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Md Mahmudul Alam, Md Wahid Murad

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The Impact of Economic Growth, Trade Openness and Technological Progress on Renewable Energy Use in Organization for Economic Co-Operation and Development Countries

Md. Mahmudul Alam *

School of Economics, Finance & Banking
Universiti Utara Malaysia
Kedah, Malaysia
Email: rony000@gmail.com
Tel: +601 824 67050

Md. Wahid Murad

University of South Australia
Adelaide, Australia
E-mail: wahid.murad@unisa.edu.au
Tel: +61 8 8302 0384

* Corresponding author

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ABSTRACT

This study investigates the short-term and long-term impacts of economic growth, trade openness and technological progress on renewable energy use in Organization for Economic Co-operation and Development (OECD) countries. Based on a panel data set of 25 OECD countries for 43 years, we used the autoregressive distributed lag (ARDL) approach and the related intermediate estimators, including pooled mean group (PMG), mean group (MG) and dynamic fixed effect (DFE) to achieve the objective. The estimated ARDL model has also been checked for robustness using the two substitute single equation estimators, these being the dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS). Empirical results reveal that economic growth, trade openness and technological progress significantly influence renewable energy use over the long-term in OECD countries. While the long-term nature of dynamics of the variables is found to be similar across 25 OECD countries, their short-term dynamics are found to be mixed in nature. This is attributed to varying levels of trade openness and technological progress in OECD countries. Since this is a pioneer study that investigates the issue, the findings are completely new and they make a significant contribution to renewable energy literature as well as relevant policy development.

Key words: Renewable Energy; Economic Growth; Trade Openness; Technological Progress; OECD Countries.

Highlights:

- Economic growth, trade openness and technological growth drive renewable energy use.
- Long-term dynamics of the variables are found homogenous across the OECD countries.
- Short-term dynamics vary as to variation in technological growth and trade openness.
- An understanding of variable dynamics is vital for increasing renewable energy use.

INTRODUCTION

In modern era the dynamics of renewable energy (RE) use comprises many terms which includes economic growth (EG), technological progress (TP) and trade openness (TO) of a country which have become issues of much debate in recent years. The relationships between usage of energy and economic growth as well as between energy use and trade openness have been a keen area of research over the years; however, the relationship to renewable energy use has had scarce research. Even though at present, a number of studies employing time series data have examined the effect of technological progress on the utilization of renewable energy, they have only examined their causal and bidirectional linkage.

Many studies investigated the nexus between economic growth and energy use from various countries' context such as Asafu-Adjaye, 2000; Mehrara, 2007; Lee and Chang, 2008; Ozturk, 2010; Alberini and Filippini, 2011; Jamil and Ahmad, 2011; Uddin, Alam and Murad, 2011; Islam et al., 2013; Alam et al. 2014; Yildirim and Ozturk, 2014. However, in the context of the economic growth and renewable energy use nexus, the studies are not so common. However, diverse associations between RE consumption and EG can be found in the different literature. For instance, a positive relationship [Lee, et al. (2014)], the lack of

any link [Lee, et al. (2009)], as well as, a bidirectional relationship between renewable energy consumption, nonrenewable energy consumption and economic growth [Payne, et al. (2012)], are examples of these relationships. Koçak and Şarkgüneşi (2017) investigated the relationship between renewable energy consumption and economic growth within the framework of traditional production function for the period of 1990–2012 in nine Black Sea and Balkan countries. They concluded that there is a long term balance relationship between renewable energy consumption and economic growth and that renewable energy consumption has a positive impact on economic growth. Their study concluded that there is a significant impact of renewable energy consumption on economic growth in Balkan and Black Sea Countries. However, a study from Afonso, et al. (2017) revealed that the relationships between energy and economic growth for 28 set of countries. This study suggests that though renewable energy has not contributed to economic growth, but non-renewable energy has contributed to their respective country's economic growth. Furthermore, a study from Shah, Hiles and Morley in 2018, suggests that countries where there is little support for the renewable energy sector, investment will be more dependent on macroeconomic aspects. Another study by Menyah and Wolde-Rufael (2010) investigated the causal relationship between renewable energy consumption and real GDP for the US for the period 1960–2007. The study found a unidirectional causality running from GDP to renewable energy consumption. Their findings are consistent with Sadorsky (2009) who found real income to be an important driver of renewable energy consumption in G-7 countries. In contrast, the results obtained by Menyah and Wolde-Rufael (2010) are opposed to Apergis and Payne (2010) who conducted the heterogeneous panel cointegration test revealing a long-run equilibrium relationship between real GDP and renewable energy consumption as well as a bi-directional causality between renewable energy consumption and economic growth in a panel of Organisation for Economic Co-operation and Development (OECD) countries in both the short -and long-run. On the other hand a study from Brini, Amara, & Jemmali (2017) examines the both the long-run as well as the short-run dynamic relationship and causality between renewable energy consumption and economic growth in Tunisia for the year 1980 to 2011. This study found that there exist a negative impact of renewable energy consumption on the economic growth. Moreover, they also found that there is a unidirectional long-run causality which is running from renewable energy consumption to economic growth

