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THE IMPACT OF ELECTRICITY PRODUCTION FROM RENEWABLE AND NON-RENEWABLE SOURCES ON CO_2 EMISSIONS: EVIDENCE FROM OECD COUNTRIES

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ABSTRACT

In view of the fact that electricity production from fossil fuels causes disastrous impact on the environment, it is of interest to examine the dynamic causal relationship between CO_2 emissions, economic growth, renewable electricity production and non-renewable electricity production for a panel of 25 OECD countries from 1990 to 2013. To realise the aims of our study, 3 approaches are used test the validity of Environmental Kuznets Curve (EKC) hypothesis, namely Pooled Mean Group (PMG), Panel FMOLS, and Panel DOLS. In addition, Dumitrescu-Hurlin (D-H) Granger causality test is used to examine the direction of causalities between all variables. The results show that the inverted U-shaped EKC hypothesis is supported for OECD countries. It is also revealed that renewable electricity production has a negative effect on CO_2 emissions while the result for non-renewable electricity production indicates the reverse. Granger causality test confirms the existence of bidirectional causality between CO_2 emissions and renewable electricity production as well as non-renewable electricity production. Furthermore, a unidirectional causality is found running from economic growth to non-renewable electricity production and CO_2 emissions. The findings suggest that the adoption of renewable energy sources in electricity generation can be an important strategy in combating the problem of global warming. Additionally, a number of policy recommendations were provided to the policy makers of investigated countries to increase the use of renewables in power sector.

Keywords: EKC hypothesis; Renewable and non-renewable electricity production; Panel ARDL; Dumitrescu-Hurlin Granger causality test.

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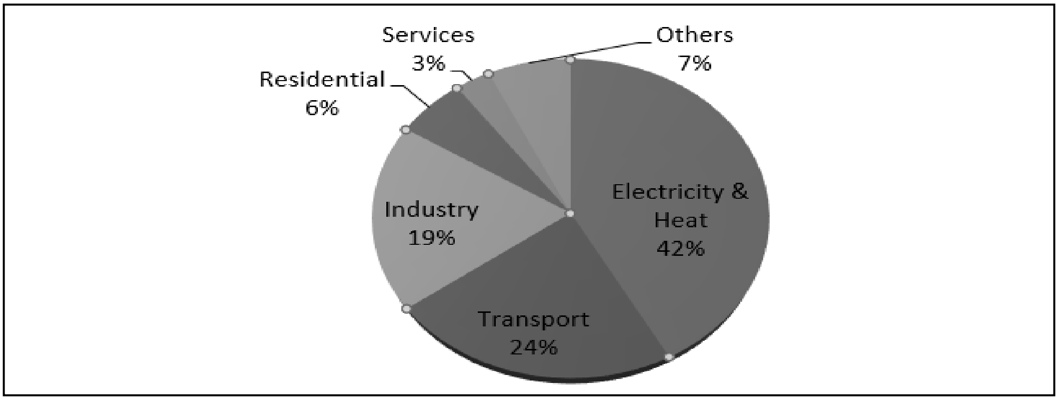
1. INTRODUCTION

The planet Earth that we are living in is severely sick due to pollution. Over the last 50 years, the average temperature on this planet has risen at the fastest pace at recorded history and the bad news is, the trend is accelerating. According to scientists, rising temperatures are fueling longer and hotter heat waves, heavier rainfalls, more frequent droughts, and more powerful hurricanes across the globe in recent years. These natural disasters have caused thousands of deaths worldwide every year. It is commonly believed that human activities have contributed significantly to global warming by adding carbon dioxide in particular and other heat-trapping gases into the atmosphere since the mid-20th century. Among others, the burning of fossil fuels particularly coal to generate electricity is the main human activity that has led to the problem of climatic change. In the United States, for example, coal-burning power plants are the biggest polluters who produce about 2 billion tons of carbon dioxide yearly (United States Environmental Protection Agency, 2016). Despite the fact that the usage of fossil fuels has led to global warming, it has been a main driver for economic growth on the other hand. Thus, policy makers of countries are concerned of the way to achieve the dual goals of low carbon emissions and high growth simultaneously with the premise that higher growth does not necessarily harm the environment. As electricity production using fossil fuels is the main culprit for CO_2 emissions, governments have looked into the possibility of replacing the dirty energy sources with renewable ones at power plants. In relation to this, many countries including OECD countries have started a turnaround by adopting energy-efficient technologies and cleaner fuels as part of their efforts in curbing climate change. It is estimated that more than 70 countries will be using renewable energy technologies in electricity production by 2017 (International Energy Agency, 2012). Despite growing attention on the adoption of renewable energy due to global warming, the contribution of renewable energy in reducing CO_2 emissions remains questionable.

Fig.1 depicts the distribution of the world CO_2 emissions by sector for the year 2015. It can be noticed that electricity and heat generation accounts for 42% of the global CO_2 emissions, followed by transport and industry with the share of 24% and 19% respectively. The electricity and heat sector alone is responsible for more than one-third of the world total CO_2 emissions. It is due to the fact that coal, the most carbon-intensive fossil fuel, has been widely used in the generation of electricity and heat (International Energy Agency, 2017a).

