries: new evidence from panel cointegration with structural breaks", *Energy Economics*, Vol. 30 No. 5, pp. 2331-2341.

Narayan, P.K. and Smyth, R. (2009), "Multivariate Granger causality between electricity consumption, exports and GDP: evidence from a panel of Middle Eastern countries", *Energy Policy*, Vol. 37 No. 1, pp. 229-236.

Narayan, P.K., Smyth, R. and Prasad, A. (2007), "Electricity consumption in G7 countries: a panel cointegration analysis of residential demand elasticities", *Energy Policy*, Vol. 35 No. 9, pp. 4485-4494.

Ocal, O. and Aslan, A. (2013), "Renewable energy consumption–economic growth nexus in Turkey", *Renewable and Sustainable Energy Reviews*, Vol. 28, pp. 494-499.

Oguz, O. and Alper, A. (2013), "Renewable energy consumption–economic growth nexus in Turkey", *Renewable and Sustainable Energy Reviews*, Vol. 28, December, pp. 494-499.

Omay, T., Hasanov, M. and Ucar, N. (2014), "Energy consumption and economic growth: evidence from nonlinear panel cointegration and causality tests", *Applied Econometrics*, Vol. 2 No. 34, pp. 36-55.

Omri, A. (2013), "CO_2 emissions, energy consumption and economic growth nexus in MENA countries: evidence from simultaneous equations models", *Energy Economics*, Vol. 40, pp. 657-664.

Ozturk, I. and Acaravci, A. (2010), "CO_2 emissions, energy consumption and economic growth in Turkey", *Renewable and Sustainable Energy Reviews*, Vol. 14, pp. 3220-3225.

Pao, H.T. and Fu, H.C. (2013), "Renewable energy, non-renewable energy and economic growth in Brazil", *Renewable and Sustainable Energy Reviews*, Vol. 25, pp. 381-392.

Pesaran, M.H., Shin, Y. and Smith, R.P. (1999), "Pooled mean group estimation of dynamic heterogeneous panels", *Journal of the American Statistical Association*, Vol. 94 No. 446, pp. 621-634.

Ricca, F. (2007), "Channels of transmission of environmental policy to economic growth: a survey of the theory", *Ecological Economics*, Vol. 60 No. 4, pp. 688-699.

Richmond, A.K. and Kaufmann, R.K. (2006), "Is there a turning point in the relationship between income and energy use and/or carbon emissions?", *Ecological Economics*, Vol. 56, pp. 176-189.

Saboori, B., Sulaiman, J. and Mohd, S. (2012), "Economic growth and CO_2 emissions in Malaysia: a cointegration analysis of the Environmental Kuznets Curve", *Energy Policy*, Vol. 51, pp. 184-191.

Salim, R.A. and Rafiq, S. (2012), "Why do some emerging economies proactively accelerate the adoption of renewable energy?", *Energy Economics*, Vol. 34 No. 4, pp. 1051-1057.

Sebri, M. and Ben-Salha, O. (2014), "On the causal dynamics between economic growth, renewable energy consumption, CO_2 emissions and trade openness: fresh evidence from BRICS countries", *Renewable and Sustainable Energy Reviews*, Vol. 39, pp. 14-23.

Shafiei, S. and Salim, R.A. (2014), "Non-renewable and renewable energy consumption and CO_2 emissions in OECD countries: a comparative analysis", *Energy Policy*, Vol. 66, pp. 547-556.

Shafik, N. (1994), "Economic development and environmental quality: an economic analysis", *Oxford Economic Papers*, Vol. 46, pp. 757-773.

Soytas, U. and Sari, R. (2003), "Energy consumption and GDP: causality relationship in G-7 countries and emerging markets", *Energy Economics*, Vol. 25 No. 1, pp. 33-37.

Soytas, U. and Sari, R. (2006), "Can China contribute more to the fight against global warming?", *Journal of Policy Modeling*, Vol. 28 No. 8, pp. 837-846.

Soytas, U. and Sari, R. (2007), "The relationship between energy and production: evidence from Turkish manufacturing industry", *Energy Economics*, Vol. 29 No. 6, pp. 1151-1165.

Soytas, U., Sari, R. and Ewing, B.T. (2007), "Energy consumption, income, and carbon emissions in the United States", *Ecological Economics*, Vol. 62 No. 3, pp. 482-489.

Stern, D.I. (1993), "Energy growth in the USA: a multivariate approach", *Energy Economics*, Vol. 15, pp. 137-150.

Sulaiman, J., Azman, A. and Saboori, B. (2013), "The potential of renewable energy: using the environmental Kuznets curve model", *American Journal of Environmental Sciences*, Vol. 9 No. 2, pp. 103-112.

Toda, H.Y. and Yamamoto, T. (1995), "Statistical inference in vector autoregressions with possibly integrated processes", *Journal of Econometrics*, Vol. 66, pp. 225-250.

Tugcu, C.T., Ozturk, I. and Aslan, A. (2012), "Renewable and non-renewable energy consumption and economic growth relationship revisited: evidence from G7 countries", *Energy Economics*, Vol. 34 No. 6, pp. 1942-1950.

Ucar, N. and Omay, T. (2009), "Testing for unit root in nonlinear heterogeneous panels", *Economics Letters*, Vol. 104, pp. 5-8.

Xepapadeas, A. (2005), "Economic growth and the environment", *Handbook of Environmental Economics*, Vol. 3, pp. 1219-1271.

Yuan, J., Zhao, C., Yu, S. and Hu, Z. (2007), "Electricity consumption and economic growth in China: cointegration and co-feature analysis", *Energy Economics*, Vol. 29, pp. 1179-1191.

Zachariadis, T. (2007), "Exploring the relationship between energy use and economic growth with bivariate models: new evidence from G-7 countries", *Energy Economics*, Vol. 29 No. 6, pp. 1233-1253.

Zhang, X.P. and Cheng, X.M. (2009), "Energy consumption, carbon emissions, and economic growth in China", *Ecological Economics*, Vol. 68 No. 10, pp. 2706-2712.

Further reading

Alper, A. and Oguz, O. (2016), "The role of renewable energy consumption in economic growth: evidence from asymmetric causality", *Renewable and Sustainable Energy Reviews*, Vol. 60, pp. 953-959.

Soytas, U. and Sari, R. (2009), "Energy consumption, economic growth, and carbon emissions: challenges faced by an EU candidate member", *Ecological Economics*, Vol. 68 No. 6, pp. 1667-1675.

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