CO_2 Emissions, Energy Consumption and Economic Growth: Evidence from the Trans-Pacific Partnership*

Duc Hong Vo
Business and Economics Research Group
Ho Chi Minh City Open University, Vietnam

Ha Minh Nguyen
Ho Chi Minh City Open University, Vietnam

Anh The Vo
Business and Economics Research Group
Ho Chi Minh City Open University, Vietnam

Michael McAleer**
Department of Finance, Asia University, Taiwan
and
Discipline of Business Analytics
University of Sydney Business School, Australia
and
Econometric Institute, Erasmus School of Economics
Erasmus University Rotterdam, The Netherlands
and
Department of Economic Analysis and ICAE
Complutense University of Madrid, Spain
and
Institute of Advanced Sciences, Yokohama National University, Japan

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** Corresponding author: michael.mcaleer@gmail.com

Abstract

The paper investigates the role of consumption of both renewable and sustainable energy, as well as alternative and nuclear energy, in mitigating the effects of carbon dioxide (CO_2) emissions, based on the Environmental Kuznets Curve (EKC). The papers introduces a novel variable to capture trade openness, which appears to be a crucial factor in inter-regional co-operation and development, in order to evaluate its effect on the environment, The empirical analysis is based on a sample of nine signatories to the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) for the period 1971-2014, which is based on data availability. The empirical analysis is based on several time series econometric methods, such as the cointegration test, two long run estimators, namely the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) methods, as well as the Granger causality test. There are several noteworthy empirical findings: it is possible to confirm the U-shaped EKC hypothesis for six countries, namely Australia, Canada, Chile, New Zealand, Peru and Vietnam; there is no evidence of the EKC for Mexico; a reverse-shaped EKC is observed for Japan and Malaysia, there are long run relationships among the variables, the adoption of either renewable energy, or alternative energy and nuclear energy, mitigates CO_2 emissions, trade openness leads to more beneficial than harmful impacts in the long run, the Granger causality tests show more bi-directional-relationships between the variables in the long run, and the Granger causality tests show more uni-directional-relationships between the variables in the short run.

Keywords: Renewable and sustainable energy, alternative energy, nuclear energy, carbon emissions, CPTPP, EKC hypothesis, DOLS, FMOLS, Granger causality, VECM.

JEL: C12, C52, Q42, Q43.

1. Introduction

Owing to the increasing threat of global warming and climate change, scholars, practitioners, policy makers, and governments have paid increasing attention to environmental pollution(see Ben Jebli and Belloumi (2017) [1]). Greenhouse gases, mainly carbon dioxide (CO_2) emissions, are considered to be the main environmental threat. According to the US Energy Information Administration (EIA), world emissions of energy-related CO_2 are projected to surge to 36 million metric tons in 2020, and reach 45 billion tons in 2040, an increase from 31 billion tons in 2010. This surge threatens the sustainability of both economic growth and the environment. These substantial changes notwithstanding, maintaining the present levels of economic growth, trading activities, and energy security is imperative, especially for open economies.

The introduction of cleaner energy sources is acknowledged in the academic and practical literature as one way of curbing greenhouse gas emissions. Most empirical studies have focused on renewable and sustainable energy, and non-renewable energy, using either a panel of countries (see Raza and Shah (2018) [3]), or a particular country (see, for example, Adebola Solarin et al. (2017) [4], Dogan (2015, 2016) [5,6], Dogan and Ozturk (2017) [7], Dogan and Seker (2016) [8], Dogan and Turkekul (2016) [9], Dogan and Seker (2016) [10], Shadzad et al. (2017) [11], and Shahbaz et al. (2017) [12]). However, only a few studies have explored the importance of alternative and nuclear energy (see, for example, Apergis et al. (2010) [2], Menyah and Wolde-Rufael (2010) [13], Dong et al. (2018) [14], and Iwata et al. (2010) [15]).

In this paper, we examine the role of two types of clean energy sources, namely renewable and sustainable energy, and alternative and nuclear energy, to evaluate the dynamic linkages that relate CO_2 emissions, economic growth, and trade openness. The paper contributes to the current literature, as follows:

(i) The contemporary literature and empirical studies focus on the importance of renewable energy in reducing the negative impacts of fossil fuel consumption on the environment and economic growth, but few have focused on the role of alternative and nuclear energy. The paper provides empirically rigorous insights on the relationship between energy consumption environment and economic growth.

(ii) The paper conducts a test of the Environmental Kuznets Curve (EKC) hypothesis as no consensus seems to have been reached in several preceding studies (see, for example, Raza and Shah (2018) [3], Dogan and Seker (2016) [8], Ali et al. (2017) [16], and Sharif et al. (2018) [17]).

(iii) In view of the establishment of numerous international trade partnerships in different parts of the world, the paper also investigates the impact of trade openness on environmental degradation.

The sample consists of signatories to the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP). The CPTPP is a trade agreement among 11 countries, namely Australia, Brunei, Canada, Chile, Japan, Malaysia, Mexico, New Zealand, Peru, Singapore, and Vietnam. The combined gross domestic product (GDP) of all the signatory countries comprises 13.4% of world GDP, approximately US$13.5 trillion, making the CPTPP the third largest free trade area, after the Free Trade Area of the Americas (FTAA) and the European Union (EU).

The empirical analysis is based on several time series econometric methods, such as the cointegration test, two long run estimators, namely the fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) methods, as well as the Granger causality test, to analyze the dynamic linkages among CO_2 emissions, the consumption of renewable and sustainable energy, the consumption of alternative and nuclear energy, gross domestic product (GDP), the squared value of GDP, and trade openness for each country. The insights from the empirical analysis should help policy makers and practitioners, as well as national governments, to design appropriate strategies for achieving common goals relating to economic growth, trade policy, environmental protection, and energy use.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature in terms of the available theoretical and empirical studies. Section 3 offers an overview of the methodology, including model specifications, data sources, and econometric techniques. The empirical results are discussed in Section 4. Some concluding remarks and policy implications are presented in Section 5.

2. Literature Review

Over a number of years, many academic studies have investigated the relationship between CO_2 and its determinants. For purposes of clarity, we can separate the literature review into three parts:

(i) The conventional linkages are between economic growth and environmental degradation, with an emphasis on the EKC hypothesis.

(ii) The roles of the consumption of renewable energy, and alternative and nuclear energy, are emphasized in mitigating harmful emissions. The linkages among economic growth, energy consumption, and CO_2 emissions have been examined extensively in the literature, so it is useful to focus on the effects of renewable energy and nuclear energy.

(iii) The effects of other key determinants of CO_2 emissions, especially trade openness, are highlighted. It has been argued that several countries have attempted to enhance co-operation across countries and within regions in different parts of the world.

2.1 Environment-Growth Nexus (EKC Hypothesis)

The first strand of the literature relates to the Environmental Kuznets Curve (EKC), which refers to the concept of the Kuznets curve on the inverted U-shaped relationship between income inequality and per capita income. As an important extension, the EKC, which hypothesizes an inverted U-shaped relationship between a country's per capita income and its environmental quality, has been estimated in many applications since the 1990s. The EKC states that an increase in a country's income leads to an increase in the level of CO_2 emissions at an early stage of economic development. However, when the level of national income reaches a certain threshold, the positive relationship is reversed.