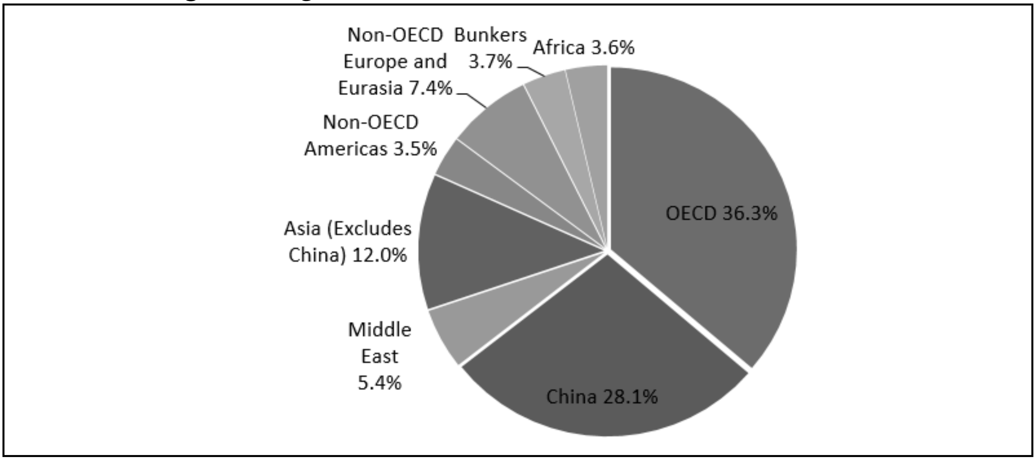
Figure 1: World CO_2 Emissions by Sector, 2015



Source: IEA, 2017a

The rationale of selecting OECD countries for our analysis is that this group of countries has recorded the highest regional shares of CO_2 emissions from fuel combustion in 2015 according to International Energy Agency (2017b). From fig.2, it can be observed that OECD countries recorded 36.3% of the world CO2 emissions from fuel combustion. The shares of other regions such as China, Asia (excludes China), and non-OECD Europe and Eurasia are much lower as exhibited below.

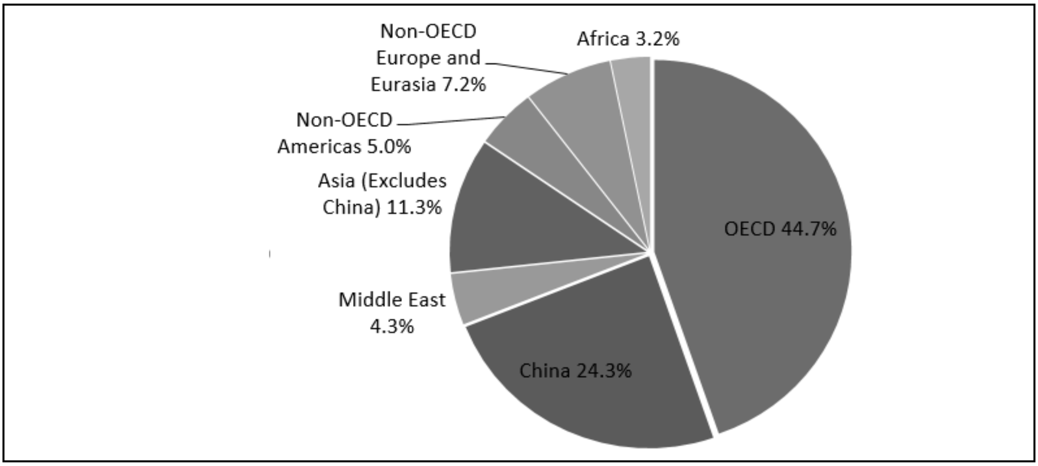
Figure 2: Regional Shares of CO_2 Emissions from Fuel Combustion in 2015



(Source: IEA, 2017b)

When it comes to electricity production, OECD countries contributed to 44.7% or almost half of the world electricity generation in 2015 as shown in fig. 3. In short, OECD countries topped the world electricity production followed by China, Asia (excludes China), and non-OECD Europe and Eurasia (International Energy Agency, 2017b). In addition, it is worth highlighting that OECD countries such as United States, Japan, Mexico and Korea are among the top ten countries in the world which have been relying on fossil fuels like coal, oil and natural gas for power generation.

Figure 3: Regional Shares of Electricity Generation in 2015



(Source: IEA, 2017b)

The above discussion leads us to our research questions: Does an inverted U-shaped relationship exist between economic growth and CO_2 emissions in OECD countries? How does electricity production from renewable and non-renewable sources affect CO2 emissions? What is the long run causal relationship among economic growth, renewable electricity production, non-renewable electricity production, and CO_2 emissions? What energy and environmental policies can contribute to sustainable development in OECD countries? Therefore, the overall aim of the study is to examine the validity of Environmental Kuznets Curve hypothesis in OECD nations and most importantly to investigate the relationships among economic growth, electricity production from renewable sources, non-renewable electricity production, and CO2 emissions. In specific, we examine the existence of long run and causal relationships among the variables in a multivariate framework using Panel ARDL bound testing approach for cointegration. The main motivation of this study lies with the fact that the findings obtained can serve as a reference to the governments of OECD countries in coming up with more appropriate energy policies that would ensure low carbon and sustainable growth.

