International Journal of Energy Economics and Policy
Vol. 4, No. 4, 2014, pp.578-587
ISSN: 2146-4553
www.econjournals.com

Renewable Energy and Economic Growth: Evidence from the Sign of Panel Long-Run Causality

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ABSTRACT: Unlike previous renewable energy-growth studies, this study examines for the first time the relationship between renewable energy and economic growth for 80 countries under the Canning and Pedroni (2008) long-run causality test, which indicates that there is long-run positive causality running from renewable energy to real GDP for the total sample as well as across regions. The empirical findings provide strong evidence that the interdependence between renewable energy consumption and economic growth indicates that renewable energy is important for economic growth and likewise economic growth encourages the use of more renewable energy source. The presence of causality provides an avenue to continue the use of government policies that enhance the development of the renewable energy sector.

Keywords: Renewable energy; Economic growth; Sign test; Panel countries
JEL Classifications: C33; E23; Q20

1. Introduction

The expansion of energy-consuming activities in the developed and emerging countries, and waste in rich countries lead to two major concerns: the depletion of the most easily accessible energy resources (i.e., oil, gas, coal) and correspondingly, the problem of global warming caused by the rapidly increasing emissions of greenhouse gases such as carbon dioxide (CO2) and methane. This global nature of energy challenges requires that renewable energy resources be appropriately managed and used. Renewable energy is commonly defined as energy generated from solar, wind, geothermal, tide and wave, wood, waste and biomass. Contrarily to conventional energy, renewable energy is clean, safe and inexhaustible. Therefore, it is growing fast around the world and according to expectations it will edge out many conventional energy components and occupies a leading position in the overall share of energy consumption.

Insufficient supply of energy affects all aspects of development, more specifically social, economic, environmental, and even quality of life. Improvements in standard of living are manifested in increased agricultural output, increased industrial output, the provision of efficient transportation, adequate shelter, healthcare and other human services and these will holistically require increased in energy consumption. Therefore, energy is considered as an important requirement for economic growth and is potentially an inhibiting factor to economic and social development.

Nowadays, multiple challenges in relation to energy exist, but in particular three hot issues drive energy discussions. First, fossil fuels are a finite resource. Although there are still large supplies of coal, oil and natural gas, given the increasing demand and limited supply it is inevitable that one day supplies will run out. Thus, it is important to search for alternative energy sources. Second, is the issue of climate change? The prevailing threat of global warming and climate change has brought the attention on the relationship between economic growth, energy consumption and environmental pollution to a new level. Attempts have been made to reduce the share of emissions in the environment, while strong emphasis on this issue was placed in 1997, under the Kyoto Protocol agreement. It obliged industrialized countries to limit their greenhouse gas emissions, mainly CO2. Consequently many countries started to shift from dependence on fossil fuels towards the use of more renewable energy sources. The International Energy Agency (IEA, 2009) suggests that current trends in energy supply and use are still economically, environmentally and socially unsustainable. It is projected that the primary energy demand will increase by 1.5 % per year between 2015 and 2030, with fossil fuels being a dominant energy source. It is expected that because of increasing energy demand the energy-related CO2 emissions will more than double by 2050 whereas, the increased demand for oil will heighten the concerns over security of energy supplies. Many countries faced with energy security and environmental challenges are, therefore, forced to look for energy alternatives to fossil fuels. Consequently, many countries are making investments in these energy sources in order to reduce greenhouse emissions and increase the supply of secure energy. Nevertheless, the actual contributions of some renewables towards reduction of CO2 can be questioned. Certain renewables, such as hydropower, geothermal and biomass are reliable and easily predictable and thus there is no doubt about their contribution towards reduction of greenhouse emissions. It is generally believed that unless dramatic actions are taken to reduce global warming the world could face an environmental catastrophe (Apergis et al., 2010a).

