From Nonrenewable to Renewable Energy and Its Impact on Economic Growth: Silver Line of Research Development Expenditures in APEC Countries

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From Nonrenewable to Renewable Energy and Its Impact on Economic Growth: Silver Line of Research & Development Expenditures in APEC Countries

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Abstract: This study disaggregates energy, i.e. non-renewable and renewable energy consumption, and investigates its effect on economic growth. The time period of 1990-2015 is used to examine Asia Pacific Economic Cooperation (APEC) countries. This paper determines the cross-sectional dependence and employs a second-generation panel unit root test for precise estimation. The Pedroni and Westerlund cointegration tests are used to examine the long-run equilibrium relationship between the variables and confirm the presence of cointegration in the long run. The FMOLS and DOLS approaches are applied to investigate long-term output elasticities between the variables. The results show the stimulating role of energy (renewable and nonrenewable) consumption in economic growth. Research and development expenditures and trade openness have a positive effect on economic growth. Moreover, the time series individual country analysis also confirms that renewable energy has a positive impact on economic growth. The Granger causality analysis reveals the unidirectional causal relationship running from renewable energy consumption to economic growth and economic growth to non-renewable energy. This empirical evidence suggests that countries should increase investment in renewable energy sectors and plan for development in renewable energy for sustainable energy growth.

Keywords: Renewable Energy, Nonrenewable Energy, Economic Growth, Trade, FMOLS, APEC

I. Introduction

Energy is considered a significant factor for economic growth (Sadorsky, 2009a). Conventionally, coal, natural gas, and petroleum are the more effective and prominent sources of energy and are drivers of economic growth (Ellabban et al. 2014). Traditional energy sources demand has increased rapidly for economic and social development in the last fifty years (Aslan et al. 2014). Moreover, 65% of energy has been produced from traditional energy sources until 2013 (International Energy Agency, (IEA), 2015). Though the early 21st century, countries have faced various types of energy-related challenges all around the world, and world dependence on traditional energy sources has become a global concern (Sadorsky, 2009a). There are other issues that have arisen due to the dependence on traditional energy sources; for instance, with the rise in income and population, challenges include meeting energy demand, the volatility in energy prices (Destek and Aslan, 2017), and the escalation in carbon emissions due to production and consumption of energy (Koçak and Şarkgüneşi, 2017).

These issues have necessitated societies and institutions to discover substitute sources of energy to replace conventional energy supplies (Ozturk and Bilgili, 2015). In December 2015, energy and international environmental experts met for the climate change summit held at the Paris Conference of the Parties (COP21), and a consensus was developed in this conference to maintain global temperatures below the critical level of 2 degrees Celsius relative to the pre-industrial temperature. Additionally, energy experts further claimed that renewable energy sources could also play an important role in mitigating carbon emissions and maintaining the environmental quality. Renewable energy would be the best possible energy source for successfully becoming a substitute for traditional energy sources (Yildirim, 2014), as it has the least detrimental impact on the environment (Danish et al. 2017). Until 2013, the estimated renewable energy consumption was 19% of global energy consumption. The International Energy Agency (IEA) has developed an optimistic scenario; according to the scenario, electricity generation from renewable energy will rise to 39% by 2015. Recently, renewable energy's role in achieving sustainable economic growth has been at the center of the debate in the emerging trends of the global energy sector (Lund, 2007).

An extensive literature has been generated on the issue of the energy consumption-economic growth nexus (Wolde-Rufael, 2009). Moreover, Apergis and Payne (2010b) argued that a significant increase in renewable energy would be an alternative source of energy. Al-Mulali et al. (2013) have discussed that renewable energy is useful for countries in reducing their dependence on traditional energy sources and that it also strengthens the capabilities in energy security. According to the International Energy Agency (IEA, 2011), renewable energy consumption is increasing by 3% each year, and it is the fastest growing energy source globally. Moreover, the IEA has developed a scenario that reveals that electricity production from renewable energy sources will rise approximately 39% by 2050. In recent years, government supported programs such as incentives, tax credits, and subsidies have been the major drivers in the development of renewable energy. Currently, countries are focused on technology and renewable energy production, and these elements have become the dominant component of energy policies.

Recently, new growth theories have been developed that emphasize the role of technological change for economic growth. These theories support the view of innovation being the key driver of modern economic growth. Moreover, Inekwe (2014) argue that research and development is the key determinant of long-run economic growth. According to Romer (1986), investment in research and development is vital for technological development by using human capital and existing knowledge. Moreover, these endogenous growth models present a framework to investigate the relationship between R&D and economic growth. Recent literature supports the importance of investment in R&D for higher economic growth. The R&D expenditures are important for economic growth, which is currently considered a competitive advantage for firms and the economy as a whole (Grossman and Helpman, 1994). Various studies have found a positive link between R&D and economic growth (Bayarçelik and Taşel 2012, Freimane and Bāliņa 2016).

According to an Asia Pacific Economic Cooperation (APEC, 2016) report, APEC countries represent 57% of the global real GDP. The electricity demand of this region is approximately 60% of the world total (IEA, 2017). Furthermore, the trade share is approximately 47% of the world total. Real GDP doubled from 1989 to 2013. Moreover, electricity demand doubled during the period of 1990-2013, and power generation capacity increased 75% within this time period. An annual average growth rate of energy demand has been rising at 2.1% in APEC countries which is slightly higher than the global rate of 1.9%. The rapid increase in economic development has accelerated energy consumption in the APEC countries, which has adversely affected the environmental quality. Moreover, carbon emissions' share is 72% of the total world carbon emissions. APEC also accounts for 41% population of the world total. At the APEC forum[1] held in Beijing on September 2, 2014, energy ministers agreed to target a doubling of renewable energy's share in the energy mix by 2030. They decided that APEC countries should develop such policies that support the adoption of technology that helps in the production of renewable energy. However, renewable energy production is increasing significantly in this region, with a growth rate of 2.5% annually (APEC, 2016). Furthermore, total install[2] capacity will reach at 6235 GW by 2040 with renewable energy's share reaches 35%.

Due to the availability of renewable energy consumption data, numerous researchers have examined the dynamic relationship between energy consumption (from renewable energy sources) and economic growth for different countries by using different regional panel data sets with different econometric approaches but have arrived at mixed empirical results. In doing so, this paper contributes to the existing literature in several aspects: (i) This study examines the impact of energy consumption from non-renewable and renewable sources on economic growth in APEC countries; (ii) Research & development expenditures are included in the augmented production function as an additional determinant of energy consumption and economic growth; (iii) The unit root and cointegration tests are applied by considering cross-sectional dependence in the panel; (iv) FMOLS and DOLS are applied for long-term estimates; (v) The Granger panel causality is applied in order to examine the causal relationship between economic growth and its determinants. Our results indicate the presence of cointegration between the variables. Moreover, renewable and nonrenewable energy consumption contributes to economic growth. Research and development expenditures have a positive effect on economic growth. Trade openness is positively linked with economic growth. The Granger causality analysis shows that renewable energy consumption causes economic growth, but economic growth causes non-renewable energy. The feedback effect exists between research and development expenditures and economic growth.

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[1] https://www.apec.org/Meeting-Papers/Sectoral-Ministerial-Meetings/Energy/2014_energy

[2] Energy production from coal will dominant with the share of 33% in total energy production, 27 % energy produce from gas, 1 % energy will be produced from oil, nuclear resources will add 5 % of energy. Moreover, energy production from hydro resources will be 14%, and 20% of energy from wind, solar, bio gas, and others renewable energy sources.