Our study contributes to the existing literature in three important ways. First, most of the existing studies consider “energy consumption” in their studies (Ang, 2007, 2008; Halicioglu, 2009; Jalil & Mahmud, 2009; Aali-Bujari, Venegas-Martínez, & Palafox-Roca, 2016; Ben Jebli, Ben Youssef & Ozturk, 2016; Pala, 2016). However, this study attempts to take a step further by employing “electricity production” as electricity generation is one of the most polluting human activities on earth as shown in Fig.1. Second, most of the existing studies focus on time series analysis (Begum et al., 2015; Iwata et al., 2011; Menyah & Wolde-Rufael, 2010). Therefore, this study uses a few panel data techniques to enhance the robustness of results. The panel data models such as panel Fully Modified Ordinary Least Squares (FMOLS) by Pedroni (1999, 2000), Dynamic Ordinary Least Squares (DOLS) by Kao and Chiang (2000), and Pooled Mean Group (PMG) by Pesaran, Shin and Smith (1999). Third, the PMG approach is able to solve the multicollinearity problem arise in the EKC framework[1].

The rest of the paper is organized as follows. Section 2 provides an overview of literature. In Section 3, research methodology is presented followed by empirical results and discussions in Section 4. The final section concludes the paper by outlining policy implications of the findings.

2. LITERATURE REVIEW

Basically, the relationships among CO_2 emissions, energy production, and economic growth have been analyzed in three different ways in the existing literature. First, many researches have investigated the CO_2 emissions and economic growth nexus. It all started with the pioneering work by Grossman and Krueger (1991) who confirm that there is an inverted U-shaped relationship between environmental pollution and economic growth. In most of the subsequent studies following Grossman and Krueger (1991), such as Apergis and Ozturk (2015), Dijkgraaf and Vollebergh (1998), Galeotti, Lanza, and Pauli (2005), Jalil and Mahmud (2009), and Kristrom and Lungren (2003), a similar inverted U-shaped relationship which is better coined as the Environmental Kuznets Curve (EKC) hypothesis[2] is depicted. The inverted U-shaped relationship suggests that CO_2 emissions increase with a rise in income initially, then reaches to a stabilization point and finally declines as economy grows further. It can be explained by the fact that at the early stage of economic development without structural and technological changes, as the scale of the economy increases, environmental quality declines. This is called the scale effect. Later, as economy grows to a certain level, both structural and technological changes that occur in the economy lead to a decrease in environmental degradation eventually. However, some studies found an invalid inverted U-shaped EKC hypothesis. Instead, the pollution-growth nexus is reported as N-shaped (e.g.de Bruyn, Van Der Bergh, & Opschoor ,1998; Friedl & Getzner, 2003; Zanin & Marra, 2012), monotonically increasing (e.g. Bertinelli & Strobl, 2005; Cialani, 2007; Rezek & Rogers, 2008) or even monotonically decreasing (e.g. Focacci, 2003). Overall, mixed results have been obtained for studies focusing on EKC hypothesis.

The second strand of literature focuses on the energy-growth nexus, which mainly investigate whether energy production or consumption encourages economic growth or vice versa. The initial studies concentrated on the relationship between energy and economic growth. Kraft and Kraft (1978) pioneered the work on the energy-growth nexus with a study on U.S. The findings show that there is Granger causality running from GDP to energy. Following Kraft and Kraft (1978), many studies (both on a single country and a panel of countries) have examined the causal relationship between energy consumption and economic growth in different countries. Ahmed et al. (2015), Belloumi (2009), Dagher and Yacoubian (2012), and Ghali and El-Sakka (2004), for

[1] The EKC hypothesis postulates an inverted U shape relation between income and pollution. The common measure of this relation relies on a quadratic form which consists of income and income squared. The milticollinearity problem is said to be caused by the correlation between income and its squared term which enter the model as independent variables. See Bento and Moutinho (2016) for application of ARDL in time series data.

[2] In 1955, a Russian American Economist called Simon Smith Kuznets introduced a hypothesis that links income to income inequality. According to his hypothesis, economic growth may cause an increase in income inequality initially, however, income inequality will tend to diminish once income has reached a certain level in the long run. This relationship can be depicted with an inverted U-shaped Kuznets curve, following the name of the researcher. Kuznets' name is applied to the inverted-U link between economic growth and pollution as the shape is similar to Kuznets' economic growth-income inequality nexus.

instance, have reported a bidirectional link between income and energy consumption in the case of Pakistan, Tunisia, Canada, and Lebanon respectively. However, the results from other studies such as Borozan (2013) for Croatia, Hossien (2012) for Saudi Arabia, and Wang et al. (2011) for China indicate that a unidirectional causality is running from energy consumption to economic growth. Their test result is in contrast to that of Cheng and Lai (1997) and Yu and Jin (1992) who confirm the existence of a unidirectional causality from energy consumption to economic growth in Taiwan and Indonesia respectively. In the meantime, an abundant of past researches have been done using panel data with mixed results obtained. For instance, Lee (2005) investigates the causal relationship for the period of 1975-2001 using the panel co-integration and panel vector error correction model in developing countries. It is evident that there is a unidirectional causal relationship running from energy to GDP both in the short run and long run. By employing similar estimation techniques, Lee, Chang, and Chen (2008) examine the relationship between energy consumption and income for 22 OECD countries for the period 1960-2001. A bidirectional causal linkage is obtained between the two variables instead. On the other hand, a study done by Al-Iriani (2006) using a panel co-integration technique found that economic growth unidirectionally Granger cause energy consumption in Gulf Cooperation Council Countries. The more recent studies on the relationship between energy consumption and economic growth have seen the decomposition of energy variable into renewable and non-renewable energy sources (Al-mulali, 2011; Apergis & Payne, 2010; Bashiri & Manso, 2012; Kum, Ocal, & Aslan, 2012; Payne & Taylor, 2008; Yang, 2000; Zoundi, 2017).