The correlation between economic growth and renewable energy consumption has constituted a substantial field of research. Particularly, examining the significance of causality direction between the two variables is of high significance, since it may provide valuable insights for policy-makers. The causal relationship between energy consumption and economic growth has been extensively examined in the literature with varying results across countries.[1] The presence of unidirectional causality from energy consumption to economic growth (growth hypothesis) signals the economy is energy dependent in which case energy conservation policies may have an adverse impact on economic growth. By contrast, unidirectional causality from economic growth to energy consumption (conservation hypothesis) suggests that energy conservation policies may have little or no impact on economic growth. It is also possible there is bidirectional causality between energy consumption and economic growth (feedback hypothesis) reflecting the interdependence and possible complementarities associated with energy consumption and economic growth. Finally, the absence of causality between energy consumption and economic growth (neutrality hypothesis) implies that energy conservation policies will have an insignificant impact on economic growth. With the growing concerns over the environmental consequences of greenhouse gas emissions from fossil fuels, high and volatile energy prices, and the geopolitical climate surrounding fossil fuel production, renewable energy sources have emerged as an important component in the world energy consumption mix.

The available evidence between energy consumption and economic growth is inconclusive and the majorities of studies do not indicate the long-run effects of energy consumption on economic growth as a whole. The goal of this paper is to investigate the causality between renewable energy consumption and economic growth in the long run and to derive policy implications from the empirical results. To this end, we use a different approach to investigate the effect of renewable energy consumption on economic growth—namely, an test that identifies the long-run sign of causality developed by Canning and Pedroni (2008) for a panel of 80 countries across the globe. The world's rapidly rising renewable energy demand (approximately 8% per year) reflects both the environmental awareness of the public and the higher per capital renewable energy consumption rates, particularly in countries like the U.S., the European Union and China.

Given the emergence of renewable energy in the discussion of a sustainable energy future, it is important to understand the dynamics between renewable energy and economic growth, which this study attempts to address. Unlike previous studies, this study considers the use of renewable energy in order to differentiate the relative impact of each in the economic growth process. Second, to circumvent the potential problem of omitted variable bias, the study utilizes a production model framework by including measures of capital and labor. Third, it examines for the first time the sign and direction of long-run panel Granger causality between renewable energy and economic growth across a very large sample of countries, while, not in line with previous studies, it reports estimates across specific regional areas. Focusing on this argument, the literature that extensively models

[1] For a survey of the international evidence on the causal relationship between energy consumption and economic growth see Payne (2010) and Ozturk (2010).

causality relationships depends entirely on the theoretical explanations to figure out the possible direction of the sign of causality. This theoretical approach has not been tested in conjunction with the Granger causality framework. Our approach in this paper, however, achieves that by making use of the Canning and Pedroni (2008) methodological approach. The only study that makes use of this approach is by Narayan and Smyth (2009) who investigate the impact of electricity consumption on exports and economic growth.

The balance of paper is organized as follows. Section 2 provides an extensive review of the relevant literature on the link between renewable energy and economic growth. Section 3 discusses the data, methodology, and empirical results. Finally, Section 4 provides concluding remarks and policy implications from the empirical findings.

2. Literature Review

A number of studies have examined the relationship between renewable energy consumption measures and economic performance within a country-specific context. Sari and Soytas (2008) estimate an ARDL model with respect to disaggregated measures of U.S. renewable energy consumption and find that industrial production has a positive impact on renewable energy consumption. In a sectoral analysis of renewable energy consumption, Bowden and Payne (2010) show unidirectional causality from residential renewable energy consumption to real output while the absence of a causal relationship between commercial and industrial renewable energy consumption and real output, respectively. Payne (2010) finds unidirectional causality from biomass energy consumption to real output for the U.S. Yildirim et al. (2012) apply the Toda-Yamamoto procedure and bootstrap-corrected causality test on the US data. Biomass energy consumption, hydropower energy consumption and biomass-wood-derived energy consumption are used along with the total renewable energy consumption, while employment and gross capital formation are used as control variables. Empirical evidence reports a unidirectional causality running from biomass energy consumption to economic growth, while the neutrality hypothesis is supported between economic growth and all of the other renewable energy types as well as the total renewable energy consumption. Ocal and Aslan (2013) examine the causal relationship between renewable energy use and economic growth in Turkey. Using the ARDL approach and Toda-Yamamoto causality tests, the authors find that there exists a unidirectional causality running from economic growth to renewable energy consumption, supporting therefore the conservation hypothesis. Finally, in contrast to some recent studies that examine the relationship between energy consumption and economic growth in a panel framework, Lean and Smyth (2013) focus on a single country, that is Malaysia. They apply a disaggregated energy type of framework, while they use an augmented production function approach to examine the relationship between disaggregated energy consumption by fuel type and economic growth in Malaysia. Their main finding is that diesel and motor petrol are the major contributors to economic growth in the long-run. Their results suggest that the challenge moving forward for Malaysia will be to replace diesel and motor petrol with cleaner biodiesel alternatives, which will not adversely affect Malaysia's growth rate. Tuggu (2013) investigates the long- and the short-run relationships between disaggregate energy consumption (i.e., alternative and nuclear, fossil and renewable) and total factor productivity growth in the Turkish economy. His results highlight that disaggregates energy consumption is cointegrated to total factor productivity growth and there exists bi-directional causal relationships among the variables in consideration, while Leitao (2014) also investigates the correlation between economic growth, carbon dioxide emissions, renewable energy and globalization. His results document that there is a strong and positive link between renewable energy and economic growth.