Also, using a panel error correction model, Apergis, et al. (2010) examined the causal relationship between renewable energy consumption and economic growth for a group of 19 developed and developing countries for the period 1984–2007. They found a bidirectional causality between renewable energy consumption and economic growth. The presence of bidirectional causality between renewable energy and economic growth, as they argued, lends support for the feedback hypothesis whereby renewable energy consumption and economic growth are interdependent. This interdependency suggests that energy policies aimed at increasing the production and the consumption of renewable energy will have a positive impact on economic growth. They also argued that the positive influence of the use of renewable energy on economic growth further enhances the viability of the renewable energy sector which provides additional support for the assertion that renewable energy can serve as an important energy source for these countries.

Al-Mulali, Ozturk, and Lean (2015) utilizing the panel data technique on 23 countries in Europe from the year 1990 to 2013, discovered that the growth of the GDP as the main factor shows a prominent positive causal impact on renewable energy production. Moreover, Sohag et al. (2015) used the autoregressive distributed lag (ARDL) bounds testing method over a period of 1985 to 2012 and discovered that fast economic growth and trade openness

are prominent determinants of energy usage increment over the study period in Malaysia. It was also discovered that innovations in technology assisted in reducing the usage of energy by improving energy efficiency in the processes of production, which in turn reduced gas emissions. The study by Sbia, Shahbaz, and Hamdi (2014) utilized the he ARDL bounds testing approach, vector error correction model and Granger causality testing to examine the contribution of FDI, trade openness, clean energy, carbon emission, and growth of the economy to the demand for energy in UAE. The findings showed that trade openness lowered the consumption of energy because of the utilization of energy efficient technologies and that trade openness was complementary to economic growth given their bidirectional causal association. FDI, trade openness, and carbon emissions were found to reduce demand for energy while economic growth and clean energy affected consumption of energy in a positive manner.

Several studies came up with conclusion that trade openness by nations influences domestic energy use in a range of ways. A study from Semancikove (2016) revealed that, trade openness is also beneficial for the sustainable development of an economy. The two major reasons are efficient utilization of resources and improvement in the economies of scale. Moreover, trade plays a vital role in terms of technology transfer for renewable energy (Khan et al., 2017). Shahbaz et al. (2014) and Wan, Baylis and Mulder (2015) argued that with economic growth, domestic energy use is influenced by trade openness through several channels including economies of scale, technological effects, and those production factors which are affected by composite effects. Also, Cole (2006) argued that an increase in export demand increases the activities related with scale of economic, which as a result increases the use of energy in the domestic economy. Also, Yanikkaya (2003) argued that trade openness promotes the diffusion of technology, which is often considered as energy efficiency, from developed economies to less developed economies. This process does help promote energy efficiency and reduce energy consumption required to produce a certain level of economic output. Some studies like Chowdhury et al. (2014); Jebli et al. (2014); and Solarin (2014) empirically established the long run association between renewable energy use and trade for different countries like Bangladesh, Central and South American Countries, Malaysia. A Furthermore, study from Aïssa, Jebli & Youssef (2014), used panel cointegration method for examining the relationship between renewable energy consumption, trade and output for 11 African countries for the period 1980 to 2008. The results reveal that there is evidence of a bidirectional causality between output and exports and between output and imports in both the short and long-run. However, in the short-run, there is no evidence of causality between trade (exports or imports) and renewable energy consumption. Also, in the long-run, there is no causality running from trade to renewable energy. In his study on Middle Eastern countries, Sadorsky (2011) found that trade volumes increase domestic use of energy. But a non-linear relationship between trade openness and energy use is also evident. Shahbaz et al. (2014) argue that there exists a U-shaped relationship in high-income countries between trade volume and energy use; whereas, an inverted U-shaped relationship is found in middle- as well as low-income countries. Also, the study of Yanikkaya (2003) reveals that the diffusion of technology from developed countries to developing countries is promoted by trade openness. This finding coincides with a large-scale study on European Union member countries by Wan, Baylis and Mulder (2015) in which they argued that energy efficiency is promoted by technological diffusion when this diffusion is taken place through trade openness. Zama et al. (2015) argue that trade openness, economic growth and human development influence energy use in the economies of Thailand, Indonesia and Malaysia. Also, Al-Mulali, Ozturk, and Lean (2015) also found trade openness has a positive causal effect on the production of renewable energy.