In recent years, many researchers have studied the dynamic relationships among energy, environmental pollution and economic growth. This strand of research attempts to blend the EKC literature with energy-growth nexus. Among others, Bastola and Sapkota (2015) find that economic growth Granger causes both carbon emissions and energy consumption unidirectionally in Nepal. Moreover, Zhang and Cheng (2009) report existence of a long run unidirectional causal relationship running from economic growth to energy consumption and from energy consumption to carbon emissions in China. Surprisingly, both carbon dioxide emissions and energy consumption are found to have no effect on economic growth. Similarly, Alkhathlan, Alam, and Javid (2012) report that energy consumption and CO_2 emissions do not Granger cause economic growth in Saudi Arabia for the period 1980-2008 using ARDL and Johansen cointegration approaches. However, a study by Saboori, Sapri, and Baba (2014) on OECD countries discovers positive long run relationships among carbon emissions, energy consumption and economic growth. Most recently, Wang et al. (2016) did a provincial analysis on the relationships among GDP, energy consumption and CO_2 using data related to cement manufacturing and combustion of fossil fuels. The study reveals that cointegration occurs among the three variables and a long run positive relationship exists. The results also show that a bidirectional positive causality is confirmed between energy consumption and GDP. A similar causality is obtained for energy consumption and economic growth. The study further suggests that China can reduce pollution by switching to renewable energy sources instead of over depending on non-renewables. Other researchers such as Apergis and Payne (2009), Nasir and Rehman (2011), and Shahbaz, Lean and Shabbir (2012) have confirmed the validity of EKC hypthosis in Central American countries, Pakistan, and Romonia respectively. Their empirical evidence also indicates that energy consumption contributes to environmental degradation.

In the meantime, some researchers have been focusing on the use of different sources of energy such as renewable energy, non-renewable energy, electricity, natural gas, crude oil, coal and nuclear energy in their studies. For instance, Sebri and Ben-Salha (2014) apply ARDL bounds testing approach to cointegration and vector error correction model reveal a long run equilibrium relationship among economic growth, renewable energy consumption, trade openness and carbon dioxide emissions and a bidirectional causality between renewable energy consumption and economic growth in BRICS countries. A study by Ben Jebli and Ben Youssef (2015) finds that EKC hypothesis does not exist in the case of Tunisia for the period 1980-2009. However, there is a unidirectional causality relationship running from GDP, carbon emissions, non-renewable energy and trade openness to renewable energy. Al-mulali, Ozturk, and Solarin (2016) use non-stationary panel data techniques to test the existence of EKC hypothesis and the link between renewable energy consumption and pollution in seven selected regions. Renewable energy consumption is found to have a negative influence on pollution in five regions including Central and Eastern Europe. In some other regions such as North Africa, renewable energy consumption does not seem to have any impact on the environment. In addition, the study concludes that EKC hypothesis is only valid in regions where renewables play an important role in reducing pollution. Furthermore, a number of authors have considered the consumption of natural gas, oil and coal in their studies. These researches include Aqeel and Butt (2001), Lotfalipour, Falahi, and Ashena (2010), Tiwari, Shahbaz, and Hye (2013) and Zamani (2007). Some other studies such as Baek (2016), Iwata, Okada, and Samreth (2011), and Wolde-Rufael (2010) have emphasized on the role of nuclear energy consumption in affecting economic growth and/or CO_2 emissions.

Specifically, a group of studies have investigated either the electricity-GDP nexus or the relationship between electricity and pollution or the mixture of both. Most of these studies have been focusing on the use of electricity consumption rather than electricity production. For instance, Narayan and Prasad (2008) employ a bootstrapped Granger causality approach and find a unidirectional links running from economic growth to electricity consumption in three OECD countries (Finland, Hungary, and Netherlands). In contrast, a unidirectional causality relationship is running from energy consumption to electricity consumption in Czech Republic, Italy, Potugal, and Slovak Republic. For Iceland, Korea and UK, evidence of a bidirectional relationship between the two variables is found. Furthermore, Narayan, Narayan, & Popp (2010) use approaches of Pedroni panel cointegration test, group mean test, and Lambda-Pearson panel test for seven world panels for the period 1980-2006. It is reported that a bidirectional causality relationship exists between electricity consumption and economic growth in all the seven panels. Single country studies that investigate the relationship between electricity consumption and GDP include Altinay and Karagol (2005) for Turkey, Lai, et al. (2011) for China, and Odhiambo (2009) for South Africa. Studies with regard to the influence of electricity production from renewable and non-renewable sources on economic growth are even more uncommon. Menegaki and Tsagarakis (2015) investigate the relationships between scale of economic activity, the production of fossil energy and renewable energy production in 33 European countries who are the producers for crude oil, natural gas, coal, and renewable energy for the period 1990-2010. The EKC hypothesis is found only in renewable energy and crude oil production, but not for gas or coal. Using autoregressive distributed lag (ARDL) bounds testing approach to cointegration, Bento and Mountinho (2016) attempt to examine the causal relationships among CO_2 emissions, GDP, renewable electricity production, non-renewable electricity production and international trade of Italy for the period 1960-2011. It confirms the validity of environmental Kuznets curve (EKC) hypothesis. In both the short run and long run, renewable electricity production leads to a reduction in CO_2 emissions. A long run unidirectional causal relation is also found running from non-renewable electricity production to renewable energy production and from economic growth to renewable electricity production. The results imply that renewable electricity production can be a remedy for pollution problem over time.