Since the development of the EKC, there have been numerous efforts to test it, with the empirical results not being clear-cut, with contradictory outcomes that support and reject the hypothesis. The mixed findings arise from various factors, ranging from different countries in the sample, the disaggregated types of pollutants, and the estimation and testing methodologies adopted in the analysis.

Specifically, the preceding studies have validated the EKC for member countries of the Organization for Economic Cooperation and Development (OECD) (see, for example, Sharif et al. (2018) [17]), in developed countries (Raza and Shah (2018) [3]), and in the European Union (Dogan and Seker (2016) [8]). Recently, Dong et al. (2018) [18] found an inverted U-shaped curve between economic growth and environmental quality for the BRICS (Brazil, Russia, India, China, and South Africa) countries, while Zoundi (2017) [19] did not obtain such as curve for 25 African countries.

Empirical analyses of different countries have led to different results. Warnick and Lazarus (2018) [47] provide a comprehensive summary of previous studies on the EKC hypothesis, especially for different countries. For example, the existence of the EKC has been observed in France (Iwata et al. (2010) [15]), Turkey (Pata (2018 [20], (2018) [21]), Indonesia (Sugiawan and Managi (2016) [22]), China (Adebola Sadarin et al. (2017) [4], Dong et al. (2018) [14], Jalil and Mahmud (2009) [23], Jayanthakumaran and Liu (2012) [24]), and Pakistan (Shahzad et al. (2017) [11], Shahbaz et al. (2015) [25]).

Interestingly, Saboori and Sulaiman (2013) [26] reveal the presence of the EKC over the period 1980-2009, while Ali, Abdullah, and Azam (2017) [16] and Gill, Viswanathan, and Hassan (2018) [27] obtain the opposite outcome for Malaysia. The same is found in Vietnam, where evidence in support of or against the EKC hypothesis varies from one study to another (Tang and Tan (2015), [28], Al-Mulali et al. (2015) [29]). These contradictory empirical findings lead to the motivation for seeking additional empirical evidence regarding the EKC hypothesis.

2.2 Nexus between the Environment and Renewable and Nuclear Energy Sources

The second strand of the literature is related to the inclusion of energy consumption in economic growth and environmental degradation. However, given increasing concerns over global warming and climate change, academic research has shifted its focus toward cleaner energy use to mitigate the negative impacts of energy consumption on CO_2 emissions. Clean energy arises from two sources, namely renewable and sustainable energy, and alternative and nuclear energy.

Sugiawan and Managi (2016) [22] assert that numerous studies in the literature have placed less emphasis on the potential role of renewable and sustainable energy in testing the EKC hypothesis. They reviewed the empirical research on Indonesia using data for the period 1971-2010. Not only do they find an inverted U-shaped EKC relationship between economic growth and CO_2 emissions in the long run, but they also revealed the merits of using renewable energy to help reverse environmental degradation in both the short run and long run.

The beneficial impacts of renewable energy on toxic emissions has been acknowledged in a panel of countries, such as in 19 developed and developing countries (Apergis et al. (2019) [2]), and in the G7 countries (Raza and Shah (2018) [3]). Researchers have added further explanatory variables, such as non-renewable energy, capital, labor, trade openness, and fossil fuels (Raza and Shah (2018) [3]), Adebola Solarin et al. (2017) [4], Dogan (2015, 2016) [5,6], Dogan and Ozturk (2017) [7], Dogan and Seker (2016) [8], Dogan and Turkekul (2016) [9], Dogan and Seker (2016) [10], Shahbaz et al. (2017) [12], Ali et al. (2017) [16]). These extensive empirical findings tend to support the view that increasing the use of renewable energy would help mitigate environmental degradation.

Contemporary academics have also considered the effects of both renewable and nuclear energy on economic growth and the environment. In the USA, Menyah and Wolde-Rufael (2010) [13] have shown uni-directional Granger causality from the consumption of nuclear energy to CO_2 emissions, but no Granger causality from the consumption of renewable energy.

Dong et al. (2018) [14] examined the role of nuclear and renewable energy in a dynamic relationship among CO_2 emissions, economic growth, and the EKC for China. They found that these two clean energy sources are important in addressing environmental problems, and that the use of nuclear energy had a considerably smaller mitigating impact on toxic emissions than did renewable energy, which may contain invaluable policy implications for China.

2.3 Nexus between the Environment and Trade Openness

Trade openness is seen as a crucial factor in the relationship among economic growth, environmental degradation, and energy use. Copeland and Taylor (2004) [30] proposed two different hypotheses to elucidate the effect of trade openness on the environment:

(i) The Pollution hypothesis claims that polluting industries will shift from countries or areas with strict environmental regulations to those with lesser concerns regarding environmental protection. Shahzad et al. (2017) [11] maintain that multinational companies are willing to take advantage of their ability to relocate polluting production activities to low-income countries with relatively weaker environmental regulations. As a consequence, these countries will face severe environmental challenges because of their openness to international trade, while higher income countries are the beneficiaries.

(ii) The Factor Endowments hypothesis stipulates that the effect of trade openness on the environment relies on the production capability within a country. Highly capital intensive countries specialize in the production of capital-intensive goods. Most capital intensive industries are closely associated with the most polluting industries as the costs of production polluting goods are lower in areas with no environmental protection (Antweiler et al. (2001) [31]). As such, free trade has the ultimate effect on the environment in that countries with greater resource abundance that are used to produce pollution intensive goods will become even more polluting, while countries with relatively abundant resources for the production of cleaner goods will become even cleaner.

Antweiler et al. (2001) [31] outline three effects, namely scale, composition, and technology, from which openness to international trade can influence a country's level of environmental quality:

(i) Scale effect: trade expansion will increase output production and trade volume, thereby increasing the amount of pollutants and harming the environment.

(ii) Composition effect: trade openness can alter a country's composition of exports and imports to produce manufacturing-based goods, thereby worsening the environment.

(iii) Technology effect: trade openness leads to the transfer and adoption of modern and less energy consuming technologies, thereby improving the environment.

Antweiler et al. (2001) [31] tested the three effects, using data on sulfur dioxide concentrations, and concluded that free trade had a favourable effect on the environment. However, other empirical studies have revealed ambiguous empirical impacts of trade openness on the environment. Some studies have concluded that trade can be harmful to the environment via the scale effect discussed above (Menyah and Wolde-Rufael (2010) [13]), as well as via the composition effect (Shahbaz et al. (2017) [32]). Other studies have shown a positive outcome arising from the technology effect (Ali et al. (2017) [16]).