The rest of the paper is arranged as follows. Section II presents the literature review. Section III describes the modeling as well as the data. The empirical methodology is detailed in Section IV. Section V reports the empirical results with a discussion. Conclusion and policy implications are drawn in Section VI.

II. Literature Review

II.I Energy Consumption-Economic Growth Nexus

In the existing energy economics literature, numerous studies have examined the causal relationship between energy consumption and economic growth for the short run and long run (Yoo 2006, Cong et al. 2008, Shahbaz and Lean 2012, Polemis and Dagoumas 2013, Hamdi et al. 2014, Aslan et al. 2014, Shahbaz et al. 2013, 2017, Alam et al. 2017), generally concentrating on electricity consumption and/or energy consumption variables. However, only a few studies have disaggregated energy consumption between nonrenewable and renewable energy and explored the dynamic association with economic growth. Therefore, it would be significant to investigate effect of energy consumption form non-renewable (renewable) on economic growth for designing comprehensive energy policies.

The literature on energy consumption and economic growth suggests four testable hypotheses. First, the growth hypothesis explains that a unidirectional causality runs from energy consumption to economic growth. It indicates that if energy consumption policy changes it directly affects economic growth. It implies that economic growth depends on energy consumption. Second, the conservative hypothesis explains that a unidirectional relationship runs from economic growth to energy consumption. In this hypothesis, energy consumption does not determine economic growth, but economic growth determines energy use. Third, the feedback hypothesis becomes validated when a bi-directional relationship exists between economic growth and energy consumption. It implies that policy regarding energy consumption affects economic growth positively or negatively, and vice versa. Fourth, the neutrality hypothesis explains that there is no causal relationship between economic growth and energy consumption. It means that if any change occurs in economic growth or energy consumption, it might not affect the other. Considering these hypothesizes, the energy-growth literature has not achieved any consensus for the various countries (Sebri, 2015). These studies seem different in terms of econometric methodology, time period, variables, countries, energy types, and results. In the last ten years, much literature has been generated on the energy-growth research direction, yet the studies that disaggregate energy consumption (renewable and non-renewable) and examine the causal relationship with economic growth are not sufficient. Taking this emphasis into account, our study will evaluate the existing literature in this line of research direction.

For instance, Sadorsky (2009b) examined the relationship between renewable energy and economic growth during the period 1994-2003 for emerging markets. The cointegration results show the existence of a long-run relationship between economic growth and renewable energy consumption. The Granger causality results show a one-way causality relationship running from economic growth to renewable energy consumption, in the long run, supporting the conservation hypothesis. The same conclusion is drawn by various authors for example, Ocal and Aslan (2013) employed Toda-Yamamoto causality method over the period of 1990-2010 for Turkey, Tiwari (2011) used structure VAR over the period 1960-2009 for India, and Kula (2014) for 19 OECD countries during the period of 1980-2008. In this context, Brini et al. (2017) examined the dynamic association between renewable energy consumption and output by incorporating oil prices and trade in the multivariate model by using the ARDL technique for the period of 1980-2011 for Tunisia. Their Granger causality results reveal the unidirectional causality relationship running from economic growth to renewable energy, supporting the conservation hypothesis.

However, Menegaki (2011) tried to explore the causal relationship between the share of renewable energy in total energy consumption and economic growth for Europe during the period of 1997-2007 within a multivariate panel framework. The dynamic error correction mechanism could not establish causality between economic growth and renewable energy consumption in either the short run or long run. These results support the neutrality hypothesis. Similarly, Bhattacharya et al. (2016) explored similar results by using heterogeneous panel causality for the top 38 renewable energy-producing countries for the period of 1991-2012, though the growth hypothesis was confirmed for nonrenewable energy. Moreover, Dogan (2015) also found feedback hypothesis using VECM approach for Turkey.

A number of studies have found growth hypothesis by adopting different econometric techniques for panel and single countries by using different time periods. For example, Yildirim et al. (2012) examined causality between energy consumption from different renewable sources and economic growth by using Toda-Yamamoto and bootstrap corrected causality tests for the USA during the period of 1949-2010. Their results show a unidirectional causal relationship running from biomass waste energy consumption to GDP growth, supporting the growth hypothesis. However, they also noted the neutral effect between renewable energy sources, i.e. hydroelectric, biomass, biomass-wood, geothermal, total renewable energy, and GDP growth. Salim et al. (2014) used data over the period 1980-2011 for OECD countries. Their panel cointegration results reveal cointegration between the study variables and energy consumption from renewable sources causes GDP growth, supporting the growth hypothesis being confirmed by causality analysis. Likewise, Bilgili and Ozturk (2015) for the G7 countries over the period 1980-2009, Hamit-Haggar (2016) gained results that support the growth hypothesis during the period of 1971-2007 for 11 Sub-Saharan African countries, and Amri (2017) used multivariate model for the period of 1980-2012 for Algeria. Using the panel data application, Inglesi-Lotz (2016) examined the influence of renewable energy consumption on economic growth during the period of 1990-2010 for 34 OECD countries. The panel estimation test results show the positive influence of renewable energy on GDP growth.

Lin and Moubarak (2014) examined relationship between energy consumption from renewable resources and economic growth for China over the period 1977-2011. Their results reveal the feedback hypothesis. Similarly, for the case of the BRICS countries, Shahbaz et al. (2016) investigated the causal relationship between biomass energy consumption and economic growth by incorporating capital and trade openness in the production function for the period of 1991Q1-2015Q4. Their results show the presence of a long-run equilibrium between the variables. They also found a bidirectional causality relationship between economic growth and biomass energy consumption. Shakouri and Yazdi (2017) studied the dynamic association between renewable energy consumption and economic growth by using the ARDL approach. Their empirical findings establish a bidirectional causality relationship between economic growth and renewable energy consumption, i.e. the feedback effect.

Various studies have found mixed results for different countries by using panel data. For example, Al-Mulali et al. (2013) examined the causal relationship between economic growth and renewable energy by dividing countries into three categories, high-income, upper-middle-income, and lower-middle-income countries, for the period of 1980-2009. Their causality results demonstrate mixed results for the various countries, including feedback hypothesis being valid for 79% of countries, the neutrality hypothesis being confirmed for 19% of countries, and the conservation hypothesis being true for 2% of countries. More recently, for the Black Sea and Balkan countries using the period 1990-2012, Koçak and Şarkgüneşi (2017) studied the link between renewable energy and output in a multivariable model with labor and capital. Their heterogeneous panel causality results provide mixed empirical results for this group of countries, i.e. the growth hypothesis was supported for Bulgaria, Greece, Macedonia, and the Russian Federation; the feedback effect for Albania, Georgia, and Romania; and the neutrality hypothesis for Turkey and the Ukraine.