3. DATA, MODEL, AND METHODOLOGY

3.1. Data and Variables

A panel dataset from 1990 to 2013 is constructed for 25 OECD countries. Adjustment has been made so that the dataset used in this study is balance[3]. All data are retrieved from the World Development Indicator (WDI), World Bank. Descriptive statistics of the variables are shown in Table 1.

Table 1: Descriptive statistics

Variables	Observations	Mean	Standard Deviation	Minimum	Maximum
CO_2 emissions (metric tons per capita)	600	8.669	3.884	2.346	20.208
GDP per capita (constant 2010 US$)	600	35661.75	18034.37	5510.63	91593.63
Electricity production from non-renewable sources (% of total)	600	53.767	33.091	0.012	99.99
Electricity production from renewable sources (% of total)	600	32.058	29.983	0.014	99.988

3.2. Model Specification

The objective of this study is to verify the EKC hypothesis in the presence of renewable and non-renewable electricity production. Hence, we develop a panel model specification underlying the EKC hypothesis as follow:

$$CO_{2it} = f(Y_{it}, Y^2_{it}, RENEW_{it}, NONRENEW_{it}) \qquad (1)$$

Where CO_2 represents the CO_2 emission measured in metric ton per capita, Y and Y^2 represents GDP and GDP^2 measured in constant 2010 US$ per capita, RENEW is the renewable electricity output measured in % of total electricity output, and lastly NONREW is the electricity production from non-renewable sources including oil, gas, and coal.
Equation (1) is specified and estimated in natural logarithm form as follows:

[3] Belgium, Czech Rep., Estonia, Germany, Greece, Hungary, Latvia, Luxembourg, Slovak Rep., and Slovenia were taken out from the analysis due to incomplete dataset. The 25 countries included in this study are Australia, Austria, Canada, Chile, Denmark, Finland, France, Iceland, Ireland, Israel, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, U.K., and U.S.

$$LnCO_{2it} = \beta_0 + \beta_1 LnY_{it} + \beta_2 LnY^2_{it} + \beta_3 LnRENEW_{it} + \beta_4 LnNONRENEW_{it} + \varepsilon_{it} \quad (2)$$

Since the model is in double log form, the coefficients of the independent variables can be used to measure elasticities. Based on the EKC hypothesis, Y is expected to have a positive sign while Y^2 is expected to have an opposite sign to dictate the inverted U-shaped curve. RENEW is expected to have a negative sign because renewable electricity production would reduce the emission of CO_2. Lastly non-renewable electricity production would increase the CO_2 emission and NONRENEW would have a positive sign.

3.3. Estimation Procedure

Equation (2) is estimated by using Panel ARDL model by utilizing the Pool Mean Group (PMG) approach of Pesaran, Shin and Smith (1999). It has an advantage over the two alternative panel estimators, Dynamic OLS (DOLS) and Fully Modified OLS (FMOLS) because it allows for the difference in the country for the short run dynamics. Furthermore, it can be applied irrespective of the order of integration of the series, as long as the series is not integrated at order 2, I(2). Therefore, we resort to panel unit root tests to ensure that the series is not I(2) before moving to long run estimation by using PMG. In this study, two panel unit root tests namely LLC and IPS are used.

After testing the integration order of the series, the next step is to test whether the variables are cointegrated in the long run. This is done by using cointegration test by Pedroni. Other than Pedroni test of cointegration, Kao test is also used to enhance the robustness of results.

Having confirmed the existence of long run cointegration, we resort to long run estimation by using PMG of Panel ARDL approach[4]. In order to estimate the long run effects and the speed of adjustments, we must allow short run dynamics for each country. This can be done by reformulating equation (2) as follow:

$$CO_{2it} = \sum_{j=1}^{p} \lambda_{ij} CO_{2i,t-j} + \sum_{j=0}^{q} \delta_{ij}\chi_{i,t-j} + \mu_i + \varepsilon_{it} \quad (3)$$