3. Methodology

3.1 Data Sources and Model Specification

The linkages among CO_2 emissions, the consumption of renewable energy, and income has been widely recognized in previous studies (see, for example, Apergis et al. (2010) [2], Menyah and Wolde-Rufael (2010) [13], and Zaidi et al. (2018) [33]). The present paper incorporates a new and interesting variable for the consumption of alternative and nuclear energy into the relationship among CO_2 emissions, the consumption of renewable energy, and economic growth. Additionally, in order to validate the well-known EKC, which hypothesizes a non-linear quadric equation for the linkage between increased economic development and environmental degradation, the squared value of GDP is incorporated in the model. The empirical analysis considers a sample of CPTPP signatory countries, which have a common goal of expanding export and import activities among the countries and other regions, which enables trade openness to be taken into account.

The paper concentrates on the relationship among CO_2 emissions, consumption of renewable energy, consumption of alternative and nuclear energy, GDP, the squared value of GDP, and trade openness in the CPTPP countries over the period 1971–2014, except for Vietnam, for which the data cover the period 1989–2013. Renewable energy is approximated by combustible renewables and waste, GDP is measured in constant 2010 US dollars, and trade openness is calculated as the sum of exports and imports over GDP.

All the data are obtained from the online database of the World Development Indicators of the World Bank. Except for trade openness, the other variables are expressed in terms of per capita GDP. All the variables are transformed into natural logarithmic form in order to generate constant variance and covariance (see, for example, Chandran and Tang (2013) [34]), and to avoid possible functional form misspecification that could arise from assuming a linear relationship for the variables. The data descriptions are given in Table 1.

[Table 1]

The following model specification is considered:

$$CO_{2t} = \alpha_0 + \alpha_1 RE_t + \alpha_2 AN_t + \alpha_3 Y_t + \alpha_4 Y_t^2 + \alpha_5 OP_t + \varepsilon_t \quad (1)$$

where CO_{2t} represents per capita CO_2 emissions, RE_t is the per capita consumption of renewable energy, AN_t is the per capita consumption of alternative and nuclear energy. Y_t and Y_t^2 are real per capita GDP and the squared value of real per capita GDP, respectively, and OP_t is trade openness. The random error term, ε_t, is assumed to be independently and identically distributed, which can be tested using diagnostic checks..

The coefficients ($\alpha_i, i = 1,..,5$) denote the long run impact of the consumption of renewable energy, the consumption of alternative and nuclear energy, real income, the squared value of real per capita GDP, and trade openness on CO_2 emissions. The parameters α_1 and α_2 are expected to be negative so that an increase in the consumption of renewable energy, and of alternative and nuclear energy, will reduce CO_2 emissions. Moreover, α_3 is expected to be positive, and α_4 is expected to be negative, for the EKC hypothesis to hold. The effect of the impact of trade openness on CO_2 emissions, α_5, is ambiguous because of the dominance of the scale, composition, and technology effects.

3.2 Cointegration Test

Estimation based on the use of non-stationary variables can lead to spurious regressions and inferences, whereby asymptotic normality is assumed when the asymptotic distribution is actually non-standard, and relies on simulated critical values. A convenient method of addressing this issue is to use first differences of the variables to render them stationary. Nevertheless, taking first differences could harm the long run relationship among the key variables. It is preferable to check the long run relationship to ensure that the variables are non-stationary. The Engle and Granger approach (1987) [35] is traditionally used to test for the existence of a long run equilibrium cointegrating relationship.

The univariate Engle-Granger approach can present some difficulties, as follows. The test is sensitive to the explained (random) endogenous variables in the regression, and is not appropriate when the cointegrating vector does not involve the dependent variable but does include the other remaining variables. Moreover, the test lacks statistical power as it does not take advantage of all the available information about the dynamic interactions of the variables.

Owing to these limitations, wit is convenient to use a more powerful cointegration test that was proposed by Johansen (1988) [36], and was developed further by Johansen and Juselius (1990) [37]. The Johansen and Johansen-Juselius tests are superior to the Engle-Granger test for the following two reasons: the tests use the maximum likelihood estimation procedure, so that they can test for a number of cointegrating variables simultaneously. Moreover, the tests can determine more than one cointegrating relationship (see, for example, Chandran and Tang (2013) [34].

The Johansen-Juselius procedure to test the long run relationship can be expressed in terms of the vector error correction model (VECM), as follows:

$$\Delta Z_t = \Pi Z_{t-1} + \Gamma_1 \Delta Z_{t-1} + \Gamma_2 \Delta Z_{t-2} + \cdots + \Gamma_{p-1} \Delta Z_{t-p+1} + \varepsilon_t$$

where:

$$\Delta Z_t = [\Delta CO_{2t}, \Delta RE_t, \Delta AN_t, \Delta Y_t, \Delta Y_t^2, \Delta OP_t]'$$

$$\Pi = -(I_m - \textstyle\sum_{i=1}^{p} A_i)$$

$$\Gamma_i = -\left(1 - \textstyle\sum_{j=1}^{i} A_j\right), \text{ for } i = 1, \ldots, p-1.$$

The matrix Π $(= \alpha\beta')$ contains the long run relationship information in Z_t which includes the vector of the speed of adjustment to equilibrium (α) and the matrix of the cointegration vectors (β). As previously discussed, the random error, ε_t, is assumed to be independently and identically distributed.

The Johansen-Juselius approach involves testing the null hypothesis for *r* cointegrating vectors in Z_t, with *r* being the rank of the matrix Π using the estimated eigenvalues, $\hat{\lambda}$. There are two types of statistics, namely the maximum eigenvalue test and the trace test, which are given as follows:

$$\lambda_{max}(r_0) = -T \log(1 - \hat{\lambda}_{r_0+1})$$

$$\lambda_{trace}(r_0) = -T \textstyle\sum_{j=r_0+1}^{k} \log(1 - \hat{\lambda}_j).$$

For the maximum eigenvalue test, the null $H_0: r \leq r_0$ against the alternative $H_1: r_0 = r_0 + 1$ can be tested whereas, for the trace test, the null hypothesis, $H_0: r \leq r_0$, is tested against the alternative hypothesis, $H_1: r_0 < r \leq k$. A rejection of the null hypothesis indicates the existence of a cointegrating relation.

3.2 Granger Causality Test

In the presence of the long run relationship among the variables from the cointegration test, we perform the Granger causality test in order to consider the dynamic effects among CO_2 emissions, the consumption of renewable energy, the consumption of alternative and nuclear energy, GDP, the squared value of GDP, and trade openness within the VECM framework. Previous research applies the VECM framework for purposes of a Granger-causality test (see, for example, Chandran and Tang (2013) [34]).