II.II Research & Development Expenditures-Economic Growth Nexus

Economic growth is important to everyone because somehow it provides wealth to all. There are many important factors for economic growth. Solow (1956) argued sustainable high-tech progress is pivotal for economic growth. Recently, technological advancement in research and development expenditures has primarily contributed to the development of individual businesses, which has improved the economy (Inekwe, 2014). The existing literature has advocated the positive impact of research and development expenditures (R&D) in the long run on economic growth. Furthermore, many models of endogenous growth theory confirmed R&D as the primary factor for economic growth. However, there is little empirical evidence available for group data. For instance, Goel et al. (2008) investigated the association between R&D expenditures and economic growth by using the ARDL approach for the USA for the period of 1953-2000. They divided R&D expenditures into different categories, and their results indicate that R&D has a positive effect on economic growth in the long run. Using Bayesian model averaging (BMA), Horvath (2011) investigated the long-run relationship between R&D and economic growth for 72 countries, finding a positive effect of R&D on real GDP. Bayarçelik and Taşel (2012) examined the relationship between innovation and economic growth by incorporating research and development expenditures and R&D employment in the production function. They found that research and development expenditures and employment have positive and significant effects on economic growth. For the case of Turkey during the period 1990-2013, Tuna et al. (2015) found no Granger causality relationship between research & development expenditures and economic growth.

Inekwe (2014) examined the impact of research & development expenditures on economic growth during the period of 2000-2009 using an extended form of the Cobb-Douglas production function by applying group means and dynamic system GMM approaches in the case of upper-middle-income countries and lower-middle-income countries. The empirical results show that research & development expenditures have a positive and significant impact on economic growth for upper-middle-income countries. Akcali and Sismanoglu (2015) investigated the role of research & development expenditures on economic growth using data of 19 developed and developing countries by using Swamy's random coefficient model for the period of 1990-2013. Their empirical evidence reveals the positive impact of R&D on economic growth. Gumus and Celikay (2015) employed a bivariate model to examine the linkages between research and development expenditures and economic growth in the case of 52 developed and developing countries. They noted that research and development expenditures stimulate economic activity. Freimane and Bāliņa (2016) used European data for the period of 2000-13 to examine the effect of research and development expenditures and FDI on economic growth by applying the Generalized Method of Moments approach. Their empirical evidence reveals that research and development expenditures strengthen the effect of FDI on economic growth. Tsaurai (2017) also reported that research and development expenditures enhance economic growth by boosting economic activity. Recently, Aydin et al. (2018) re-investigated the relationship between research and development expenditures and economic growth for OECD countries and reported that research and development expenditures affect economic growth by improving the total factor productivity.

So far in the literature, studies have found mix results for renewable (non-renewable) energy and economic growth as well as R&D expenditures and economic growth in the long run. Thus, no consensus has been reached on whether renewable (non-renewable) energy significantly affects economic growth, not by incorporating R&D expenditures in production function? In doing so, this paper fills the gap in the existing literature by investigating the effect of renewable energy consumption, nonrenewable energy consumption and R&D expenditures on economic growth for the APEC region.

III. Modeling and Data

This paper investigates the effect of nonrenewable and renewable energy consumption on economic growth by incorporating research and development expenditures and trade openness as additional determinants in a multivariable production function, and gross fixed capital is included as a control variable. It is argued by Romer (1994) that research and development expenditures contribute to economic growth through innovations and increases in total factor productivity. Similarly, innovations in the energy sector affect energy demand, which affects domestic production and, hence, economic growth (Álvarez-Herránz at el. 2017). Trade openness affects energy consumption and economic growth through scale, technique, composition and comparative advantage effects (Gozgor, 2017). Similarly, Shahbaz at el. (2015) argued that trade openness may affect energy consumption negatively if the technique effect dominates over the scale effect; otherwise, trade openness adds to energy consumption. This indicates the importance of research and development expenditures and trade openness in the augmented production function while investigating the relationship between energy (renewable and nonrenewable) consumption and economic growth in the APEC region. The general form of the augmented multivariable production function is modeled as follows:

$$Y_t = f(RE_t, NRE_t, R_t, K_t, O_t) \qquad (1)$$

The data for all the variables are transformed into natural log to diminish the sharpness in the time series panel data. Log-linear transformation is also preferred by Shahbaz et al. (2016) and Bhattacharya et al. (2016), who argued that the log-linear specification provides empirical consistent and efficient results compared to simple linear specification. The log-linear specification of the augmented multivariable production function is modeled as follows:

$$\ln Y_{t,i} = \beta_0 + \beta_1 \ln RE_{t,i} + \beta_2 \ln NRE_{t,i} + \beta_3 \ln R_{t,i} + \beta_4 \ln K_{t,i} + \beta_5 \ln O_{t,i} + \mu_i \qquad (2)$$

where β_0 represents the slope coefficient, *i* indicates the countries (*1 2 3 4……N*), *t* represents the time period (1990-2015), and μ is the error term. Moreover, $\beta_1, \beta_2, \beta_3, \beta_4$ and β_5 are the coefficients of RE, NRE, R, K and O are used for renewable energy consumption, nonrenewable energy consumption, research & development expenditures, capital and trade openness, respectively. Y is used real GDP per capita.

This study covers the period of 1990-2015. The list of the APEC countries includes Australia, Singapore, China, the USA, New Zealand, Mexico, Japan, Indonesia, South Korea, the Philippines, Thailand, Canada, Malaysia, Russia, Peru, and Chile[3]. Annual data are used for the period of 1990-2015. The empirical analysis includes non-renewable (billion kilowatt hours) and renewable energy consumption (billion kilowatt hours), gross domestic product (constant 2010 US dollar), gross fixed capital formation (constant 2010 US dollar), R&D expenditures (constant 2010 US dollar) and trade openness (constant 2010 US dollar). Renewable energy consumption sources are hydroelectric, solar, wind, tide, waste, biomass energy, and geothermal. Nonrenewable energy consumption sources are petroleum, coal, and natural gas. Trade openness is the sum of exports and imports. The total population is used to convert data into per capita units. The Energy Information Administration (EIA, 2017) collects data on non-renewable and renewable energy consumption. The World Development Indicators (CD-ROM, 2017) provide data for gross domestic product, gross fixed capital formation, research and development expenditures, and trade (exports plus imports).

IV. Methodological Framework

IV.I Cross-Sectional Dependence Test

In the energy economics literature, numerous studies have used panel data but did not check the cross-sectional dependence. Cross-sectional dependence commonly exists in the panel data because countries are interlinked with each other at the regional and global levels. If studies do not control for the cross-sectional dependence, then the estimators will be inconsistent and biased (Phillips and Sul 2003). Therefore, it is important to examine the cross-sectional dependence in the panel data. In doing so, this study uses two different sets of tests to check cross-sectional

[3] We exclude Vietnam, Hong Kong, Papua New Guinea, and Brunei countries because of the unavailability of data.

dependence. First, we use the CD test suggested by Pesaran (2004). The following equation CD test is used for examining the cross-sectional dependence:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\rho_{ij}\right) \tag{3}$$

where *N* represents the sample size, *T* indicates the time period, and p_{ij} shows the estimate of the cross-sectional correlation of errors of country *i* and *j*. Breusch and Pagan (1980) suggested the LM test to investigate the cross-sectional dependence. The following second equation, for the LM test, is used to examine the cross-sectional dependence:

$$y_{it} = \alpha_i + \beta_i x_{it} + \varepsilon_{it} \tag{4}$$

where ***i*** represents the cross-sectional dimension from 1 to *N* and *t* represents the time period from 1 to *N*. The null hypothesis is no cross-sectional dependence, and the alternative hypothesis is the existence of cross-sectional dependence.