Where χ_{it} is a (4 x 1) vector of independent variables (Y_{it} ,Y^2_{it} ,$RENEW_{it}$, and $NONRENEW_{it}$ in natural logarithm), μ_i represents the fixed effects and lastly the error term, ε_{it} is assumed to be independently distributed across *i* and *t*, with zero means and positive variances. Furthermore, the error correction model of equation (3) can be specified as follow:

$$\Delta CO_{2it} = \varphi_i\left(CO_{2i,t-1} - \alpha_{oi} - \alpha'_i\chi_{it}\right) + \sum_{j=1}^{p-1} \lambda_{ij}{}^{*} \Delta CO_{2i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}{}^{*\prime} \Delta\chi_{i,t-j} + \mu_i + \varepsilon_{it} \quad (4)$$

Where $\varphi_i = -(1 - \sum_{j=1}^{p} \lambda_{ij})$; $\alpha_i = -(\sum_{j=0}^{q} \frac{\delta_{ij}}{\varphi_i})$; $\lambda_{ij}{}^{*} = -\sum_{m=j+1}^{p} \lambda_{im}$, j= 1, 2…., p-1; and $\delta_{ij}{}^{*\prime} = -\sum_{m=j+1}^{p} \delta_{im}$, $j = 1,2, \ldots, q-1$.

However, the squared term of GDP (Y^2) in equation (2) is always said to cause multicollinearity problem in the model. To minimize this problem, the squared term of GDP (Y^2) is not included in the PMG estimation. Following Cerdeira Bento and Moutinho (2016), the validity of the EKC

[4] For more on PMG approach, see Pesaran and Smith (1995) and Pesaran, Shin and Smith (1999).

hypothesis is observed through the long run and short run dynamics. To enhance the robustness, we include the squared term of GDP (Y^2) in the model as in equation (2) and estimate with the other two long run estimators, DOLS and FMOLS.

The estimation by using PMG, DOLS and FMOLS approach does not provide any information regarding the direction of causality between the variables. The direction of causality is vital for policy makers to regulate appropriate regulations and policies on the reduction of CO_2 emission. Therefore, we employ the Dumitrescu-Hurlin panel Granger causality test to find out the causal relationships among the variables.

This Dumitrescu-Hurlin panel Granger causality test is calculated by running standard Granger Causality regressions for each cross-section individually. The next step is to take the average of the test statistics, which are termed the Wbar statistic. It is shown that the standardized version of this statistic, appropriately weighted in unbalanced panels, follows a standard normal distribution. This is termed the Zbar statistic. The null hypothesis of this test indicates that there is no homogeneous Granger causality for all cross section units whereas the alternative hypothesis supports that at least one Granger causality exists in the panel data. The test can be represented by the following linear heterogeneous model:

$$y_{i,t} = \alpha_i + \sum_{i=1}^{K} \gamma_i{}^{(k)} y_{i,t-k} + \sum_{i=1}^{K} \beta_i{}^{(K)} \chi_{i,t-k} + \varepsilon_{i,t} \tag{5}$$

Where $K \in N^+$ and $K \in N^*$ and $\beta_i = (\beta_i{}^{(1)}, \dots., \beta_i{}^{(k)})$ and α_i, $\gamma_i{}^{(k)}$, and $\beta_i{}^{(K)}$ indicate constant term, lag parameter, and coefficient slope respectively.

There are a few advantages using Dumitrescu-Hurlin panel Granger causality test. First, it can be used in both situations where the number of years is smaller than the number of cross sections or vice versa. Second, it can be applied in unbalanced and heterogeneous panel even in the presence of cross-sectional dependence. Furthermore, this test is more superior as compared to the standard Pairwise Granger causality as it is able to solve the bias posed by homogeneity assumption (Dumitrescu & Hurlin, 2012).

4. EMPIRICAL RESULTS AND DISCUSSION

The results of panel unit root tests are reported in Table 2. From the results, it can be concluded that all variables are integrated at first order, I(1). The results fulfil the requirement to use the PMG approach to estimate the long run relationship. Table 3 shows the results of Pedroni and Kao test for cointegration. The results of Pedroni test confirm that the variables are cointegrated in the long run. This is further supported by the Kao test.

Having confirmed the existence of long run cointegration, the long run elasticities are computed using the PMG approach, FMOLS and DOLS. The results are shown in Table 4. From the PMG approach, the EKC hypothesis is validated. This can be seen from the negative sign of Y and positive sign of D(Y). The positive sign of D(Y) indicates short run economic growth will increase CO_2 emission while the negative sign of Y indicates the opposite in the long run. The other two variables RENEW and NONRENEW have correct expected sign and they are significant. Moving to the error correction term, the coefficient is -0.207 and it is statistically significant. This suggests that deviation from the long run equilibrium is corrected by approximately 20.7% in a year.

From FMOLS and DOLS, it can be noticed that all variables are statistically significant with correct expected sign. The coefficient of real GDP per capita is significant and positive while the sign of GDP square is negative and statistically significant. The negative coefficient of the squared term of the real GDP per capita indicates that after a threshold of income is reached, CO_2 emissions is expected to fall as income increases further. It is apparent that an inverted U-shaped relationship exists between CO_2 emissions and economic growth in OECD countries. The outcome is consistent with many of the existing studies such as Galeotti, Lanza, and Pauli (2005), Jalil and Mahmud (2009), Kristrom and Lungren (2003), and Tiwari, Shahbaz, and Hye (2013) who have validated the EKC. However, the result is contradictory with Rezek and Rogers (2008) and Zanin and Marra (2012) who argue that an inverted U-shaped nexus between pollution and GDP does not exist. Our finding suggests that the income level has reached a threshold in OECD countries where CO_2 emissions can be reduced by stimulating economic growth. Furthermore, non-renewable electricity production has a positive impact on CO_2 emissions as expected. However, it is found that renewable electricity production and CO_2 emissions are negatively related. The findings are in line with Bento and Mountinho (2016) who argue that non-renewable electricity production causes pollution while electricity production from renewable sources is an important remedy for environmental problems. This implies that the use of renewable energy sources particularly in electricity generation could be an alternate solution to reduce CO_2 emission in OECD countries.