The testing framework for Granger causality is given as follows:

$$\Delta CO_{2t} = \pi_0 + \sum_{j=1}^{n} \pi_{1j} \Delta CO_{2t-j} + \sum_{j=0}^{n} \pi_{2j} \Delta RE_{t-j} + \sum_{j=0}^{n} \pi_{3j} \Delta AN_{t-j} + \sum_{j=0}^{n} \pi_{4j} \Delta Y_{t-j} + \sum_{j=0}^{n} \pi_{5j} Y_{t-j}^2 + \sum_{j=0}^{n} \pi_{6j} \Delta OP_{t-j} + \varphi_1 ECT_{t-1} + \epsilon_{1t} \tag{2}$$

$$\Delta RE_t = \pi_0 + \sum_{j=0}^{n} \beta_{1j} \Delta CO_{2t-j} + \sum_{j=1}^{n} \beta_{2j} \Delta RE_{t-j} + \sum_{j=0}^{n} \beta_{3j} \Delta AN_{t-j} + \sum_{j=0}^{n} \beta_{4j} \Delta Y_{t-j} + \sum_{j=0}^{n} \beta_{5j} \Delta Y_{t-j}^2 + \sum_{j=0}^{n} \beta_{6j} \Delta OP_{t-j} + \varphi_2 ECT_{t-1} + \epsilon_{2t} \tag{3}$$

$$\Delta AN_t = \pi_0 + \sum_{j=0}^{n} \gamma_{1j} \Delta CO_{2t-j} + \sum_{j=0}^{n} \gamma_{2j} \Delta RE_{t-j} + \sum_{j=1}^{n} \gamma_{3j} \Delta AN_{t-j} + \sum_{j=0}^{n} \gamma_{4j} \Delta Y_{t-j} + \sum_{j=0}^{n} \gamma_{5j} \Delta Y_{t-j}^2 + \sum_{j=0}^{n} \gamma_{6j} \Delta OP_{t-j} + \varphi_3 ECT_{t-1} + \epsilon_{3t} \tag{4}$$

$$\Delta Y_t = \pi_0 + \sum_{j=0}^{n} \delta_{1j} \Delta CO_{2t-j} + \sum_{j=0}^{n} \delta_{2j} \Delta RE_{t-j} + \sum_{j=0}^{n} \delta_{3j} \Delta AN_{t-j} + \sum_{j=1}^{n} \delta_{4j} \Delta Y_{t-j} + \sum_{j=0}^{n} \delta_{5j} \Delta Y_{t-j}^2 + \sum_{j=0}^{n} \delta_{6j} \Delta OP_{t-j} + \varphi_4 ECT_{t-1} + \epsilon_{4t} \tag{5}$$

$$\Delta Y_t^2 = \pi_0 + \sum_{j=0}^{n} \theta_{1j} \Delta CO_{2t-j} + \sum_{j=0}^{n} \theta_{2j} \Delta RE_{t-j} + \sum_{j=0}^{n} \theta_{3j} \Delta AN_{t-j} + \sum_{j=0}^{n} \theta_{4j} \Delta Y_{t-j} + \sum_{j=1}^{n} \theta_{5j} \Delta Y_{t-j}^2 + \sum_{j=0}^{n} \theta_{6j} \Delta OP_{t-j} + \varphi_5 ECT_{t-1} + \epsilon_{5t} \tag{6}$$

$$\Delta OP_t = \pi_0 + \sum_{j=0}^{n} \rho_{1j} \Delta CO_{2t-j} + \sum_{j=0}^{n} \rho_{2j} \Delta RE_{t-j} + \sum_{j=0}^{n} \rho_{3j} \Delta AN_{t-j} + \sum_{j=0}^{n} \rho_{4j} \Delta Y_{t-j} + \sum_{j=0}^{n} \rho_{5j} \Delta Y_{t-j}^2 + \sum_{j=1}^{n} \rho_{6j} \Delta OP_{t-j} + \varphi_6 ECT_{t-1} + \epsilon_{6t} \tag{7}$$

where Δ indicates first differences, and *n* is the number of optimal lags, and ECT_{t-1} is a one-period lagged error correction term that is derived from the long run estimation of equation (1). The random errors ($\epsilon_{it}, i = 1,..,6$) are assumed to be independently and identically distributed.

If the variables are not cointegrated, the Granger causality test is based on the vector autoregressive (VAR) framework with stationary variables. Instead, with the appearance of the cointegration relationship, this VECM specification provides both the short and long run Granger causal relationships among the variables.

Based on the vector of equations above, the short run impact of Granger causality from economic growth on CO_2 emissions is validated by testing the null hypothesis that the coefficients of economic growth in equation (2), both income and the squared value of income, are all simultaneously equal to zero. In other words, the test is of $\pi_{4j} = \pi_{5j} = 0 \ \forall \ n$, using the Wald test. A rejection of the null hypothesis implies a uni-directional impact of Granger-caused economic growth on CO_2 emissions. Similarly, in order to examine whether CO_2 emissions have a Granger causal effect on economic growth, equations (5) and (6) are estimated to test the significance of the parameters, $\delta_{1j} = \theta_{1j} = 0 \ \forall \ n$, based on the Wald test.

In the long run Granger causality test, a coefficient of the one-period lagged error correction term is added to the null hypothesis in conducting the test. Specifically, $\varphi_1 \neq \pi_{4j} \neq \pi_{5j} \neq 0$ indicates economic growth does Granger-cause CO_2 emissions, whereas $\varphi_1 \neq \varphi_1 \neq \delta_{1j} \neq \theta_{1j} \neq 0$ implies a reverse Granger-caused relationship from CO_2 emissions to economic growth in the long run. The same procedure is applied to test the short and long run Granger causal relationships among other pairs of variables in the system of equations.

4. Empirical Results

4.1 Results of Unit Root Tests and Cointegration Tests

It is necessary to perform a unit root test to check the nonstationary features in the time series. Three tests are commonly used, based on the augmented Dickey-Fuller (ADF) (see Mackinnon (1996) [38] and Dickey and Fuller (1979) [39], Phillips and Perron (PP) (1988) [40], and Kwiatkowski, Phillips, Schmidt and Shin (KPSS) (1992) [41]. The ADF and PP tests have the same null hypothesis of the presence of unit roots, such that the time series are nonstationary. In contrast, the KPSS test has a null hypothesis that the series are stationary. Table 2 depicts the results of the three tests for the levels and first differences of all the variables

The ADF and PP tests do not reject the null hypothesis in all series, indicating that all the variables for the six selected countries have a unit root in the levels of the variables. The KPSS test also supports this conclusion. In first differences of the variables, the three tests indicate stationarity, although the KPSS test fails to reject the null hypothesis in some cases, such as renewable energy consumption. Based on these test outcomes, it is safe to conclude that the variables in virtually all the countries are integrated of order I(1).

[Table 2]

The following step checks for the existence of a long run relationship among the variables using the cointegration test of Johansen and Juselius (1990) [37]. Table 3 illustrates the results of the Johansen-Juselius test. Although Cheung and Lai (1993) [48] suggest the max-lambda statistic for the Johansen-Juselius cointegration test seems to be inappropriate because of the small sample size, Ahn and Reinsel (1990) [49] and Reimers (1992) [50] propose an adjusted trace statistic that has greater power in small samples.