IV.II Panel Unit Root Test

Recent empirical studies have used the newly developed unit root test in the energy-economic literature because first generation unit root tests do not consider the cross-sectional dependence in the panel (Dogan and Seker, 2016). Therefore, this study employs the cross-sectional augmented IPS (CIPS) test, suggested by Pesaran (2007), and the cross-sectional augmented ADF (CADF) test. These tests are considered in second-generation unit root tests to examine the stationarity of variables. The reliability of the results increases by using the right unit root tests with the existence of cross-sectional dependence in the panel. Pesaran (2007) suggested the following third equation of the IPS cross-section augmented version to test the unit root:

$$\Delta x_{it} = \alpha_{it} + \beta_i x_{it-1} + \rho_i T + \sum\nolimits_{j=1}^{n} \theta_{ij}\Delta x_{i,t-j} + \varepsilon_{it} \tag{5}$$

where Δ represents the difference operator, x_{it} shows the analyzed variable, α is an individual intercept, T denotes the time trend in the data and ε_{it} is the error term. The lag length is determined by the Schwarz information criterion (SIC) method. The null hypothesis is that all individuals are not stationary within a panel, and the alternative hypothesis is that at least one individual is stationary within a panel.

IV.III Pedroni Panel Cointegration Test

To examine the presence of long-run relation between the variables, we apply the Pedroni panel cointegration test developed by Pedroni (1999, 2004). Apergis and Payne (2012) argued that Pedroni cointegration takes into account cross-sections and time series together in the short run. The Pedroni cointegration test uses two approaches for testing the cointegration between the variable, that is, within dimension and group dimension. First, within dimension contains four components, including panel-v statistic (nonparametric and based on variance ratio), panel-pp, panel-rho, and panel-ADF statistics. The second group statistics have three components, including group-rho, group-ADF, and group-PP. The group statistics are computed by dividing the numerator and denominator prior to summing over cross sections. The null hypothesis for all these tests assumes no cointegration between the variables, while the alternative hypothesis suggests that there is cointegration between the variables. The following regression is used for the Pedroni panel cointegration test:

$$y_{it} = a_i + \delta_i + \beta_{1i} x_{1i,t} + \beta_{2i} x_{2i,t} + \cdots \beta_{ki} x_{ki,t} + \varepsilon_{i,t} \qquad (6)$$

where i represents the time period from *1……. N*, t represents the cross-section from *1…….N.* y_i and x_i are supposed to be integrated in order 1(1). Individual and trend effects are represented by α_i and δ_i, respectively, while ε represents the residual. The null hypothesis of no cointegration is tested based on residuals: if the residuals in regression-6 are integrated in order 1(1), the null hypothesis cannot be rejected. The regression $\varepsilon_{it} = \rho \varepsilon_{it-1} + \omega_{it}$ is used to determine the integration of the residual.

IV.IV Westerlund Cointegration Test

Westerlund (2007) suggests four basic panel cointegration tests based on structural dynamics and thus does not impose any common factor limitation. A restricted panel error correction model is used to test the significance of the error-correction term, and p-values generated by the bootstrapping are robust against the cross-sectional dependencies. Two tests are employed to examine the alternative hypothesis of cointegration for the panel as a whole (Gt and Ga), whereas the two other tests are considered to assess the alternative that a minimum of one cross-sectional unit is cointegrated (Pt and Pa). The first two tests are referred to as group statistics, whereas two other tests are referred to as panel statistics. While estimating group-mean statistics, the error-correction constants are assessed for each cross-sectional unit separately, and thus, average statistics are examined. The null hypothesis of this technique may be written as "there is not any error-correction". If the null is rejected, then there is proof of cointegrating association between the variables in question. The following error correction model is considered by Westerlund:

$$\Delta Y_{it} = \delta_i^{'} d_t + \alpha_i Y_{i,t-1} + \lambda_i^{'} X_{i,t-1} + \sum_{j=1}^{pi} \alpha_{ij} \Delta Y_{i,t-1} + \sum_{j=-qi}^{pi} \gamma_{i,j} \Delta X_{i,t-1} + \varepsilon_{it} \qquad (7)$$

where i represents the cross-sections and t represents observations, d_t refers to the deterministic components, and α_i computes the speed of convergence to the equilibrium state after an unexpected shock.

IV.V Continuously Updated FMOLS Test

Bai et al. (2009) suggested a panel cointegration test, which not only considers the cross-sectional dependence, which might have been generated out of the unobserved non-linearity of the panel members. In order to handle the endogeneity and serial correlation, which are arising out of the asymptotic bias, the authors prepared the CUP-BC estimator. On the other hand, the CUP-FM estimator keeps the limiting distribution of the model parameters intact. These parameters are continuously updated (CUP) through iterations, by the time they reach the convergence.

IV.VI Granger Causality Test

To determine the causal relationship between the variables, we apply the Vector Error Correction Model (VECM) Granger causality test proposed by Engle and Granger (1987). This test provided direction of causality between the variables not only in long run but also in short run.

The panel based VECM can be written as follows:

$$\begin{bmatrix} \Delta \ln Y_{it} \\ \Delta \ln RE_{it} \\ \Delta \ln NRE_{it} \\ \Delta \ln K_{it} \\ \Delta \ln R_{it} \\ \Delta \ln O_{it} \end{bmatrix} = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \\ \delta_6 \end{bmatrix} + \sum_{p-1}^{q} \begin{bmatrix} \theta_{11p} & \theta_{12p} & \theta_{13p} & \theta_{14p} & \theta_{15p} & \theta_{16p} \\ \theta_{21p} & \theta_{22p} & \theta_{23p} & \theta_{24p} & \theta_{25p} & \theta_{26p} \\ \theta_{31p} & \theta_{32p} & \theta_{33p} & \theta_{34p} & \theta_{35p} & \theta_{36p} \\ \theta_{41p} & \theta_{42p} & \theta_{43p} & \theta_{44p} & \theta_{45p} & \theta_{46p} \\ \theta_{51p} & \theta_{52p} & \theta_{53p} & \theta_{54p} & \theta_{55p} & \theta_{56p} \\ \theta_{61p} & \theta_{62p} & \theta_{63p} & \theta_{64p} & \theta_{65p} & \theta_{66p} \end{bmatrix} \times \begin{bmatrix} \Delta \ln Y_{it-p} \\ \Delta \ln RE_{it-p} \\ \Delta \ln NRE_{it-p} \\ \Delta \ln K_{it-p} \\ \Delta \ln R_{it-p} \\ \Delta \ln O_{it-p} \end{bmatrix} + \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \\ \alpha_6 \end{bmatrix} ECT_{it-1} + \begin{bmatrix} \mu_{1it} \\ \mu_{2it} \\ \mu_{3it} \\ \mu_{4it} \\ \mu_{5it} \\ \mu_{6it} \end{bmatrix} \quad (8)$$

where Δ symbolizes the first difference operator, p represents auto-regression lag length, the Schwarz information criterion (SIC) determines the lag length, which is equal to 2, the error correction term (ECT) is extracted from the first equation for the long-run relationship between variables, *and* μ represents the random error term. The VECM is a two-step procedure to estimate the long-run and short-run causality between the variables. In the first step, the equation-2 is used to extract the residuals. The long-run causality exists, if the coefficient on the error correction term is statistically significant with a negative sign based on the t-statistic. In the second step, the short-run causality is examined by using F-statistic based on Wald tests to the difference and lag difference of all the independent variables. For example, the short-run causality is revealed by testing the null hypothesis H_0: θ_{12}, $p=0$.