Summarizing the results from PMG, FMOLS and DOLS, it can be concluded that the results in this paper are robust and consistent where i) the EKC hypothesis is supported in the OECD countries, ii) renewable electricity production can help in reducing CO_2 emission, and lastly iii) non-renewable electricity production should be reduced as it may increase the emission of CO_2.

Table 5 presents the results of Dumitrescu-Hurlin Granger causality test. Summarizing the results, it can be concluded that economic growth Granger causes CO_2 emissions unidirectionally. We obtain similar results to those revealed by Bastola and Sapkota (2015) and Fodha and Zaghdoud (2010) that confirm a unidirectional causality between GDP and pollution with the causality running from GDP to pollution. However, the results contradict with Ghosh (2010) and Alam et al. (2011) who find no causality between economic growth and CO_2 emissions.

Moreover, the results of Dumitrescu-Hurlin Granger causality test indicate the existence of a bidirectional causality between non-renewable electricity production and CO_2 emissions as it is in the case of Ben Jebli, Youssef, and Ozturk (2016). These findings confirm that the level of pollution tends to influence the use of fossil fuels in electricity generation. In the meantime, electricity production using non-renewable sources such as coal does play an important role in affecting the environmental quality in OECD countries. Similarly, a bidirectional causal relationship is observed between renewable electricity production and CO_2 emissions. The results imply that renewable energy sources do have an impact on pollution and vice versa, as suggested by Salim and Rafiq (2012).

The outcome of the causality analysis confirms that there is a bidirectional causality between economic growth and renewable electricity production. Besides, a unilateral causal relationship is discovered running from economic growth to non-renewable electricity production. This indicates that economic growth not only influences renewables used in electricity production but also the adoption of fossil fuels at power plants in OECD countries.

In addition, a two-way causality is found between renewable electricity production and non-renewable electricity production. The result is in line with the findings by Apergis and Payne (2012) on 80 countries and Ben Jebli, Youssef, and Ozturk (2016) on OECD countries. According to these authors, the bidirectional causality indicates that the two energy sources are substitutes to one another. As such, our result shows that the substitutability between renewable electricity and non-renewable electricity in terms of production exists in the case of OECD countries.

Table 2: Panel Unit Root tests

	LLC		**IPS**	
	Level	**First difference**	**Level**	**First difference**
CO_2	-0.2323	-18.0072***	1.0793	-17.5141***
	(0.4082)	(0.000)	(0.8598)	(0.0000)
	(3)	(4)	(3)	(4)
Y	3.4120	-12.1433***	4.3865	-11.3203***
	(0.9997)	(0.0000)	(1.0000)	(0.000)
	(3)	(4)	(3)	(4)
Y^2	3.3119	-12.1714***	4.1196	-11.3672***
	(0.9995)	(0.000)	(1.0000)	(0.0000)
	(3)	(4)	(3)	(4)
NONRENEW	3.1769	-12.9151***	3.6803	-12.9672***
	(0.9993)	(0.0000)	(0.9999)	(0.0000)
	(4)	(4)	(4)	(4)
RENEW	5.9816	-21.4370***	-0.5317	-21.6166***
	(1.0000)	(0.0000)	(0.2975)	(0.0000)
	(2)	(2)	(2)	(2)

***Notes*:** Figures without bracket is the test statistic. First bracket indicates the p-value. The last bracket is the maximum lag length selected based on SIC.

Table 3: Panel Cointegration Tests

A) Pedroni	
Panel cointegration statistics (within-dimension)	
Panel v-statistic	-0.043 (0.517)
Panel rho-statistic	0.051 (0.520)
Panel PP-statistic	-3.846*** (0.000)
Panel ADF-statistic	-3.574*** (0.000)
Group mean panel cointegration statistics (between-dimension)	
Group rho-statistic	1.808 (0.965)
Group PP-statistic	-4.700*** (0.000)
Group ADF-statistic	-3.474*** (0.000)

B) Kao	
ADF	-4.409*** (0.000)

Notes**:** Both tests examine the null hypothesis of no cointegration for the variables. *** indicates the rejection of null hypothesis at 1%. The figures without bracket represent test statistic values. Probability values are shown in the bracket. The lag length is selected automatically based on SIC.