In terms of causality, several studies find a bidirectional relationship between renewable energy consumption and economic growth (Apergis and Payne, 2010; Fang, 2011; among others). Esso (2010) examines the long-run causality relationship between energy and economic growth for 7 sub-Sahara countries and applies bounds testing approach to cointegration. His findings suggest unidirectional relationship between GDP and energy consumption across all countries. Fang (2011) finds that for China a 1% increase in renewable energy consumption increases real GDP by 0.12%. Tiwari (2011) reveals that while the growth rate of non-renewable energy consumption has a negative impact, the growth rate of renewable energy consumption has a positive impact on the growth rate of GDP. Apergis and Payne (2012) find a unidirectional causality from renewable electricity consumption to economic growth in the short run, but bidirectional causality in the long run in six Central American countries. Pao and Fu (2013) examine the causal relationship between economic growth and aggregated and disaggregated renewable energy consumption in the case of Brazil. They use annual data on GDP and four types of energy consumption, namely non-hydroelectric renewable energy consumption, total renewable energy consumption, non-renewable energy consumption and the total primary energy consumption. Mixed results are derived regarding the direction of causality between the variables. However, the authors insist on the role of renewable energy with its different components in promoting the Brazil's economic growth process. Based on a bivariate model, Bildirici (2013) focuses on biomass energy as a type of renewable energy in 10 Latin American developing countries. He finds that for the majority of countries in his country sample, there exists bidirectional causality between biomass energy and economic growth, while for the remaining countries only biomass energy Granger causes economic growth. Therefore, this type of energy may be considered as a solution for the developing countries to meet their needs without expensive conversion devices.

To exploit the additional power associated with panel cointegration techniques, a number of studies have undertaken a multi-country examination of the causal relationship between renewable energy consumption and economic growth. Sadorsky (2009) estimates a bivariate panel error correction model for 18 emerging market economies to show bidirectional causality between renewable energy consumption and economic growth. Apergis and Payne (2010) confirm the results from previous panel studies in finding bidirectional causality in both the short-run and long-run between renewable energy consumption and economic growth for a panel of six Central American countries. Menegaki (2011), by employing a random effect model to cointegration and a panel error correction model framework on a group of 27 European countries, does not confirm any Granger causality direction between renewable energy and economic growth. Her results provide support to the neutrality hypothesis, implying that the lower levels of renewable energy consumption across Europe cannot play a significant role in promoting economic growth.

3. Empirical Analysis

3.1 Data

Annual data from 1990 to 2012 were obtained from the *U.S. Energy Information Administration* and *World Bank Development Indicators*, CD-ROM. 80 countries are included included in the analysis[2]. Data on real GDP (Y) in billions of constant 2000 U.S. dollars, renewable energy consumption (RE) defined in million of kilowatt hours, stock of capital (K) that represents real gross fixed capital formation in billions of constant 2000 U.S. dollars, and labor (L) in total labor force in millions were used.

3.2 Methodology

This section presents the empirical model that investigates the long-run impact of renewable energy consumption on economic growth. The long-run equation yields:

$$Y_{it} = \alpha_i + a_{1i}\, RE_{it} + \varepsilon_{it} \qquad (1)$$

where $i = 1,\ldots,N$ for each country in the panel, $t = 1,\ldots,T$ refers to the time period, Y is real GDP and RE denotes renewable energy consumption The parameter α_i allows for the possibility of country-specific fixed effects. Equation (1) is estimated for 80 countries as well as for a number of different regions, namely European Union, Western Europe, Asia, Latin America, and Africa. The Canning and Pedroni (2008) methodological approach considers a dynamic error correction (EC) model but within a panel data framework. The EC model employed yields:

k k

[2] Algeria, Argentina, Australia, Austria, Bangladesh, Belgium, Bolivia, Brazil, Bulgaria, Canada, Cameron, Chile, China, Comoros, Costa Rica, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Ethiopia, Finland, France, Gabon, Germany, Ghana, Greece, Guatemala, Guinea, Honduras, Hungary, Iceland, India, Indonesia, Iran, Ireland, Italy, Japan, Jordan, Kenya, Korea, Luxembourg, Madagascar, Malawi, Malaysia, Mali, Mauritius, Mexico, Morocco, Mozambique, Netherlands, New Zealand, Nicaragua, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Romania, Senegal, South Africa, Spain, Sri Lanka, Sudan, Swaziland, Sweden, Switzerland, Syria, Thailand, Tunisia, Turkey, Uganda, United Kingdom, United States, Uruguay, Venezuela, Zambia.

$$\Delta Y_{it} = \beta_{1i} + \sum_{j=1}^{k} \beta_{11ij}\, \Delta Y_{i,t-j} + \sum_{j=1}^{k} \beta_{12ij}\, \Delta RE_{i,t-j} + \lambda_{1i}\, \varepsilon_{it-1} + \eta_{1it} \qquad (2)$$

$$\Delta RE_{it} = \beta_{2i} + \sum_{j=1}^{k} \beta_{21ij}\, \Delta Y_{i,t-j} + \sum_{j=1}^{k} \beta_{22ij}\, \Delta RE_{i,t-j} + \lambda_{2i}\, \varepsilon_{it-1} + \eta_{2it} \qquad (3)$$

$$\Delta K_{it} = \beta_{3i} + \sum_{j=1}^{k} \beta_{31ij}\, \Delta Y_{i,t-j} + \sum_{j=1}^{k} \beta_{32ij}\, \Delta RE_{i,t-j} + \lambda_{3i}\, \varepsilon_{it-1} + \eta_{3it} \qquad (4)$$

$$\Delta L_{it} = \beta_{4i} + \sum_{j=1}^{k} \beta_{41ij}\, \Delta Y_{i,t-j} + \sum_{j=1}^{k} \beta_{42ij}\, \Delta RE_{i,t-j} + \lambda_{4i}\, \varepsilon_{it-1} + \eta_{4it} \qquad (5)$$

3.3 Empirical results

In order to infer the degree of integration and stationarity properties of the respective variables to undertake panel cointegration tests, a battery of panel unit root tests are performed. The panel based ADF test proposed by Levin et al. (2002) assumes homogeneity in the dynamics of the autoregressive coefficients for all panel units. Alternatively, Maddala and Wu (1999) employ nonparametric methods in conducting panel unit root tests with the Fisher-ADF and Fisher-PP tests which has the advantage of allowing for as much heterogeneity across units as possible. Under the Levin et al. (2002), Fisher-ADF, and Fisher-PP tests the null hypothesis is a unit root and the alternative hypothesis is no unit root. In addition, our unit root testing analysis makes use of the Im et al. (2003) test (i.e. IPS test) that permits to solve Levin and Lin's serial correlation problem by assuming heterogeneity between units in a dynamic panel framework. The test shows that under the null hypothesis of non stationary, the statistic follows the standard normal distribution asymptotically. The panel unit root tests, shown in Table 1, reveal that each variable is integrated of order one. These results hold both on an overall sample basis and across regions. The panel unit root results recommend the potential presence of panel cointegration, which we perform next.