Interestingly, the max-lambda and trace statistics have a consistent conclusion, as both reject the null hypothesis of no cointegration at the 5% significance level. The trace test also rejects the null hypothesis of "at most two" cointegrating ranks ($r \leq 2$) for all countries, although the test outcomes for "at most three" cointegrating ranks ($r \leq 3$) holds for for Chile and New Zealand. The time frame of the data series comprise several decades, which may exhibit structural breaks due to, among other possibilities, the Asian financial crisis in 1997 and the global financial crisis that occurred during the period 2007-2009.

Given the possibility of structural changes over an extended period, we perform the cointegration test of Gregory and Hansen (1996) [42], which takes account of structural breaks (see Table 4). As can be seen, the ADF and t-statistics support a long run relationship with breaks in five countries, namely Australia, Mexico, Malaysia, New Zealand, and Vietnam. In summary, the cointegration test seems to advocate a long run relationship in the key variables.

[Tables 3 and 4]

4.2 Estimation Results

Based on the confirmation of the cointegrated relationship in the key variables, we use two types of long run estimators, namely the fully modified ordinary least squares (FMOLS) estimator of Phillips and Hansen (1990) [43] and the dynamic ordinary least squares (DOLS) estimator of Stock and Watson (1993) [44]. Table 5 reports the estimated results of these two long run estimators. There are have several notable findings, although the two estimators have marginally different quantitative outcomes.

[Table 5]

The existence of the EKC curve for Australia, Canada, Chile, and New Zealand is due to a consistent finding in both of the long run estimators. We can also verify the EKC hypothesis for Peru and Vietnam to a lesser extent, as the two countries have either a negative coefficient of GDP or a positive coefficient of the squared value of GDP that is significant for the DOLS and FMOLS estimators, respectively. These empirical findings contradict some previous results, which do not confirm the EKC hypothesis for either Vietnam or Peru Almulali et al. (2015) [29] and Zambrano-Monserrate et al. (2018) [45], respectively.

In Mexico, an increase in GDP produces greater CO_2 emissions, but the EKC hypothesis is not empirically valid, which is in line with previous analyses, such as Ertugrul et al. (2016) [46]. Japan and Malaysia are special cases, with a reverse EKC phenomenon. The coefficient for GDP is negative, while that for the squared value of GDP is positive, and both are highly significant at the 1% significance level These empirical findings differ from those in recent studies, such as Ali et al. (2017) [16] and Gill et al. (2018) [27], which support the EKC for Malaysia.

Based on either the FMOLS or DOLS estimators, using renewable energy helps to reduce CO_2 emissions for Australia, Chile, Japan, Mexico, New Zealand, and Peru. The estimates unexpectedly confirm that consumption of renewable energy is positively related to CO_2 emissions for Malaysia and Vietnam, while no statistically significant effect is seen for Canada. Similarly, the use of alternative and nuclear energy is found to be negatively associated with CO_2 emissions in six of the nine countries, with Mexico, Malaysia and Japan being the exceptions. In general, using a cleaner source of energy, namely renewable, alternative and nuclear, has beneficial effects on the environment.

Trade openness has a statistically negative impact on CO_2 emissions for Australia, Japan, Mexico, Peru, and Vietnam, but a positive effect for Malaysia and New Zealand. The evidence for Canada and Chile is inconclusive. An interesting implication is that, based on the specific country characteristics, trade expansion could be more harmful than beneficial for the environment. As such, different countries should encourage the implementation of an appropriate strategy and policy in favour of trading environmentally-friendly products in order to gain the benefits from the establishment of the CPTPP, as well as to minimize the negative impacts on the environment of conducting international trade.

4.3 Results of Granger-Causality Tests

As the key variables are cointegrated, we proceed to analyze the short and long run Granger causality in the VECM framework. Table 6 shows the outcomes of the Granger causality test of CO_2 emissions, consumption of renewable energy, consumption of alternative and nuclear energy, GDP, the squared value of GDP, and trade openness. In general, the pattern in the Granger causality relationships among the variables differs considerably across the countries, and most experience a uni-directional rather than bi-directional Granger causal link between the variables in the short run.

[Table 6]

In the long run, some countries have bi-directional causality among pairs of variables. For Canada, two pairs of variables, namely CO_2 emissions and consumption of alternative and nuclear energy, and consumption of renewable energy and consumption of alternative and nuclear energy, have a bi-directional Granger causal relationship.

Chile has a link between CO_2 emissions and renewable energy, while Malaysia has a relationship that consists of trade openness and economic growth. For Mexico, there is a bi-directional causal relationship for three variables, namely CO_2 emissions, economic growth, and trade openness.

A striking finding is observed for Peru, which has a bi-directional relationship between CO_2 emissions and consumption of renewable energy, and also between economic growth and consumption of alternative and nuclear energy. Peru displays a strong dynamic link among CO_2 emissions, economic growth, and clean energy (consumption of renewable, as well as alternative and nuclear energy).

Malaysia and New Zealand both have a similar pattern, in which there are long run uni-directional causal relationships from economic growth to the remaining variables, such as CO_2 emissions, consumption of renewable energy, consumption of alternative and nuclear energy, and trade openness.

For Australia, an increase in the degree of trade openness Granger causes economic growth and the consumption of nuclear and alternative energy in both the short and long run. The uni-directional impacts of trade openness on renewable energy use and CO_2 emissions are also observed in the long run.

In Japan, the consumption of nuclear and alternative energy is a leading factor in establishing causal relationships, as it not only causes CO_2 emissions in the long run, but also has uni-directional effects on economic growth, consumption of renewable energy, and trade openness, in both the short and long run.

For Vietnam, there are uni-directional Granger causal relationships from trade openness to CO_2 emissions and economic growth, as well as from the consumption of alternative and nuclear energy to trade openness in both the short and long run.

5. Concluding Remarks and Policy Implications

One of the most challenging problems that many countries all over the world are facing today is the issue of global warming and climate change, because of the increase in CO_2 emissions caused by the production and consumption of energy that are based on non-renewable fossil fuels. This issue has attracted great interest among policy makers and practitioners, as well as academics, in recent decades.

One possible solution is the use of cleaner sources of energy production. The merits of consuming renewable energy have been examined extensively in numerous empirical research in very recent years. However, research on the adoption of alternative n=renewable and sustainable sources, as well as nuclear energy, is still relatively limited.

For these reasons, the paper investigated the role of the consumption of both renewable energy and consumption of alternative renewable and sustainable, and nuclear, energy in mitigating CO_2 emissions based on the environmental Kuznets curve. The paper also examined the impact of trade openness in evaluating its effect on the environment. This interesting variable appears to have been a crucial factor in the movement toward inter-regional co-operation, development and policy making in recent years.

In order to evaluate such empirical effects, the paper considered a sample of countries that are signatories to the CPTPP for the period 1971-2014. We applied various time-series econometric methods, such as the Johansen-Juselius cointegration test, the FMOLS, and DOLS estimators, and the Granger causality test.

The paper has several noteworthy findings, with the effects varying considerably across different countries:

(i) It is possible to confirm the U-shaped EKC hypothesis for six countries, namely Australia, Canada, Chile, New Zealand, Peru and Vietnam.