V. Empirical Results and their Discussion

Table 2 shows the annual average growth rate for all the variables. The results reveal that China has the highest annual growth rate of real GDP by (9.98%), followed by Korea (4.46%), Malaysia (3.58%), Chile (3.77%), and Singapore (3.57%). Russia and Japan had the lowest annual average GDP growth rate during this period. Singapore is the highest renewable energy consumer with an annual growth rate of (13.02%), followed by China (10.93%). Canada and Russia are the lowest renewable energy consumers with the annual growth rate of (1.34%) and (-0.25), respectively. Moreover, China is also highest consumer of non-renewable energy with an annual growth rate of (5.73%), followed by Thailand (5.73%) and Singapore (5.01%). The USA, Japan, and Russia are the lowest nonrenewable energy consumers. In addition, the Philippines, Peru, Russia, and the USA have an annual growth rate of renewable energy consumption even lower than that of non-renewable energy. However, for other countries included in APEC, their annual average growth rate of renewable energy consumption is higher than that of non-renewable energy consumption.

Table 2: Annual Average Growth Rate

Country	$\ln Y_t$	$\ln RE_t$	$\ln NRE_t$	$\ln K_t$	$\ln R_t$	$\ln O_t$
Australia	1.7338	5.5536	1.6143	3.0857	1.8912	2.8221
Canada	1.2952	1.3424	1.2584	1.9533	2.2284	2.5960
Chile	3.7752	5.0509	3.4712	6.8516	5.5082	3.8314
China	9.9815	10.9360	5.7366	12.9247	19.5005	11.9596
Indonesia	3.3615	6.1069	4.4652	4.0772	9.9424	3.4348
Japan	0.8878	3.9671	0.3730	-0.4440	2.4010	3.8986
Korea	4.4601	8.9590	4.6570	3.4198	6.8146	6.9328
Malaysia	3.5810	6.8016	4.8668	4.3249	18.8494	3.4062
Mexico	1.1723	3.0401	2.0444	2.4571	6.4902	4.4065
New Zealand	1.4764	1.6211	1.0168	3.0964	1.6735	1.7992
Peru	3.2800	3.5767	4.8151	6.2049	13.8114	5.4052
Philippines	2.2081	2.5892	3.7166	2.6788	-0.0424	2.6897
Russia	0.9318	-0.2550	-0.0800	-1.3264	2.6697	8.7080
Singapore	3.5715	13.0230	5.0111	3.6208	15.6849	3.7277
Thailand	3.4442	8.3011	5.8896	1.8886	9.9895	5.8380
USA	1.4378	3.1826	0.3965	1.8979	2.3461	3.1184

Table 3: Cross-Sectional Dependence Analysis

Variables	$\ln Y_t$	$\ln RE_t$	$\ln NRE_t$	$\ln K_t$	$\ln R_t$	$\ln O_t$
CD-tests	8.2951***	25.036***	9.205***	2.285***	40.30***	25.378***
p-value	0.000	0.000	0.000	0.004	0.000	0.000
LM-test	986.1826***	1222.371***	1073.077***	961.254***	1158.83***	1056.05***
p-value	0.000	0.000	0.000	0.000	0.000	0.000
Note: ***and ** show significance at the 1% and 5% levels, respectively.						

Before proceeding to examine the unit root properties of the variables, we investigate whether cross-sectional dependence is present in panel data of APEC countries. In doing, we have applied CD and LM tests, and the results are reported in Table 3. These results reveal that the null hypothesis of no cross-sectional dependence is rejected. It implies the presence of the cross-sectional dependence in the panel. The next step is to check the unit root with the existence of cross-sectional dependence in the panel. The first-generation unit root tests may provide ambiguous empirical results, as these tests ignore the issue of cross-sectional dependence in the panel data. This issue is solved by applying CIPS and CADF cross-sectional dependence unit root tests, and the results are detailed in Table 4. The empirical results from the CIPS unit root test indicate that economic growth, nonrenewable energy consumption, renewable energy consumption, research and development expenditures, trade openness, and capitalization contain unit root problems at level with intercept. These variables are stationary at the 1st difference in the presence of cross-sectional dependence. This finding shows that all the variables are integrated at I(1). The empirical results provided by the CADF unit root test also confirm the findings of the CIPS test. It validates the reliability and robustness of the empirical findings.

Table 4: Panel Unit Root Analysis with Cross-Sectional Dependence

Variables	CIPS		CADF	
	level	First difference	level	First difference
$\ln Y_t$	-2.402	-3.540***	-2.299	-3.042 ***
$\ln RE_t$	-1.221	-5.158***	-2.677	-4.263***
$\ln NRE_t$	-2.302	-4.456 ***	-2.006	-3.010***
$\ln K_t$	-2.246	- 3.674 ***	-2.427	-2.751 **
$\ln R_t$	-2.590	-4.478 ***	-2.296	-3.215***
$\ln O_t$	-2.401	-4.212 ***	-2.048	-3.329 ***
Note: *** and ** show significance at the 1% and 5% levels, respectively.				

Table 5: Pedroni Panel Cointegration Analysis

Within dimension (panel statistic)			Weighted Statistics	
Test	Statistics	Prob.	Statistics	Prob.
Panel v-statistic	4.6282***	0.0000	0.1212	0.4517
Panel rho-statistic	2.7614	0.9971	2.3221	0.9899
Panel PP-statistic	-1.2170	0.1118	-2.2565**	0.0120
Panel ADF-statistic	-2.1538**	0.0156	-3.1444***	0.0008
Between dimension (individual statistic)				
Test	Statistics	Prob.		
Group rho-statistic	4.0179	1.0000		
Group PP-statistic	-1.6971**	0.0450		
Group ADF-statistic	-2.3491***	0.0098		
Note: ***, ** and * show significance at the 1%, 5% and 10% levels, respectively.				

Table 6: Westerlund (2007) Cointegration Analysis

Statistic	Value	Z-value	P-value	Robust P-value
G_t	-3.250	-4.333	0.000	0.000
G_a	-10.885	-2.956	0.000	0.000
P_t	-10.514	-3.652	0.000	0.000
P_a	-9.308	-1.910	0.026	0.000

Table 7: Continuously Updated FMOLS Analysis

Variables	LSDV	Bai-FM	CUP-FM	CUP-BC
ln RE_t	0.2375***	0.1326***	-0.0929***	-0.0425***
	(9.4951)	(10.3313)	(-6.5505)	(-3.5432)
ln NRE_t	0.1910***	0.3051***	-0.0494	0.1030***
	(7.0902)	(24.6204)	(-3.718)	(9.0975)
ln K_t	0.1443***	0.1928***	-0.0942***	0.0244**
	(5.5718)	(16.0484)	(-7.3837)	(2.2424)
ln R_t	0.2161***	0.0692***	-0.0340**	0.0239*
	(7.7756)	(5.3736)	(-2.3996)	(2.0060)
ln O_t	0.0803**	0.0494***	-0.1750***	-0.0707***
	(3.1433)	(3.9002)	(-11.9756)	(-5.8182)
Note: ***, ** and * show significance at the 1%, 5% and 10% levels, respectively. t-statistics are within parentheses				