Table 1. Panel unit root tests

	Fisher-	Fisher-			Fisher-	Fisher-		
Variabes	LLC	ADF	PP	IPS	LLC	ADF	PP	IPS
Total					**European Union**			
Y	-0.58	24.56	25.32	-2.36	-0.46	21.64	22.29	-2.46
ΔY	-6.54*	91.23*	120.76*	-6.72*	-6.71*	87.35*	109.60*	-5.83*
RE	-0.59	22.34	24.56	-2.18	-0.52	25.60	21.64	-1.94
ΔRE	-8.44*	88.73*	89.65*	-7.11*	-7.81*	92.37*	97.55*	-6.82*
Western Europe					**Asia**			
Y	0.42	20.45	19.63	-1.52	-0.73	25.51	25.61	-2.59
ΔY	-5.94*	81.58*	92.47*	-5.72*	-5.82*	94.84*	119.75*	-7.31*
RE	-0.46	22.48	20.45	-2.36	-0.62	28.05	26.36	-2.67
ΔRE	-6.35*	83.72*	90.38*	-6.13*	-6.92*	96.25*	105.81*	-5.91*
Latin America					**Africa**			
Y	-0.65	22.16	20.17	-2.46	-0.38	21.83	23.46	-2.57
ΔY	-5.36*	90.45*	102.56*	-5.71*	-6.27*	98.45*	127.52*	-7.04*
RE	-0.42	21.39	22.65	-2.43	-0.31	21.10	21.64	-2.43
ΔRE	-6.24*	88.53*	89.17*	-8.93*	-6.48*	118.54*	157.19*	-6.61*

Notes: Panel unit root tests include intercept and trend. An '*' denotes the non-rejection of the null hypothesis on stationarity at 1%.

Before we proceed to panel cointegration tests, we must ensure first, the presence of heterogeneity and, second, the absence of cross-sectional dependence and relative to model (1). In terms of the first property, we follow the heterogeneity test suggested by Pesaran and Yamagata (2005) which recommends a two-step procedure. In particular, we first run a regression of renewable energy consumption, capital and labor force on real income. The residuals from this regression are then used in the second stage to estimate dynamics of the right-hand variables. Specifically:

$\varepsilon_{it} = \alpha_i + \lambda\varepsilon_{it-1} + \sigma_{i(\varepsilon)} v_{it}$

where within each country λ is assumed to be homogeneous across the different income levels. Our interest is to test the hypothesis that $\lambda = \lambda_i$ across all i in e. The test results provide the following results:

Total
Δ test = 56.72
Bias-corrected bootstrap p-value = [0.00]
European Union
Δ test = 45.28
Bias-corrected bootstrap p-value = [0.00]
Western Europe
Δ test = 49.06
Bias-corrected bootstrap p-value = [0.00]
Asia
Δ test = 58.51
Bias-corrected bootstrap p-value = [0.00]
Latin America
Δ test = 63.49
Bias-corrected bootstrap p-value = [0.00]
Africa
Δ test = 40.21
Bias-corrected bootstrap p-value = [0.00]

The Δ statistic and the associated bootstrapped p-value imply the strong rejection of the homogeneity hypothesis. In terms of the second property, we apply Pesaran's (2004) Cross Dependence (CD) test for balanced samples to test for cross sectional dependence. In particular:

$$CD = \sqrt{(2T/N(N-1)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \rho_{ij}$$

where, ρ_{ij} is the sample estimate of the pairwise correlation of the residuals:

$$\rho_{ij} = \rho_{ji} = \sum_{t=1}^{T} \varepsilon_{it}\varepsilon_{jt} / (\sum_{t=1}^{T} \varepsilon_{it}^2)^{1/2} (\sum_{t=1}^{T} \varepsilon_{jt}^2)^{1/2}$$

and ε are the residuals from the panel model (1). Pesaran shows that under the null hypothesis of no cross-sectional dependence, CD → N (0, 1) for N →∞ and T sufficiently large. The results show that:

Total-CD = 62.71 with p-value [0.00]
European Union-CD = 59.86 with p-value [0.00]
Western Europe-CD = 52.39 with p-value [0.00]
Asia-CD = 50.63 with p-value [0.00]
Latin America-CD = 61.48 with p-value [0.00]
Africa-CD = 55.69 with p-value [0.00]

As we can see, the CD test strongly rejects the null hypothesis of no cross-sectional dependence.

Next, the Pedroni (1999, 2001) heterogeneous panel cointegration test, which allows for cross-section interdependence with different individual effects, is estimated to determine whether a long-run equilibrium relationship exists. Following Pedroni (1999, 2001) two sets of panel cointegration tests are undertaken. The panel tests, based on the within dimension approach, includes four statistics: panel v, panel ρ, panel PP, and panel ADF-statistics that take into account common time factors and heterogeneity across countries and the group tests, based on the between dimension approach that include three statistics: group ρ, group PP, and group ADF-statistics. These statistics are based on averages of the individual autoregressive coefficients associated with the unit root tests of the residuals for each country in the panel. Table 2 reports both the panel and group mean panel cointegration test statistics. All seven test statistics reject the null hypothesis of no cointegration at the 1% significance level for both the total sample and across regions. The panel cointegration findings point out the presence of Granger causality as well. In pursuit of testing for causality we also plan to explore the direction and sign of causality, which is not known.