(ii) There is no evidence of the EKC for Mexico.

(iii) A reverse-shaped EKC is observed for Japan and Malaysia.

(iv) There are long run relationships among the numerous variables.

(v) The adoption of either renewable energy, or alternative energy and nuclear energy, mitigates CO_2 emissions.

(vi) Trade openness leads to more beneficial than harmful impacts in the long run.

(vii) The Granger causality tests show more bi-directional-relationships between the variables in the long run.

(viii) The Granger causality tests show more uni-directional-relationships between the variables in the short run.

On the basis of these empirical findings, caution should be exercised in the expansion of trade among the CPTPP countries because of the potentially harmful environmental effects. Creation of a larger trading market can lead to more by-products, thereby placing pressure on the environment. The CPTPP countries should promote the exchange and adoption of more advanced production technology to shift manufacturing to more environmentally-friendly products and reduce harmful polluting by-products.

In this way, the benefits from the establishment of the CPTPP can be optimized, and the use of alternative cleaner sources of energy should be encouraged to maintain control over, and mitigate the effects of, harmful CO_2 emissions.

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Table 1
Data Description

	Australia	Canada	Chile	Japan	Mexico	Malaysia	New Zealand	Peru	Vietnam
Mean									
CO_2	2.74	2.80	1.06	2.17	1.30	1.31	1.95	0.23	-0.32
RE	5.50	5.91	5.45	3.74	4.50	4.53	5.37	4.86	5.16
AN	4.40	7.30	4.44	5.87	4.14	2.80	6.88	3.80	2.81
Y	3.63	3.62	1.98	3.54	2.06	1.62	3.29	1.29	-0.22
Y^2	13.20	13.15	4.11	12.60	4.26	2.85	10.84	1.71	0.21
OP	3.25	3.82	3.78	2.93	3.36	4.68	3.76	3.61	4.40
Std Dev									
CO_2	0.12	0.05	0.32	0.09	0.16	0.58	0.15	0.21	0.64
RE	0.09	0.16	0.38	0.29	0.14	0.25	0.27	0.41	0.03
AN	0.14	0.25	0.34	0.75	0.49	0.54	0.18	0.26	0.59
Y	0.24	0.20	0.42	0.28	0.15	0.47	0.17	0.20	0.40
Y^2	1.73	1.44	1.71	1.90	0.60	1.51	1.12	0.54	0.24
OP	0.34	0.29	0.38	0.29	0.61	0.38	0.27	0.25	0.61
Min									
CO_2	2.47	2.69	0.57	2.00	0.86	0.41	1.66	-0.11	-1.34
RE	5.25	5.59	4.88	3.48	4.20	4.09	4.89	4.18	5.11
AN	4.23	6.55	3.75	4.37	3.14	1.64	6.59	3.29	1.60
Y	3.27	3.23	1.36	2.96	1.69	0.72	3.03	0.96	-0.87
Y^2	10.68	10.43	1.86	8.77	2.85	0.52	9.17	0.92	0.00
OP	2.77	3.40	3.03	2.50	2.47	4.06	3.32	3.17	3.41
Max									
CO_2	2.90	2.90	1.56	2.29	1.47	2.08	2.18	0.69	0.53
RE	5.62	6.15	6.38	4.47	4.71	4.85	5.76	5.53	5.23
AN	4.91	7.57	5.03	6.66	4.67	3.66	7.36	4.15	3.92
Y	4.00	3.92	2.69	3.84	2.26	2.34	3.59	1.76	0.40
Y^2	15.99	15.34	7.22	14.74	5.09	5.48	12.87	3.11	0.75
OP	3.78	4.18	4.27	3.47	4.20	5.16	4.12	4.01	5.21

Notes: CO_2 = CO2 emissions, RE = consumption of renewable energy, AN = consumption of nuclear and alternative energy, Y = real per capita GDP, Y^2 = squared real per capita GDP, OP = trade openness.

Table 2
Unit Root Tests for Levels

		Australia	Canada	Chile	Japan	Mexico	Malaysia	New Zealand	Peru	Vietnam
ADF	**CO_2**	-0.83	-2.28	-2.34	-2.20	-2.21	-2.03	-1.81	-0.89	-0.86
	RE	-1.32	-2.94	-2.74	-0.60	-2.17	-1.84	-2.21	1.03	-2.72
	AN	-0.61	-2.99	-3.01	1.10	-0.76	-1.81	-1.63	-3.05	-2.80
	Y	-2.06	-2.40	-3.33*	-0.85	-2.78	-2.21	-1.69	-0.13	-0.94
	Y^2	-2.05	-2.26	-3.08	-0.70	-2.69	-2.24	-1.58	0.26	0.26
	OP	-2.73	-1.04	-1.00	-2.40	-1.62	-0.40	-1.48	-2.06	-0.66
PP	**CO_2**	-0.79	-2.41	-2.35	-2.26	-2.15	-2.11	-2.01	-0.74	-1.22
	RE	-1.40	-3.07	-2.73	-0.52	-2.56	-1.72	-2.25	1.21	-2.73
	AN	-0.55	-2.97	-3.03	1.54	-0.57	-1.97	-1.54	-2.97	-2.90
	Y	-2.13	-2.67	-3.27*	-0.89	-2.85	-2.36	-1.94	-0.47	-1.67
	Y^2	-2.10	-2.57	-2.99	-0.78	-2.80	-2.38	-1.80	-0.06	0.07
	OP	-2.72	-1.34	-1.06	-2.24	-1.86	-0.38	-1.57	-2.19	-0.96
KPSS	**CO_2**	0.20**	0.10	0.19**	0.12*	0.18**	0.14*	0.17**	0.27***	0.15**
	RE	0.13*	0.15**	0.17**	0.22***	0.22***	0.22***	0.25***	0.27***	0.17**
	AN	0.14*	0.27***	0.16**	0.26***	0.28***	0.18**	0.10	0.11	0.11
	Y	0.18**	0.07	0.19**	0.3***	0.11	0.16**	0.19**	0.27***	0.12*
	Y^2	0.21**	0.07	0.24***	0.29***	0.09	0.12*	0.21**	0.27***	0.24***
	OP	0.16**	0.15**	0.16**	0.24***	0.14*	0.20**	0.19**	0.20**	0.18**