Studies also argued that technological progress is crucial for improving energy efficiency (Fisher-Vanden et al., 2004; Hang and Tu, 2007; Zhou, Levine and Price, 2010; and Jiahua et al., 2010). That said, technological progress is crucial to achieve energy efficiency which in turn promotes the use of renewable energy. Hence the fall in price of energy could be an expected outcome of energy efficiency. Greening, Greene and Difiglio (2000) argued that if the price of energy falls due to an increase in energy efficiency, the reduced price is expected to encourage energy users to use more energy. Lee and Chiu (2013) argued that energy is an essential factor of production with no close substitute, and thus they found economic growth and energy prices inelastic in the contexts of OECD economies. Also, Zhou and Teng (2013) found energy as an inelastic factor of production in the case China due to, as the predicted, the country's huge industrialization. Also, a major study by Dahl (2012) reveals by studying 120 developing and developed economies that as energy products such as gasoline and diesel are essential raw materials of production the elasticities of price and income are insignificant in explaining energy use. Studying the Turkish economy, however, Altinay (2007) concluded that neither the energy price nor the economic growth is responsive to import demand function but this excluded domestic energy demand. On the other hand a study from Liobikiene and Butkus (2017) suggest that to achieve the Environmental Kuznets Curve (EKC) occurrence at the world level it is necessary to increase the efficiency and promotion of energy consumption.

However, evidences from industrialized and developing economies suggest that energy efficiency plays a pivotal role in the use of energy by economic agents in domestic market. For example, Wong, Chang and Chia (2013) studied OECD economies in this regard and they find that these economies experience higher energy efficiency, which is due to their large-scale technological innovation. On the other hand, as developing economies lack considerable technological innovation their experience with energy efficiency is dissimilar to those of industrialized economies. This tunes with the finding of Brock and Taylor (2005) who argue that technological innovation increases the quality of production by increasing energy efficiency. Relevant to this is a number of studies, including Gillingham, Newell and Palmer (2006), Linares and Labandeira (2010), Matisoff (2008), Popp (2011), Stern (2011) and Wei, Patadia and Kammen (2010), which empirically identified the factors that could potentially influence the adoption of energy efficiency technologies and policies. In a study in 2013, Viardot identifies a number of possible constraints to RE which includes technological constraints, physical constraints, financial and legal constraints and finally ontological and social constraints. On the other hand as the biosphere pollution is increasing, the share of RE is getting more priority in the policy agenda. As a result of this the development of RE becomes a major challenge for the society and day by day the people of the society is adopting it slowly (Gezahegn, 2018). Whilst these studies argue that differences in endowments, preferences and technological progress make differences in the adoption of energy efficient technologies across economies, but the rates of adoption may also be influenced by market failures, such as environmental externalities, lack of access to information, and liquidity constraints in capital markets, and behavioral factors. This just indicates huge research potential of research on technological progress, energy efficiency and renewable energy use at both the micro and macro levels.

Nevertheless, the current study is an attempt to empirically investigate the impact of economic growth, trade openness, and technological progress on renewable energy use among 25 OECD nations by utilizing data obtained for the years 1970 to 2012. This study is expected to identify and reexamine the issues related to these dynamics that have not been

addressed in past studies. For instance, past studies have not examined the robustness of the renewable energy use, economic growth, trade openness, and technological progress among the OECD countries being addressed in this study. In addition, as mentioned in the above discussions, dynamics including renewable energy use and technological progress have not been thoroughly examined resulting in a gap in research potential. Thus, this study aims to offer a wider scope to examine the dynamics based on the number of variables and countries. The rest of this study is organized as follows: Section 2 presents the research methodology, which includes the data, unit root test, and the dynamic model. Section 3 provides the empirical findings, discusses the main results, and presents the model's dynamic check findings. The final section draws some conclusions from this study.