Table 4: Results of PMG, FMOLS, and DOLS

	PMG	**FMOLS**	**DOLS**
Independent variable	Coefficient (t-stat)	Coefficient (t-stat)	Coefficient (t-stat)
Y	-0.049* (-1.822)	1.826*** (0.000)	1.572** (2.226)
Y^2	-	-0.078*** (0.000)	-0.067* (-1.932)
NONRENEW	0.124*** (7.756)	0.141*** (0.000)	0.114*** (0.000)
RENEW	-0.181*** (-8.995)	-0.123*** (0.000)	-0.058*** (-3.580)
Error-correction	-0.207*** (-3.801)	-	-
Short-run elasticities	Coefficient (t-stat)	-	-
D(CO_2)	-0.179*** (-2.931)	-	-
D(Y)	0.477*** (0.000)	-	-
D(NONRENEW)	0.519 (0.386)	-	-
D(RENEW)	-0.615 (0.371)	-	-

Notes: *** indicates significance at 1%.

Table 5: Dumitrescu-Hurlin Granger Causality Test

Null hypothesis	**Prob**	**Conclusion**
Y does not homogeneously cause CO_2	0.0000***	Unidirectional causality from Y to CO_2
CO_2 does not homogeneously cause Y	0.2248	
NONRENEW does not homogeneously cause CO_2	0.0000***	Bidirectional causality between NONRENEW and CO_2
CO_2 does not homogeneously cause NONRENEW	0.0000***	
RENEW does not homogeneously cause CO_2	0.0000***	Bidirectional causality between RENEW and CO_2
CO_2 does not homogeneously cause RENEW	0.0000***	
NONRENEW does not homogeneously cause Y	0.4046	

Null hypothesis	Prob	Conclusion
Y does not homogeneously cause NONRENEW	0.0000***	Unidirectional causality from Y to NONRENEW
RENEW does not homogeneously cause Y	0.0619*	Bidirectional causality between Y and RENEW
Y does not homogeneously cause RENEW	0.0063***	
RENEW does not homogeneously cause NONRENEW	0.0703*	Bidirectional causality between RENEW and NONRENEW
NONRENEW does not homogeneously cause RENEW	0.0368**	

Notes: *,** and *** denote rejection of null hypothesis at 10%, 5% and 1% respectively. The optimal lag length is 2, the results for Y^2 is not reported. However, it will be made available upon request.

5. CONCLUSION AND POLICY IMPLICATION

This research investigates the validity of Environmental Kuznets Curve (EKC) hypothesis in OECD countries by incorporating renewable electricity production and non-renewable electricity production into a pollution model. We use Panel ARDL bound testing approach for cointegration and Dumitrescu-Hurlin Granger causality test to examine the existence of long run and causal relationships among the variables.

The results show evidence of an EKC hypothesis indicating that CO_2 emissions can be reduced by increasing GDP. It is expected as most of the countries in the panel are developed countries. In other words, economic growth can be a natural remedy for environmental problems in OECD countries over time. Moreover, non-renewable electricity production is found to be harmful to the environment while renewable electricity production plays a vital role in reducing pollution. It is also evidence that economic growth Granger causes CO_2 emissions unilaterally. Moreover, the Granger causality test shows the existence of bidirectional causality between non-renewable electricity production and CO_2 emissions. Likewise, renewable electricity production is found to have a bidirectional causality with CO_2 emissions. In addition, our results portray that there is a unidirectional causality running from GDP to non-renewable electricity production but bidirectional causality between GDP and renewable electricity production.

As economic growth seems to be a good 'policy strategy' to curb pollution, thus it is vital for the policy makers of OECD countries to design appropriate growth-oriented policies and strategies so that CO_2 emissions can be reduced continuously in these countries. In relation to this, strategies aimed at improving energy efficiency, energy savings and the use of renewables should be incorporated as part of the growth policies to ensure an inverted U-shaped relationship between economic growth and CO_2 emissions over time. Our findings also imply that OECD countries should reduce their dependency on fossil energy for electricity production. Instead, the countries have to consider using more of renewable energy sources such as wind and solar power in electricity generation to reduce CO_2 emissions and subsequently to avoid the disastrous effects of global warming. Moreover, the adoption of renewables can help to enhance the energy security of those OECD countries that have been relying on imported fossil fuels for electricity production.

According to International Energy Agency (2015a), OECD countries' share of renewables in total energy supply is merely 9 per cent as compared to 49.6 per cent in Africa, 29.2 per cent in Non-OECD Americas, 25.7 per cent in Non-OECD Asia and 10.7 per cent in China. Most importantly, the share of renewable energy used in electricity production has declined from 51.6 per cent in 1990 to 48.8 per cent in 2013. The above figures indicate that there are still rooms for improvement when it comes to the utilization of renewable sources for energy production in OECD countries. Even though a strong directive has been implemented to increase the share of renewable energy to 20 per cent by 2020 in OECD Europe, more relevant energy policies are needed particularly in OECD Americas and OECD Asia Oceania to encourage renewable electricity production in order to reduce CO_2 emissions as suggested by our results.

As the adoption of renewables requires huge initial investment costs, financial incentives such as subsidies should be provided by the governments to encourage the use of renewable energy sources in electricity generation. In recent years, however, some OECD countries have started to slash subsidies for renewable sources due to plunging renewable energy technology prices and/or domestic political and economic situations. On the other hand, much greater efforts are required to reduce those subsidies that encourage the use of non-renewables and thus act as a hurdle to cut CO_2 emissions in OECD countries. In short, it is essential for OECD countries to implement and to continue with government policies that support and nurture the growth of renewable energy sector in order to move onto a more sustainable development path.

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