Table 2 (cont)
Unit Root Tests for First Differences

Test	Variable	Australia	Canada	Chile	Japan	Mexico	Malaysia	New Zealand	Peru	Vietnam
ADF	**ΔCO_2**	-5.88***	-5.99***	-4.39***	-6.71***	-6.97***	-7.93***	-6.23***	-6.65***	-3.7**
	ΔRE	-6.75***	-5.04***	-4.23***	-6.26***	-4.44***	-6.93***	-6.82***	-4.95***	-3.69**
	ΔAN	-6.48***	-5.02***	-6.11***	-4.02***	-7.23***	-5.24***	-7.05***	-8.35***	-5.03***
	ΔY	-5.76***	-4.79***	-4.54***	-4.88***	-5.28***	-5.66***	-5.5***	-3.85***	-2.77*
	ΔY^2	-5.58***	-4.79***	-4.38***	-4.93***	-5.41***	-5.99***	-5.51***	-3.86***	-0.05
	ΔOP	-7.36***	-5.05***	-6.24***	-7.87***	-4.57***	-6.09***	-7.29***	-5.75***	-3.56**
PP	**ΔCO_2**	-5.91***	-6.03***	-4.34***	-6.8***	-6.97***	-7.84***	-6.22***	-6.65***	-3.76***
	ΔRE	-6.76***	-4.98***	-4.18***	-6.26***	-4.45***	-7.09***	-6.82***	-5.16***	-3.65**
	ΔAN	-6.48***	-4.97***	-6.15***	-3.94***	-7.18***	-5.15***	-7.09***	-8.58***	-5.10***
	ΔY	-5.73***	-4.69***	-4.47***	-4.89***	-5.23***	5.64	-5.49***	-3.82***	-2.86*
	ΔY^2	-5.54***	-4.7***	-4.31***	-4.95***	-5.36***	-5.97***	-5.49***	-3.83***	-0.20
	ΔOP	-7.41***	-5.05***	-6.3***	-8.19***	-4.46***	-6.09***	-7.25***	-5.84***	-3.56**
KPSS	**ΔCO_2**	0.08	0.08	0.12*	0.07	0.09	0.08	0.05	0.07	0.10
	ΔRE	0.09	0.06	0.16**	0.12*	0.10	0.07	0.07	0.17**	0.15**
	ΔAN	0.13*	0.13*	0.04	0.12*	0.08	0.08	0.11	0.05	0.13*
	ΔY	0.11	0.06	0.11	0.07	0.07	0.05	0.06	0.09	0.09
	ΔY^2	0.11	0.06	0.1	0.07	0.07	0.05	0.06	0.11	0.08
	ΔOP	0.18**	0.15**	0.07	0.06	0.10	0.2**	0.14*	0.11	0.11

Note: The tests include a constant and deterministic trend; ***, **, and * denote significance at 1%, 5%, and 10%, respectively.

Table 3
Johansen-Juselius Cointegration Tests

H0	H1	Australia	Canada	Chile	Japan	Mexico	Malaysia	New Zealand	Peru	Vietnam
Max - lambda										
r = 0	**r ≥ 1**	198.45**	184.74**	148.96**	140.01**	158.09**	210.7**	79.19**	134.14**	95.83**
r ≤ 1	**r ≥ 2**	111.31**	69.31**	87.88**	76.81**	99.43**	145.22**	59.13**	38.45**	50.86**
r ≤ 2	**r ≥ 3**	18.39	17.75	75.95**	18.66	40.74**	37.57**	46.63**	26.50	24.00
r ≤ 3	**r ≥ 4**	6.74	6.25	18.41	5.63	2.68	3.09	4.90	3.43	10.30
r ≤ 4	**r ≥ 5**	0.73	3.09	5.14	0.36	1.10	2.04	1.65	0.98	1.24
r ≤ 5	**r ≥ 6**	0.05	0.28	1.17	0.04	0.00	0.16	0.01	0.21	0.13
Trace										
r = 0	**r ≥ 1**	335.68**	281.42**	337.52**	241.51**	302.05**	398.79**	191.52**	203.73**	182.35**
r ≤ 1	**r ≥ 2**	137.23**	96.68**	188.56**	101.5**	143.97**	188.09**	112.33**	69.59**	86.52**
r ≤ 2	**r ≥ 3**	25.91	27.37	100.68**	24.69	44.53	42.87	53.2**	31.13	35.67
r ≤ 3	**r ≥ 4**	7.52	9.62	24.73	6.03	3.79	5.30	6.57	4.63	11.67
r ≤ 4	**r ≥ 5**	0.77	3.37	6.32	0.41	1.11	2.21	1.67	1.20	1.37
r ≤ 5	**r ≥ 6**	0.05	0.28	1.17	0.04	0.00	0.16	0.01	0.21	0.13

Note: ***, **, and * denote the null hypothesis of no cointegration at rank r is rejected at 1%, 5%, and 10% significance, respectively.

Table 4
Gregory-Hansen Cointegration Test with Structural Breaks

Test	Australia	Canada	Chile	Japan	Mexico	Malaysia	New Zealand	Peru	Vietnam
ADF	-5.78*	-4.62	-5.25	-5.23	-6.98***	-5.96***	-6.37***	-5.60*	-5.86***
	-6.43**	-5.84	-4.59	-5.00	-6.93***	-7.15***	-7.11**	-5.88	-6.28**
	-6.16	-5.74	-5.94	-5.83	-7.6***	-7.18**	-8.08**	-6.29	-6.27
Zt	-5.85**	-5.09	-5.44	-5.29	-7.06***	-6.03**	-6.45**	-5.66*	-6.11**
	-6.51**	-5.33	-5.24	-5.24	-7.01***	-7.23***	-7.19**	-5.95	-6.42**
	-6.23	-5.34	-5.91	-5.89	-7.69***	-7.26**	-8.18**	-6.37	-6.40
Za	-40.06	-31.34	-33.79	-33.71	-47.02	-39.45	-42.43	-37.94	-29.14
	-43.95	-34.72	-30.34	-33.74	-47.17	-48.21	-48.00	-39.78	-31.54
	-41.90	-34.80	-37.94	-39.71	-50.35	-48.43	-53.39	-42.53	-31.45

Note: The test specifies a break in the constant, slope and deterministic trend; ***, **, and * denote the null hypothesis of no cointegration is rejected at 1%, 5%, and 10% significance, respectively.

Table 5
Long Run Estimates for CO_2

	Australia	Canada	Chile	Japan	Mexico	Malaysia	New Zealand	Peru	Vietnam
FMOLS									
RE	-0.08	-0.02	-0.37***	-0.08**	-0.39***	0.48*	-0.28	-0.08	3.63***
AN	-0.15**	-0.58***	-0.46***	0.00	0.15***	0.08***	-0.3**	-0.39***	-1.39***
Y	6.71***	17.34***	2.98***	-25.98***	4.4*	-0.15	18.71***	0.74*	5.14***
Y^2	-0.77***	-2.32***	-0.38***	3.78***	-0.79	0.35***	-2.78***	0.16	-0.68***
OP	-0.43**	-0.05	-0.11	-0.41***	-0.25***	0.51***	0.78***	0.03	-1.23***
Intercept	-8.92***	-24.84***	1.14**	48.09***	-2.44	-4.28***	-28.81***	0.72	-8.44***
DOLS									
RE	-0.21***	0.11	0.05	-0.19***	-0.56***	1.13***	-0.37***	-0.33***	2.01*
AN	-0.26***	-0.64***	-0.63***	-0.08***	0.28***	0.04***	-0.31***	-0.64***	0.12
Y	5.4***	21.93***	2.25***	-16.7***	2.72*	-0.35***	20.08***	1.92***	2.17
Y^2	-0.63***	-2.92***	-0.24**	2.47***	-0.27	0.53***	-3.05***	-0.2***	-1.31*
OP	-0.22***	-0.21	-0.03	-0.3**	-0.38***	0.36***	0.94***	-0.17***	-1.15
Intercept	-5.46***	-33.38***	0.22	32.27***	-0.52	-6.63***	-30.46***	2.69***	-5.46

Note: ***, **, and * denote significance at 1%, 5%, and 10%, respectively.