METHODOLOGY

Panel Data Set

This study utilized data from 25 OECD countries during the duration of 1970 to 2012 for the purpose of panel data analysis. The data for renewable energy usage, technological progress (number of patents as a measurement of technological progress), trade openness, and economic growth (GDP per capita) were collected from the World Developed Indicators (WDI, 2019). After that, all the values are taken at real time.

Unit Root Test

We examined the short and long term effect of the explanatory variables on economic growth by determining the presence of the unit roots in the data series. This study has chosen the Im, Pesaran and Shin (IPS) unit root test that is based on the popular Dickey-Fuller (DF) approach. Moreover, IPS method introduced a test to determine whether the unit roots existence in panels which combined the time series data with the cross sectional dimension; thus fewer observations over time are needed for the test to be powerful. As the IPS method has been proven to hold a superior testing power by economic scholars in analyzing long term associations in the panel data, we utilized this approach for this study as well. The IPS is initiated by identifying separate ADF regression for each cross section with individual impacts and no time patterns. The benefit of using the IPS is that it utilizes separate unit root tests for the N cross-section units. The test is carried out according to the Augmented Dickey-fuller (ADF) statistics averaged across the groups. The IPS (1997) demonstrates that it performs better when the N and T are smaller.

Dynamic Model

The study is aimed examining the dynamics of economic growth, technological progress, trade openness, and renewable energy usage. We utilized the dynamic panel framework to estimate the heterogeneous data using suitable tools and context. Using the data's characteristics, we utilized the autoregressive distributed lag (ARDL, p,q) model in the error correction based on three estimators. Moreover, according to Pesaran and Smith (1995) as well as to Pesaran et al. (1999), respectively this model includes the mean group (MG), pooled mean group (PMG) estimators, as well as the dynamic fixed effect (DFE) model. The ARDL specification is formulated as shown below based on Loayza and Ranciere (2006):

$$\Delta(y_i)_t = \sum_{j=1}^{p-1} \gamma_j^i \Delta(y_i)_{t-j} + \sum_{j=0}^{q-1} \delta_j^i \Delta(X_i)_{t-j} + \varphi^i [(y_i)_{t-1} - \{\beta_0^i + \beta_1^i (X_i)_{t-1}\}] \epsilon_{it} \quad (1)$$

whereby, Y represents the renewable energy, X represents a set of independent variables which includes the GDP per capita, technological progress, and trade openness, the short-term coefficients of dependent as well as of independent variables are respectively represented by γ and δ , β represents the long-term coefficients, φ represents the coefficient of speed of adjustment to the long-term status. Moreover, country and time, are represented by the subscripts of i and t respectively. Terms in the square brackets denote the long-term growth regression. Furthermore, Equation (1) can be calculated by utilizing the panel ARDL methods of either PMG or MG or even DFE estimators whereby all the three models take into consideration both the long-term equilibrium and the heterogeneity of the dynamic adjustment process (Demetriades and Law, 2006).

According to Pesaran and Smith (1995) and Pesaran, Shin, and Smith (1999), the ARDL methods in the error correction form are comparatively new tests for cointegration. Nevertheless, these researchers pointed the necessity of having simple modifications to standard techniques to portray consistent and efficient parameter estimates in a relationship that is long-term. The studies by Johansen (1995) and Phillips and Hansen (1990) revealed that the long-term relations are present only in the context of cointegration among the integrated variables. However, Pesaran and Shin (1999) pointed out the assumptions and demonstrated numbers of the econometric benefits of the PMG and MG methods compared to other approaches. Firstly, using the PMG and MG estimators, the researchers are able to avoid the need for cointegration tests and the validity of stationary or integration between the variables to calculate the long-term relations and the pre-test for unit roots. This is because the methodology permits the estimation of various variables with various order of stationary, which means, it is valid for both variables of interest such as $I(1)$ or $I(0)$. Moreover, this model is suitable for the panel data with large N and T dimensions. Secondly, this estimator allows the estimation of short and long-term impacts from the ARDL model simultaneously. Thirdly, the problem of failing to test the hypotheses on the estimated coefficients in the long-term because of issues of endogeneity in the Engle Granger approach can be overcome using the ARDL method.