Table 2. Panel cointegration tests

Total			
Panel Test Statistics:		*Group Mean Panel Test Statistics:*	
Panel v-statistic	53.34562*	Group ρ-statistic	-55.69135*
Panel ρ-statistic	-52.47198*	Group PP-statistic	-54.82472*
Panel PP-statistic	-52.71430*	Group ADF-statistic	-8.97329*
Panel ADF-statistic	-8.17846*		
European Union			
Panel Test Statistics:		*Group Mean Panel Test Statistics:*	
Panel v-statistic	50.56347*	Group ρ-statistic	-50.13542*
Panel ρ-statistic	-48.71920*	Group PP-statistic	-50.47682*
Panel PP-statistic	-48.02557*	Group ADF-statistic	-7.32419*
Panel ADF-statistic	-7.86361*		
Western Europe			
Panel Test Statistics:		*Group Mean Panel Test Statistics:*	
Panel v-statistic	51.36772*	Group ρ-statistic	-50.35247*
Panel ρ-statistic	-51.98365*	Group PP-statistic	-50.47378*
Panel PP-statistic	-50.30762*	Group ADF-statistic	-6.29347*
Panel ADF-statistic	-6.46137*		
Asia			
Panel Test Statistics:		*Group Mean Panel Test Statistics:*	
Panel v-statistic	47.62351*	Group ρ-statistic	-46.35357*
Panel ρ-statistic	-46.47385*	Group PP-statistic	-46.24516*
Panel PP-statistic	-46.04652*	Group ADF-statistic	-6.39475*
Panel ADF-statistic	-6.16489*		
Latin America			
Panel Test Statistics:		*Group Mean Panel Test Statistics:*	
Panel v-statistic	45.64731*	Group ρ-statistic	-45.65376*
Panel ρ-statistic	-44.47879*	Group PP-statistic	-44.23209*
Panel PP-statistic	-44.30298*	Group ADF-statistic	-6.29136*
Panel ADF-statistic	-6.08446*		
Africa			
Panel Test Statistics:		*Group Mean Panel Test Statistics:*	
Panel v-statistic	43.22579*	Group ρ-statistic	-42.13675*
Panel ρ-statistic	-40.71384*	Group PP-statistic	-42.73652*
Panel PP-statistic	-40.14289*	Group ADF-statistic	-6.32279*
Panel ADF-statistic	-6.00846*		

Notes: All reported values are distributed N (0,1) under null of unit root or no co-integration. Panel stats are weighted by long-run variances. An '*' denotes the rejection of the null hypothesis of no cointegration at the 1 percent significance level.

To identify the direction and sign of causality, the panel causality test developed by Canning and Pedroni (2008) is employed. This particular test makes use of the corresponding to panel cointegration error correction model as it is presented from equations (2)-(5). The coefficients λ_1, λ_2, λ_3 and λ_4 show the speed of adjustment to equilibrium. In order to get the presence of the long-run relationship, Granger causality implies that at least one of the λ coefficients must be different from zero. According to the test of Canning and Pedroni, the null hypothesis is that there is no panel Granger causality. They report two tests in order to investigate the validity of the null hypothesis. First, they report the group mean (GM) test which yields:

$$\bar{\lambda}_1 = \sum_{i=1}^{N} \lambda_{1i} / N \qquad (6)$$

and the joint the panel test statistic (TT) which yields:

$$\bar{t}_{\lambda 1} = \sum_{i=1}^{N} t_{\lambda 1i} / N \qquad (7)$$

with N being the number of countries in the panel, and $t_{\lambda 1}$ is the individual country test for the null hypothesis that renewable energy consumption does not Granger cause GDP, i.e. $\lambda_{1i} = 0$. The test statistic has a standard normal distribution. The second test they develop is the Lambda-Pearson (LP) panel test, which yields:

$$p_{\lambda 1} = -2 \sum_{i=1}^{N} \ln p\lambda_{2i} \qquad (8)$$

where $\ln p\lambda_{2i}$ is the log of the p-value coming from the t-test statistic used to test the null hypothesis. This test combines p-values associated with each of the individual countries that make up the panel. The LP statistic follows a chi-square distribution with 2N degrees of freedom. For each country i if a causal connection $RE_{it} \rightarrow Y_{it}$ exists, then the sign of the long run impact is equal to *sign*($-\lambda_1/\lambda_2$). The estimates for λ_{1i} and λ_{2i} are normally distributed, so the ratio will be distributed Cauchy. Canning and Pedroni (2008) develop a bootstrap test based on the median of these ratios. The *sign* on $-\lambda_1/\lambda_2$ is expected to have the same sign as the long-run effect of renewable energy consumption on GDP. In other words, this particular coefficient is considered as a test of the impact of the long-run as well as a test of the sign of that long-run effect. Table 3 reports the long-run Granger causality tests. They document that the following findings:

- In terms of panel long-run causality running from renewable energy consumption to GDP, both GM and LP statistics recommend the rejection of the null hypothesis of no Granger causality at the 1% significance level both in the total sample and across regions.
- In terms of the sign effect based on the ratio of lambda coefficients reported in the last column of Table 3, the evidence reveals a positive sign across all regions in the sample.
- Finally, in terms of the panel long-run Granger causality running from GDP to renewable energy consumption, once again both tests document the rejection of the null hypothesis at the 1% significance level across all regions in the sample.

Table 3. Long-run panel Granger causality tests

Test	λ_1	GM	LP	λ_2	GM	LP	*sign*($-\lambda_1/\lambda_2$)
Total	-0.12	-3.2*	74.9*	0.16	-2.6*	82.6*	0.21(0.06)
European Union	-0.29	-4.7*	95.2*	0.24	-3.7*	118.9*	0.27(0.08)
Western Europe	-0.23	-4.3*	104.6*	0.20	-3.8*	116.8*	0.28(0.10)
Asia	0.18	-3.6*	90.8*	-0.19	-3.2*	95.9*	0.24(0.05)
Latin America	-0.16	-3.2*	78.1*	0.15	-2.9*	84.6*	0.36(0.09)
Africa	0.14	-2.6*	72.5*	-0.16	-2.4*	78.3*	0.16(0.03)

Notes: λ_1 = re causes y, λ_2 y causes re. Figures in parentheses denote standard errors.
An '*' denotes statistical significance at 1% level.

4. Conclusions

Renewable energy consumption has emerged as an energy source that may alleviate the growing concerns over greenhouse gas emission, high and volatile energy prices, and the dependency on foreign energy sources, not to mention the geopolitical climate associated with fossil fuel production in some parts of the world. Unlike previous studies this study makes uses of a new test to consider the sign of long-run panel causality. To this end, first, it employed a production type of model that considered not only GDP and renewable energy consumption but also measures of capital and labor within a multivariate panel error correction model for 80 countries over the period 1990 to 2012 and second, a new panel Granger causality test that allows the determination not only of the presence of long-run causality, but also the sign on the direction of causation.

The evidence for the total sample as well as across regions, i.e. European Union, Western Europe, Asia, Latin America and Africa, revealed that renewable energy consumption Granger causes positively GDP in the long-run across all regions considered. At the same time, the results documented that GDP Granger causes renewable energy consumption in the long-run and across the same regions.

The interdependence between renewable energy consumption and economic growth suggests that this type of energy source is important for economic growth and likewise economic growth encourages the use of more renewable energy source. The presence of causality provides an avenue to continue the use of government policies that enhance the development of the renewable energy sector. In addition, as pointed out by Kaygusuz (2007), the expansion of the renewable energy sector may serve as the impetus for the modernization of the energy sector in meeting sustainability objectives specified by policy makers. In order to facilitate the expansion of the renewable energy sector, economic growth is vital in generating the resources needed for research and development of renewable energy technologies and corresponding infrastructure. At the same time, policy makers must introduce the appropriate incentive mechanisms for the development and market accessibility of renewable energy. The establishment of partnerships between the public and private sector would also facilitate the technology transfer process of bringing renewable energy projects to market.

A shortcoming of the paper, which the authors plan to investigate it further in a future venue of research, is associated with the omitted variable bias. Many studies of this type include more variables that significantly contribute towards economic growth, i.e. non-renewable energy, foreign trade, foreign direct investments, financial development levels, in order to account for the omitted variable bias.

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