Table 6
Short Run Granger Causality Test

	Australia	Canada	Chile	Japan	Mexico	Malaysia	New Zealand	Peru	Vietnam
$\Delta CO_2 \neq \Delta RE$	0.02	0.78	0.00	1.62	8.15**	0.88	2.99	5.90*	1.75
$\Delta CO_2 \neq \Delta AN$	1.84	0.66	6.8**	1.96	10.52***	1.02	1.20	12.04***	3.12
$\Delta CO_2 \neq \Delta Y, \Delta Y^2$	0.98	1.49	4.13	1.62	9.67**	2.61	2.57	22.56***	5.53
$\Delta CO_2 \neq \Delta OP$	0.98	15.68***	1.42	1.12	13.78***	1.53	5.40*	2.16	1.44
$\Delta RE \neq \Delta CO_2$	0.04	0.04	0.02	3.95	2.83	3.58	3.08	11.17***	0.77
$\Delta RE \neq \Delta AN$	0.05	1.08	1.04	1.18	0.37	0.66	3.43	4.53	0.13
$\Delta RE \neq \Delta Y, \Delta Y^2$	1.05	0.80	4.79	0.55	0.03	5.48	2.20	5.13	2.24
$\Delta RE \neq \Delta OP$	0.79	6.37**	0.10	7.61**	1.58	0.33	3.60	2.19	0.95
$\Delta AN \neq \Delta CO_2$	0.57	0.11	1.35	3.32	1.98	2.82	0.53	5.86*	1.12
$\Delta AN \neq \Delta REC$	11.89***	0.76	2.63	6.31**	2.65	1.50	4.74*	2.02	5.96*
$\Delta AN \neq \Delta Y, \Delta Y^2$	3.37	1.46	1.28	9.54**	4.11	2.50	6.09	8.13*	5.48
$\Delta AN \neq \Delta OP$	2.53	2.20	1.74	17.67***	4.79*	1.17	7.96**	10.24***	5.94*
$\Delta Y, \Delta Y^2 \neq \Delta CO_2$	4.40	2.91	5.37	9.34*	4.78	8.42*	4.64	2.89	6.96
$\Delta Y, \Delta Y^2 \neq \Delta RE$	1.92	3.35	2.72	8.63*	1.81	13.33***	25.69***	19.05***	0.04
$\Delta Y, \Delta Y^2 \neq \Delta AN$	2.29	3.59	2.17	0.12	5.87	4.44	10.36	3.47	4.69
$\Delta Y, \Delta Y^2 \neq \Delta OP$	2.86	0.76	1.70	12.54**	11.16**	13.3***	6.90	16.44***	5.23
$\Delta OP \neq \Delta CO_2$	1.53	0.46	1.04	3.76	3.98	5.00*	2.76	0.27	9.32***
$\Delta OP \neq \Delta RE$	3.45	1.18	0.28	3.14	3.91	6.51**	2.59	3.41	0.95
$\Delta OP \neq \Delta AN$	22.34***	1.06	0.60	0.33	1.53	0.10	2.17	0.09	2.27
$\Delta OP \neq \Delta Y, \Delta Y^2$	35.11***	7.25	3.22	1.73	8.66*	8.63*	10.81**	5.83	9.14*

Table 6 (cont)
Short Run Granger Causality Test

	Australia	Canada	Chile	Japan	Mexico	Malaysia	New Zealand	Peru	Vietnam
$\Delta CO_2 \neq \Delta RE$	0.02	22.95***	3.39***	1.69	11.21**	1.44	3.76	7.49*	5.07
$\Delta CO_2 \neq \Delta AN$	3.22	23.09***	6.8***	3.69	10.53**	1.02	1.22	12.11***	4.47
$\Delta CO_2 \neq \Delta Y, \Delta Y^2$	1.59	22.66***	4.65***	1.65	9.70**	2.62	7.41	22.60***	5.53
$\Delta CO_2 \neq \Delta OP$	0.99	25.42***	3.38	4.14	13.85***	1.74	5.55	2.65	5.43
$\Delta RE \neq \Delta CO_2$	0.08	5.99	0.07*	4.33	3.81	3.75	3.09	14.17***	4.57
$\Delta RE \neq \Delta AN$	0.24	7.36*	1.67	1.56	1.40	1.66	3.45	6.34*	0.17
$\Delta RE \neq \Delta Y, \Delta Y^2$	1.14	6.25	5.41	1.85	1.90	5.67	4.15	6.33	4.87
$\Delta RE \neq \Delta OP$	0.91	7.29*	0.13	7.62*	3.18	1.26	6.35*	3.49	1.00
$\Delta AN \neq \Delta CO_2$	4.12	6.54*	2.20	7.33*	4.54	3.90	4.09	6.25	6.23
$\Delta AN \neq \Delta REC$	12.95***	7.06*	2.67	54.04***	4.01	1.60	20.81***	3.30	6.14
$\Delta AN \neq \Delta Y, \Delta Y^2$	4.59	6.70	1.35	14.45***	5.02	4.08	8.46	10.61*	5.49
$\Delta AN \neq \Delta OP$	4.38	6.92*	1.86	17.71***	4.92	2.44	10.13**	11.25**	7.73*
$\Delta Y, \Delta Y^2 \neq \Delta CO_2$	8.05	3.81	8.52	13.26**	22.23***	24.84***	21.94***	17.21***	7.50
$\Delta Y, \Delta Y^2 \neq \Delta RE$	5.09	4.20	6.05	9.40	21.79***	30.75***	28.27***	30.18***	10.03
$\Delta Y, \Delta Y^2 \neq \Delta AN$	9.34	4.37	4.82	7.60	22.37***	24.58***	29.93***	19.62***	6.19
$\Delta Y, \Delta Y^2 \neq \Delta OP$	7.51	1.46	6.27	20.44***	27.83***	27.09***	30.74***	29.57***	8.33
$\Delta OP \neq \Delta CO_2$	23.41***	0.69	12.68***	4.82	9.44**	9.85**	3.95	3.35	9.32**
$\Delta OP \neq \Delta RE$	23.93***	1.41	7.93**	3.14	10.74**	9.94**	5.15	3.36	5.98
$\Delta OP \neq \Delta AN$	37.42***	1.24	12.37***	2.93	6.70*	10.20**	2.19	2.09	3.32
$\Delta OP \neq \Delta Y, \Delta Y^2$	38.73***	9.01	17.19***	3.87	16.88***	12.38**	11.11**	6.22	12.44**

Note: ***, **, and * denote significance at 1%, 5%, and 10%, respectively.