The option to choose among these estimators requires a general trade-off between efficiency and consistency. Thus, the best approach is to understand the conditions and assumptions of each estimator.

The Pooled Mean Group Estimator (PMG)

However, the key characteristic of PMG which is the first estimator, is that it permits short-term coefficients, which include the intercepts, the adjustment speed to the long-term equilibrium values, and the error variances to be heterogeneous country by country, while the long-term slope coefficients are restricted to be homogeneous across the countries.

Moreover, this methodology's key requirements for efficiency, consistency, and validity are firstly, the presence of a long-term relation among the variables under study, which needs the coefficient on the error-correction term to be not less than -2 and negative. Secondly, a critical assumption for the PMG estimates' consistency is needed which is the resulting residual of the error-correction model be serially non-correlated and the explanatory variables can be regarded as exogenous. These conditions are fulfilled after the ARDL (p,q) lags are included for both the dependent (p) as well as for the independent (q) variables in the error-correction form. Thirdly, the relative size of T and N is of utmost importance in this

instance as having both to be large permits the researchers to work on the dynamic panel method that assists in preventing bias in the average estimators and overcoming the heterogeneity issue. As in a study in 2010, Eberhardt and Teal argue, in this instance, to understand the process of growth the treatment of heterogeneity is essential.

The Mean Group Estimator (MG)

The second method known as the Mean Group (MG) estimator that was presented by Pesaran and Smith in 1995. Moreover, MG estimator includes the estimation of separate regressions for each country as well as the coefficients as the un-weighted means of the estimated coefficients for the individual country. It does not have any limitations on the procedures for estimations. It permits all the coefficients to differ and be heterogeneous in the short and long-term. Nevertheless, the required conditions for validity and consistency in this method are to possess adequately large (approximately 20 to 30 countries based on Pesaran et al. 1999) and approximately similar magnitudes.

Dynamic Fixed Effect (DFE)

Finally, the third approach known as the dynamic fixed effect (DFE) estimator is the same as the PMG estimator and it limits the coefficient of the co-integrating vector to be equal among all the panels in the long-term. Moreover, the DFE model limits the speed of the adjustment coefficient and the short-term coefficient to be the same or equal. Panel-specific intercepts are also allowed. In addition, the DFE estimator has cluster options for calculating the intra-group correlation with the standard error (Blackburne and Frank, 2007). Moreover, Baltagi, Griffin, and Xiong (2000) clarify that the DFE models are subject to a simultaneous equation bias from the endogeneity between the error term and the lagged dependent variable. However, the Hausman test can be performed easily to calculate the endogeneity's extent.

PMG or MG or DFE?

The PMG estimator provides an increment in estimate efficiency in relation to the MG estimators and it serves the aim of this study under the assumption of the long-term homogeneity slope (Pesaran et al., 1999). Moreover, the Hausman test could be utilized to examine the significant differences among the PMG, MG, as well as the DFE. This test's null hypothesis denotes the non-significance of the difference between PMG and MG estimations. If the null hypothesis is supported, it shows that there is no significant difference and thus one would utilize the PMG estimator given its efficiency. However, the alternative is that a significant difference exists between the PMG and MG. If the null hypothesis is not supported, it shows there is a significant difference and thus the average estimator would be utilized. This concept is utilized in the estimation of the difference between the PMG and DFE or the MG and DFE.

RESULTS AND DISCUSSION

Data Description

The descriptive statistics in this section provides an overall perspective of the dataset. In Table 1 it is shown that the renewable energy (RE) use's average logarithmic form is 22.86 units and the renewable energy use's minimum and maximum accounts are 0 and 26.99 units, respectively. Moreover, the average technological innovation (TI) is 8.75, and there is little

variability since the standard deviation is only at 1.90. Table 1 denotes the average value of trade openness (TO) at 72.29 units and the average logarithmic form of GDP per capita in real term USD, which accounts for the economic growth, is 10.18 and a small variability.