After confirming the integrating order of the variables, we apply the Pedroni panel cointegration test, and the results are reported in Table 5. We find that 6 statistics of 11 reject the null hypothesis, i.e., no cointegration, which confirms the presence of cointegration between the variables. The empirical results by the Pedroni cointegration may be biased due to the ignorance of cross-sectional dependence in panel data. This issue is covered by applying the (Westerlund, 2007). The Westerlund cointegration approach is applied for examining the cointegration between the variables in the presence of cross-sectional dependence in panel data. The results are reported in Table 6, and we note that the null hypothesis of no cointegration is rejected at the 1 and 5 % levels of significance. Moreover, using the continuously updated FMOLS approach developed by Bai et al. (2009), we have checked the cointegration among the panel variables in presence of cross-sectional dependence and unobserved non-linearity. In order to show the robustness of empirical analysis, LSDV (Least Square Dummy Variable) and Bai and Ng (2006) two-step fully-modified estimator results are also shown. The results are reported in Table 7, and we find the presence of cointegrating between the variables. This shows the presence of long-run equilibrium among economic growth, nonrenewable energy consumption, renewable energy consumption, research and development expenditures, trade openness, and capitalization for the period of 1990-2015 in the APEC region. Moreover, it implies the robustness of the cointegration empirical analysis.

Table 8: Panel Long Run Analysis

Variables	Panel least square		FMOLS		DOLS	
	Coefficient	t-statistics	Coefficient	t-statistics	Coefficient	t-statistics
$\ln RE_t$	0.1309	10.1206***	0.1232	4.5515***	0.1480	4.2070***
$\ln NRE_t$	0.1014	10.336***	0.1065	3.9009***	0.1097	4.5080***
$\ln K_t$	0.4413	16.705***	0.3950	10.3456***	0.3805	9.5100***
$\ln R_t$	0.1072	7.9803***	0.0897	2.4471**	0.0810	2.5109**
$\ln O_t$	0.1234	5.6717***	0.1355	6.0905***	0.1204	5.8949***
Note: ***, ** and * indicate significance at the 10%, 5%, and 1% levels, respectively.						

The existing econometrics literature has suggested various methods to investigate the long-run output elasticities estimation. However, we have applied fully modified ordinary least square (FMOLS) proposed by Pedroni (2000, 2001), dynamic ordinary least square (DOLS) developed by Mark and Sul (2003), and panel least square. These approaches are effective in panel data as FMOLS and DOLS methods control the endogeneity problem and remove the serial correlation in the regressor (Fei et al. 2011). Furthermore, FMOLS estimator use the non-parametric approach to control the endogeneity and autocorrelation problem while parametric approach is used by DOLS estimator to solve these issues. The results are reported in Table 8, and we find that renewable energy consumption adds to economic growth. A 1% increase in renewable energy consumption boosts economic growth by 0.1232-0.1480%. These long-run empirical results are similar to Menegaki (2011) for 27 European countries, Salim et al. (2014) for OECD countries, Shahbaz et al. (2015b) for Pakistan, and Koçak and Şarkgüneşi (2017) for the Black Sea and Balkan countries. The relationship between nonrenewable energy consumption and economic growth is positive and significant. A 0.1014-0.1097% increase in economic growth is due to a 1% increase in nonrenewable energy consumption. This result is in line with Apergis and Payne (2012a) for 80 countries, Bhattacharya et al. (2016a) for 38 countries with the most renewable energy consumption, Ohlan (2016) for India, and Amri (2017) for Algeria. Capitalization has a positive and significant effect on economic growth. A 1% increase in capitalization will boost economic growth by 0.3805-0.4413%. Our results are consistent with Bilgili and Ozturk (2015) for G7 countries, Inglesi-Lotz (2016) for 34 OECD members countries, and Rafindadi and Ozturk (2017) for Germany. The impact of research and development expenditures on economic growth is positive and statistically significant. A 0.0810-0.1072% increase in economic growth is linked with a 1% increase in research and development expenditures. Similar results were reported by Freimane and Bāliņa (2016) for EU countries. Trade openness stimulates economic growth. Keeping other things constant, a 1% increase in trade openness leads to economic growth of 0.1355-0.1204%. These same empirical findings are reported by Shahbaz et al. (2016) for the BRICS countries and Shakouri and Khoshnevis Yazdi (2017) for South Africa.

Table 9. FMOLS Long Run Analysis

Variables	$\ln RE_t$	$\ln NRE_t$	$\ln K_t$	$\ln R_t$	$\ln O_t$	Constant	R^2	Adj-R^2
Australia	0.083***	0.397***	0.116**	-0.023	0.137***	7.962***	0.994	0.992
Canada	0.223**	0.008	0.320***	0.144**	0.042	6.050***	0.990	0.988
Chile	0.046**	0.131***	0.122**	0.419**	-0.008	7.026***	0.995	0.994
China	0.187***	0.203***	0.098	0.296***	-0.062	5.554***	0.999	0.998
Indonesia	0.074	0.282**	0.451***	-0.009	-0.024	4.728***	0.989	0.986
Japan	0.031**	0.084	0.045**	0.199***	0.059***	8.017***	0.988	0.985
S-Korea	0.013	0.418**	0.268	0.056	0.187*	4.505**	0.989	0.986
Malaysia	0.023	0.541***	0.169**	-0.005	0.052	6.840***	0.982	0.977
Mexico	0.067*	0.033	0.217***	0.058	0.024	7.024***	0.969	0.960
New Zealand	0.129***	0.092	0.250***	0.191***	0.138***	5.787***	0.994	0.993
Peru	0.207***	0.147*	0.141***	0.088***	0.002	7.619***	0.996	0.996
Philippines	0.338***	-0.114	1.113***	-0.39***	-0.473***	5.184***	0.964	0.955
Russia	-0.205	-0.169	0.294***	0.458***	0.084	4.740***	0.984	0.980
Singapore	0.068**	0.333***	0.198**	-0.042**	0.284***	6.087***	0.991	0.989
Thailand	-0.007	0.390***	0.183***	0.067***	0.076	5.764***	0.995	0.994
USA	-0.007	0.367*	0.328***	0.315***	0.100**	6.177***	0.988	0.985
Note: ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.								

Table 9 reports the empirical results of country-wise analysis. It is very significant to examine the influence of non-renewable and renewable energy consumption on economic growth on the individual country level. The results can be divided into three groups. In the first group, renewable energy has a positive and significant effect on economic growth in the long run for Australia, Canada, China, Chile, Japan, Peru, Mexico, New Zealand, the Philippines, and Singapore. This finding implies that an increase in renewable energy consumption enhances economic growth. Renewable energy has a statistically insignificant impact on economic growth for Indonesia, Malaysia South Korea, Thailand, and the USA. However, nonrenewable energy consumption statistically significant impact on economic growth. This suggests that these countries are dependent on non-renewable energy consumption for economic growth and infrastructure for renewable energy consumption is still at an early stage and may be mismanagement in utilization. In other words, the share of renewable energy consumption in the energy mix is still not enough to significantly have an impact on economic growth. Our findings suggest that Indonesia, Malaysia South Korea, Thailand and the USA should continue to use non-renewable energy source for economic growth. These results are similar to the findings of Brini et al. (2017) and Dogan (2015). Moreover, nonrenewable energy does not significantly affect economic growth for Canada, Japan, Mexico, New Zealand, and the Philippines. This finding is supported by the argument of Soytas and Sari (2009) that the excessive and inefficient use of fossil fuels may decrease economic growth. Moreover, the economic cost on the environment due to carbon emissions outweigh the economic benefit associated with the use of fossil fuel in the long run (Apergis and Payne 2010a, Wolde-Rufael 2010).