Table 1. Descriptive Statistics

Variables	Observations	Mean	Std. Dev.	Min	Max
RE Use (RE)	1075	22.861	3.313	0	26.994
Technological Innovation (TI)	1075	8.751	1.905	3.178	13.163
Trade Openness (TO)	1075	72.294	44.131	10.729	333.532
GDP Per Capita (GDPC)	1075	10.180	0.488	7.838	11.381

Panel Unit-Root Tests

The study aims to utilize the PMG estimators from Pesaran et al. (1999) to examine the short and long-term impacts of economic growth, trade openness, and technological innovation on renewable energy usage. Nevertheless, it is critical to scrutinize the order of integration of the variables as the asymptotic properties of the parameter estimates are established by whether the variables of interests are all I(1) or I(0). Two various unit-root methods are applied including those from Im, Pesaran, and Shin (2003) and Maddala and Wu (1999). The findings revealed in the second and third columns of Table 2 clarify that unit-root exists in all variables that are used in this model. It confirms all the variables of interests are stationary at first difference after applying these methods. These results confirm the notion that the variables under study are all I(1) variables, and thus the ARDL framework is a suitable tool for data analysis.

Table 2. Results of the Panel Unit-root

	Levels		1 st Difference	
	Im, Pesaran & Shin (2003)	Maddala & Wu (1999)	Im, Pesaran & Shin (2003)	Maddala & Wu (1999)
RE Use	-1.385	1.841	-8.133***	-22.926***
Trade Openness	-1.930	2.489	-7.477***	-21.287***
Technological Innovation	-1.298	-0.425	-5.152***	-8.068***
GDP Per Capita	-1.938	-0.715	-4.546***	-8.644***

*** indicates significance at 1% level

Technological Progress and Energy Use: Dynamic Analysis

Moreover, Table 3 presents the estimated results under the PMG estimator, MG estimator, and DFE estimators along with the Hausman specification test (h-test) in measuring their efficiency and consistency. The findings show that the GDP per capita affects renewable energy use in a positive and significant manner in the long-term. However, the LGDPC affects renewable energy use negatively in the short-term based on the PMG estimator. This result is similar to the results achieved from the MG estimator as the table shows that the coefficient of LGDPC has no effect in the short term but has a positive and significant effect in the long-term. In turn, the DFE estimator shows that likewise the LGDPC promotes renewable energy use in the long-term but the short-term coefficient is insignificant. The Hausman test is used to rationalize the long-term homogeneity restriction among the countries. The Hausman specification test as anticipated shows the null hypothesis of the homogeneity restriction on the regressors in the long-term, which reveals that the PMG is a more efficient estimator compared to the MG and the DFE.

In reference to trade openness, the long-term coefficient is both positive and also significant using the PMG estimator, which shows that trade openness promotes renewable energy use. Furthermore, the effect of trade openness on renewable energy use does not exist in the short-term using the PMG estimator. AS a result, the MG and DFE estimators contradict the findings of the PMG estimator.

In terms of the effects of technological progress, the long-term coefficients are negative but insignificant using all the three estimators. This shows that technological progress does not promote the RE's supply side economy. Likewise, Table 3 additionally clarifies that technological progress does not explain renewable energy use in the short-term as well.

Table 3. Technological Progress and Renewable Energy Use: Dynamic Analysis

D.V: Renewable Energy Use	PMG		MG		DFE	
	Long Term	Short Term	Long Term	Short Term	Long Term	Short Term
Error Correction		-0.308*** (0.056)		-0.472*** (0.050)		-0.0730*** (0.010)
Δ Trade Openness		0.002 (0.001)		0.002 (0.001)		0.006 (0.002)
Δ GDP Per Capita		-0.325* (0.183)		0.277 (0.326)		0.215 (0.653)
Δ Technological Progress		-0.008 (0.102)		-0.0852 (0.106)		-0.049 (0.092)
<i>Hausman Test</i>				4.06 (0.13) [#]		0.93(0.81) ^{\$}
Trade Openness	0.002* (0.001)		0.003 (0.006)		0.009 (0.016)	
GDP Per Capita	0.565*** (0.041)		4.415** (1.832)		1.996** (0.968)	
Technological Progress	-0.014 (0.0170)		-0.293 (0.469)		-0.304 (0.331)	
Constant		5.643*** (1.051)		0.973 (3.495)		0.378 (0.687)
Observations	1,050	1,050	1,050	1,050	1,050	1,050

*** indicates significance at the 1% level, ** indicates significance at the 5% level, * indicates significance at the 10% level; Standard Error in the parenthesis; [#] indicates comparing MG with PMG (P-value is within the parenthesis); ^{\$} indicates comparing DFE with PMG (P-value is within the parenthesis)

The country specifics are explored further by comparing and contrasting particular findings with the general findings in the short-term. Table 4 presents the results. Technological progress influences renewable energy use in the short-term in Netherland and Norway's economies.

Table 4. Short Term Country Specific Results

Countries	Constant	Trade Openness	GDP per Capita	Technological Progress	Comments
Netherlands	-0.246***	0.009	-0.77	1.984*	<i>Technology with Expected Sign and Significance</i>
Norway	-0.555***	0.005	-0.818	0.164*	
France	-0.667***	0.002	0.356	-1.025**	<i>Technology with Unexpected Sign and</i>
Iceland	-0.013	0.003	0.404	-0.049*	

United States	-0.482***	0.014	-0.916	-0.784**	<i>Significance</i>
Australia	-0.518***	0.001	0.295	0.023	
Belgium	0.005***	0.004	-0.503	0.196	
Finland	-0.317***	0.013***	-0.883	0.093	
Greece	-0.143	-0.014	-0.256	0.03	
Ireland	0.592	0.302	0.189	0.067	<i>Technology with</i>
Israel	0.946	0.477	0.819	0.875	<i>Expected Sign but</i>
Italy	-0.06	-0.002	-1.302***	0.113	<i>insignificant</i>
Japan	-0.779***	0.004	0.858	0.012	
Korea, Rep.	-0.470***	-0.002	-1.048	0.33	
Luxembourg	-0.397***	0.005*	-0.42	0.011	
Portugal	-0.779***	0.024**	-1.466	0.133	
Austria	-0.342***	0.001	-1.107	-0.1	
Canada	-0.140***	0.004**	0.109	-0.022	
Denmark	0.002***	-0.006	1.473	-0.084	
Germany	0.042	0.007	-1.091	-0.087	<i>Technology with</i>
New Zealand	-0.139***	0.001	0.298	-0.1	<i>unexpected sign but</i>
Spain	-0.367***	0.002	-2.367	-0.001	<i>insignificant</i>
Sweden	-0.632***	0.006	-0.216	-0.054	
Switzerland	-0.728***	0.002	-1.022	-0.125	
United Kingdom	0.086**	-0.003	0.769	-0.099	

*** indicates significance at the 1% level, ** indicates significance at the 5% level, * indicates significance at the 10% level

On the contrary, technological progress lowers renewable energy use in France, Iceland, and United States. An anticipated indication though insignificant parameter of renewable energy use is discovered in countries such as Belgium, Australia, Finland, Ireland, Greece, Israel, Japan, Italy, Korea, Portugal, and Luxembourg. Nevertheless, an unanticipated indication though insignificant parameter of renewable energy use is discovered in countries such as Canada, Austria, Germany, Denmark, New Zealand, Sweden, Spain, the United Kingdom, and Switzerland.

Robustness Check

The findings from the ARDL estimator (Table 3) were assessed by utilizing the two substitute single equation estimators such as the dynamic ordinary least squares (DOLS) as well as the totally modified OLS (FMOLS). The main benefit of the DOLS framework is still the efficiency during the existence of a mixed order of integration of the related variables in the cointegrated framework. The DOLS process is performed by regressing one of the I(1) variables against the other variables, some of which are I(1) with leads (p) and lags (-p) of the first difference while others are I(0) variables that contain a constant term (Ang, 2010). Therefore, this method considers two significant constraints such as a potential problem with endogeneity and a small sample bias. Nevertheless, Table 5 shows that renewable energy use is significantly influenced by economic growth, which is in line with the PMG estimator's findings. In terms of the effect of trade openness, it shows a negative and significant effect, which is contradictory to the findings using the PMG estimator. Nevertheless, the DOLS offers similar findings as the PMG estimator based on the effect of technological progress. Table 5 demonstrates the negative but insignificant effect of technological progress over renewable energy use using the DOLS estimator.

Following this, the totally modified OLS (FMOLS) approach for heterogeneous cointegrated panels is evaluated using the Pedroni (2001) criteria, as revealed in Table 5.