The empirical results reported in Table 9 reveal that long-run economic growth elasticities with respect to capitalization are positive and significant in all countries except China and South Korea. The findings suggest that capitalization is vital for economic growth in the APEC region. Likewise, the long-run elasticities of economic growth with respect to R&D expenditures indicate a significant and positive impact on economic growth in the case of Canada, Chile, China, Japan, New Zealand, Peru, Russia, Thailand, and the USA. In contrast, R&D expenditures have a significant and negative effect on economic growth in countries such as the Philippines and Singapore. Research and development expenditures have a negative annual average growth rate for the Philippines, and a substantial decline in R&D expenditure causes decreased economic growth. Furthermore, the R&D expenditure growth rate is not at that level for Singapore, for which it is positive and significantly affects economic growth. Moreover, Singapore should increase the R&D expenditure in the technology sector to substantially stimulate economic growth after a certain period. Moreover, the 2007-8 financial and economic crisis has directly or indirectly affected the economies around the world and resulting from this crisis, the economies cut R&D expenditure. Cincera et al. (2011) argued that during economic crises, businesses usually decrease their R&D expenditures as a cost-reduction strategy. In the remaining countries, research and development expenditures affect economic growth insignificantly. Time series analysis shows the importance of research and development expenditures for economic growth. The empirical long-run evidence shows that trade has a positive and significant effect on economic growth in Australia, Japan, South-Korea, New Zealand, Singapore, and the USA. Trade openness negatively affects economic growth in the Philippines. The negative influence of trade on economic growth is perhaps due to the negative trade balance position, with the volume of imports being more than that of exports, and exchange rate depreciation. For the remaining countries, trade openness has an insignificant influences economic growth.

Table 10. Panel VECM Granger Causality Analysis

Dependent	$\Delta\ln Y_t$	$\Delta\ln RE_t$	$\Delta\ln NRE_t$	$\Delta\ln K_t$	$\Delta\ln R_t$	$\Delta\ln O_t$	ECM_{t-1}
$\Delta\ln Y_{t-1}$	....	12.608*** (0.000)	0.2543 (0.6143)	6.8805*** (0.0090)	2.0033 (0.1577)	0.05111 (0.8212)	-0.0579 [0.000]***
$\ln RE_{t-1}$	2.5205 (0.1132)	....	2.3031 (0.1299)	0.4894 (0.4845)	0.07998 (0.7774)	0.9260 (0.3364)	-0.2312 [0.000]***
$\ln NRE_{t-1}$	10.399*** (0.0013)	8.7302*** (0.0033)	....	3.3945* (0.0661)	8.9212*** (0.0030)	1.7111 (0.1916)	-0.1191 [0.111]***
$\ln K_{t-1}$	17.7173*** (0.0000)	8.8252*** (0.0031)	0.2878 (0.5919)	....	0.5104 (0.4753)	0.1175 (0.7318)	-0.0598 [0.000]***
$\ln R_{t-1}$	17.3787*** (0.000)	2.1055 (0.1475)	12.0189*** (0.0005)	5.2342** (0.0226)	....	3.6534* (0.0567)	-0.1309 [0.000]***
$\ln O_{t-1}$	21.1098*** (0.0000)	1.5931 (0.2076)	15.9660*** (0.0000)	8.0104*** (0.0048)	3.3012* (0.0700)	....	-0.2270 [0.000]***

Note: Δ indicates the first difference; *, **, and *** indicate significant at the 10%, 5%, and 1% levels, respectively, p-values of F statistics are listed in parenthesis, and p-values of the t-statistics are listed in brackets.

After examining the presence of cointegration between economic growth and its determinants, the causal relationship between the variables is investigated by applying the panel VECM Granger causality approach. The empirical results of panel VECM Granger causality are shown in Table 10. In the long run, we find the feedback effect, i.e., bidirectional causality between renewable (nonrenewable) energy consumption and economic growth. This finding is parallel with Apergis and Payne (2012b), Al-Mulali et al. (2014), and Kahia et al. (2017), who noted the feedback hypothesis, but contrary to Payne, (2009), who claimed a neutral effect between renewable (nonrenewable) energy consumption and economic growth. Tugcu el al. (2012) also found no causal relationship between renewable energy and GDP growth, but Hamit-Haggar (2016) noted that cleaner energy Granger causes economic growth. Capitalization causes economic growth and as a result, economic growth causes capitalization in a Granger sense. This empirical evidence is consistent with Salim et al. (2014), Shahbaz et al. (2016) and Amri (2017). The bidirectional causal relationship exists between R&D expenditures and economic growth. This empirical evidence is dissimilar from Tsaurai (2017), who noted that R&D expenditures lead to economic growth. The relationship between trade openness and economic growth is bidirectional, i.e., trade openness and economic growth interdependent. This empirical finding is in line with Al-Mulali et al. (2011) and Ohlan (2016), who report that trade openness causes economic growth, and as a result, economic growth causes trade openness in a Granger sense. Trade openness causes renewable energy consumption (nonrenewable), and as a result, renewable energy consumption (nonrenewable) causes trade openness in a Granger sense. This result is consistent with Al-Mulali et al. (2014) but contradictory with Shakouri and Yazdi, (2017) who find no causal relationship between renewable energy consumption (nonrenewable) and trade openness.

In the short run, renewable energy consumption causes economic growth, but economic growth causes nonrenewable energy consumption. The feedback effect is found between capitalization and economic growth, but renewable energy consumption causes capitalization. Economic growth causes R&D expenditures, but similar is true from the opposite side. The unidirectional causality is found running from capitalization and trade openness to R&D expenditures. The bidirectional causal relationship exists between nonrenewable energy consumption and research and development expenditures. Economic growth, nonrenewable energy consumption and capital Granger cause trade openness.

VI. Policy Implications

According to the empirical finding, it seems that renewable and nonrenewable energy consumption are both important for the economic activities of the APEC countries. The bidirectional causality between renewable energy to economic growth in the long run implies that these economies are seeking to achieve energy independence and protect their economic activities from the results of the price volatility of fossil fuel. These results support the governmental policies by using renewable energy consumption for economic growth. The development of renewable energy production has increased significantly across the world in the last two decades. Government intervention is required for a successful transition toward a renewable energy supply from a nonrenewable energy supply. The government should provide a favorable environment for investors through property rights, developing human expertise, enhancing macroeconomic stability, transparency, and removing political barriers. On the financial side, governments should place emphasis on investment subsidies, lowering tariffs, credit incentives, tax incentive, establishing quotas, and green certificate trading for the development of renewable energy. The role of trade openness is also important for the development of economic growth in APEC through technology transfer, which would support investment in the renewable energy sector across these countries. However, energy production from the non-renewable energy share is still 82% in the energy mix. APEC countries' energy policies' focus should be in decreasing energy consumption from fossil fuel sources gradually without harming economic growth. Moreover, APEC is seeking to reduce energy intensity by up to 45 percent between 2005 and 2035. The positive relationship between R&D expenditures and economic growth encourages the role of R&D expenditures in APEC for sustainable economic growth. In addition, APEC countries' governments should develop such strategies that strengthen public-private linkages and provide such incentives to the private sector for spending more on the research & development sector.