Table 5. Technological Progress and Renewable Energy Use: Dynamic OLS (DOLS) and Totally Modified OLS (FMOLS)

DV: Ren. Energy	DOLS		FMOLS [#]	
	Coefficient	Std. Error	Coefficient	Std. Error
LGDP	1.297***	0.169	2.351***	0.0008
LTRD	-0.348*	0.092	0.784***	0.0002
LTP	-0.113	0.169	0.460***	0.0003
R ² 0.87	Adj R ² 0.81		R ² 0.85	Adj R ² 0.83

*** indicates significance at the 1% level, ** indicates significance at the 5% level, * indicates significance at the 10% level; [#] First-stage residuals use and heterogeneous long-term coefficients

Moreover, the FMOLS has specific benefits compared to the standard dynamic panel estimators. The method modifies the ordinary least squares to remove the endogeneity bias in the regressors resulting from the existence of the cointegration relations (Saboori et al, 2014). Additionally, the FMOLS is efficient and an asymptotically unbiased estimator. This estimator permits first-stage residuals to be heterogeneous with long-term coefficients. Nevertheless, the findings retrieved from the FMOLS estimator are sensible based on a theoretical viewpoint. The findings from the FMOLS also reaffirm the fact that economic growth significantly promotes renewable energy use in the long-term in OECD countries and their economies. It is evident that the OECD countries focus on generating more renewable energy to overcome the issues of CO₂ emissions and to ensure energy security in comparison to non-OECD countries. Table 5 also shows that trade openness promotes renewable energy use using both demand and supply sides. First, given the international market competition, local companies have become more efficient using RE. Second, renewable energy is more readily available to local economies using trade openness. Lastly, Table 5 reveals the positive and significant coefficient of technological progress, which implies that renewable energy use, is significantly improved with the augmentation of technological progress. This result is however inconsistent with the other estimators utilized in this study. The FMOLS estimator findings varies when we permit the long-term coefficient to be heterogeneous. It cannot be denied that although OECD countries show many similarities based on their economic structures, their levels of technological progress does not follow a homogeneous trait.

CONCLUSIONS AND IMPLICATIONS

This study is aimed at examining the dynamics of economic growth, trade openness, technological progress, and renewable energy use among OECD countries. Specifically, it investigated the impact of economic growth, trade openness, and technological innovation on renewable energy use among the OECD countries. The panel data was analyzed from the year 1970 to 2012 from 25 OECD countries by utilizing the PMG, MG, and DFE estimators with the ARDL framework. DOLS and FMOLS were also utilized to further examine the dynamism of the results. In general, it was discovered that economic growth promotes renewable energy use significantly in the long-term but in the short-term it has adverse effects. The positive long-term relationships between economic growth and renewable energy use is supported by earlier findings by Sbia, Shahbaz, and Hamdi (2014) on UAE, Al-Mulali, Ozturk, and Lean (2015) on Europe, and Sohag et al. (2015) on Malaysia. The main results of these studies pointed out that an increase in the GDP per capita and trade openness resulted in a positive effect on renewable energy usage. The empirical findings of this study additionally

proves that trade openness promotes renewable energy use in the long-term among OECD countries. This long-term relationship coincides with the findings of several earlier studies such as Chang, Kaltani and Loayza (2009), Sbia, Shahbaz, and Hamdi (2014), and Al-Mulali, Ozturk, Sohag et al. (2015), and Lean (2015). Though the relationship between technological progress and renewable energy use in OECD countries is not found statistically significant through ARDL framework, the FMOLS estimator showed that technological progress improved renewable energy use significantly in these OECD countries. Moreover, there are many variations were found in the short-term relationship between technological progress and renewable energy use among the OECD countries. The results are also similar to results obtained earlier by Sohag et al. (2015) on Malaysia and Irandoust (2016) on Nordic countries such as Finland, Denmark, Sweden, and Norway.

This study offers significant implications for the studied economies in securing renewable energy and in achieving economic growth, promoting trade openness, and achieving technological progress. Specifically, the increased usage of renewable energy would enhance the general environmental health among the OECD countries. This study's findings reveal that since the OECD countries achieved huge technological progress, a higher renewable energy use has become an indisputable reality for these countries. Therefore, the role of technological progress in the growth of an effective renewable energy market is pivotal. But, achieving any major objectives such as widely usage of renewable energy would essentially require sustaining trade openness, technological progress, and a long-term economic growth in the OECD economies.

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