According to the time series analysis, it seems that renewable energy is more important than nonrenewable energy for economic growth in Canada, Japan, and Mexico. Energy consumption from renewable sources instead of energy consumption from nonrenewable sources will be a rational policy for these countries. The results suggest nonrenewable and renewable are both important for Australia, Chile, China, New Zealand, Peru, the Philippines, and Singapore. These countries should continue to promote energy consumption from renewable energy sources for sustainable economic growth. However, conservative policy for nonrenewable energy may damage economic growth. These countries government should develop such policies that are helpful to shift stepwise from nonrenewable to renewable energy. However, nonrenewable energy is more important than renewable energy for Indonesia, South Korea, Malaysia, Russia, Thailand, and the USA. It is due to the smaller renewable energy share in the total energy consumption. The governments of these countries should implement such policies that promote energy production from renewable sources and increase the share of nonrenewable energy consumption in the energy mix for sustainable and long-run economic growth in future. In addition, Canada, Chile, China, Japan, New Zealand, Peru, Russia, Thailand, and the USA should enact policies to increase R&D expenditures for higher economic growth, while the Philippine and Singaporean governments should implement policies that provide tax incentives and financial assistance to promote greater R&D spending. Trade also plays an important role in the import and export of technology between countries and stimulates economic growth.

Furthermore, APEC countries have set their future targets to accomplish renewable energy production and develop the strategies. According to their master plan, Australia will generate 23.5% renewable energy by 2020 of its total energy, Chile and China plan to generate 20% renewable energy by 2025 to meet their needs, Japan will add 22% to 24% renewable energy in total energy by 2030, South Korea has set a plan to add 13.4% renewable energy by 2035, Mexico will generate 29.1% renewable energy by 2028, New Zealand has set a plan to generate 90% renewable energy of total energy by 2025, Peru will contribute approximately 60% renewable energy of total energy by 2020, Russia will add 4.5% renewable energy by 2030, and Thailand will generate 20% renewable energy of total energy by 2036.

VII. Conclusion and Future Directions

The importance of renewable energy sources has grown all around the world due to its lower negative impact on the environment and for attaining sustainable economic development. Moreover, renewable energy is useful for decreasing the dependence on conventional energy. It is also convenient for sustaining a country's economic position because volatility in fossil fuel prices retards economic growth. This study explores the possible effect on economic growth of non-renewable and renewable energy consumption for the APEC countries in the presence of R&D expenditures, capital and trade openness in the production function. We use the time period of 1990-2015, as renewable energy production policies were developed and implemented in the APEC region. Most importantly, second generation tests are employed to examine the stationarity of the variables and identify the cross-sectional dependence in a panel of countries. Pedroni and Westerlund's (2007) panel cointegration methods are used to investigate the long-term equilibrium relationship between economic growth and its determinants. The panel Granger causality test is employed to explore the short-run and long-run causality between variables. Further, DOLS and FMOLS models are used to explore the long-run output elasticities.

The empirical results show the presence of cointegration between the variables. Moreover, renewable and nonrenewable energy consumption has a positive effect on economic growth. Capitalization accelerates economic growth. Trade openness adds to domestic production, and hence, economic growth is stimulated. Research and development expenditures enhance economic growth. The panel Granger causality analysis reveals the feedback effect between energy (renewable and nonrenewable) consumption and economic growth. Capital causes economic growth, and economic growth causes capital in a Granger sense. The bidirectional relationship exists between trade openness and economic growth. The relationship between research and development expenditures and economic growth is bidirectional.

This study opens up the future research direction to further examine the impact of different sources of renewable energy on different economic sector levels. Future studies can also classify the research & development expenditures into different categories, such as applied research, basic research, and spending on education, and examine the impact of each type of R&D spending on economic growth as well as on each economic sector.

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Appendix A

Table A: Summary of Existing Studies on Renewable Energy Consumption and Economic Growth

Authors	Period	Methodology	Country	Hypothesis
Apergis and Payne (2010c)	1992-2007	FMOLS, panel error correction model	Eurasia	Feedback
Apergis and Payne (2010b)	1985-2005	FMOLS, panel error correction model	20 OECD	Feedback
Ben Jebli and Ben Youssef (2015)	1980-2010	OLS, FMOLS, DOLS, Granger causality	69 countries	Neutrality
Apergis and Payne (2011b)	1980-2006	FMOLS, Granger causality test	Six central American	Feedback
Apergis and Payne (2012a)	1990-2007	FMOLS, panel error correction model	80 countries	Feedback
Apergis and Payne (2012)	1990-2007	Panel error correction model	Central America	Growth and feedback
Arifin and Syahruddin (2011)	1971-2008	Toda and Yamamoto	Indonesia	Growth
Dogan (2015)	1990-2012	ARDL approach, Vector error correction model	Turkey	Growth
Tugcu et al. (2012)	1980-2009	ARDL approach, Hatemi.j developed causality test	G7	Feedback
Chang et al. (2015)	1990-2011	Granger causality	G-7 countries	Feedback
Lin and Moubarak (2014)	1977-2011	ARDL approach, Granger causality	China	Feedback
Furuoka (2017)	1992-2011	Granger causality, Dumitrescu-Hurlin panel causality	Baltic region	Conservation
Cetin (2016)	1992-2012	FMOLS, Heterogeneous panel causality	E-7	Neutrality
Menegaki and Ozturk (2016)	1997-2009	Fixed effect model, Granger causality	MENA	Growth
Shahbaz et al. (2016)	1991-2015	Fixed effect model, Vector error correction model,	BRICS	Feedback
Shahbaz, et al. (2015a)	1972-2011	ARDL approach, VECM granger causality	Pakistan	Feedback
Shakouri and Khoshnevis Yazdi (2017)	1971-2015	ARDL approach, Granger causality	South Africa	Feedback
Carmona et al. (2017)	1973-2015	Toda and Yamamoto	USA	Neutrality
Destek and Aslan (2017)	1980-2012	Bootstrap panel causality	Emerging economies	Feedback, Neutrality, Conservation, and Growth
Tugcu and Tiwari (2016)	1992-2012	A panel bootstrap Granger causality	BRICS	Neutrality
Ohlan (2016)	1971-2012	ARDL approach, VCCM	India	Growth and Feedback
Khoshnevis Yazdi and Shakouri, (2017)	1979-2014	ARDL approach and Granger causality	Iran	Growth and Feedback
Arifin and Syahruddin (2011)	1971-2008	Granger causality	Indonesia	Growth
Ben Aïssa et al. (2014)	1980-2008	FMOLS, DOLS, OLS, VECM	11 Africa countries	Neutrality
Apergis and Payne (2011a)	1990-2007	FMOLS, DOLS, VECM	Developed and developing countries	Feedback
Al-Mulali et al. (2014)	1980-2010	DOLS approach, VECM	18 Latin American countries	Feedback
Bildirici (2016)	1980-2010	ARDL approach, Granger causality	Selected developed countries	Conservation, Growth and Feedback
Inglesi-Lotz (2016)	1990-2010	Panel cointegration, Fixed effect	34 OECD member countries	Renewable energy positively affects economic growth.