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# Environmental Quality, Renewable Energy, Trade Openness and Economic Growth: Evidence from Two Groups of Developing Countries

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**Abstract:** The purpose of this study is to examine the short-run and long-run causal relationship between economic growth, renewable energy, trade openness and carbon dioxide emission ($CO_2$) as an indicator of environmental quality for two panels of developing countries including nine Asian developing countries and six European developing countries. A panel vector error correction model (Panel-VECM) causality is employed to investigate causality relation between the variables of interest. The empirical finding of short-run indicates bidirectional causality between GDP and $CO_2$ emissions and unidirectional causality from renewable energy and trade openness to $CO_2$ emissions for both Asian and European panels. Furthermore, there is evidence of unidirectional causality from GDP to renewable energy for Asian panel, while for European panel, bidirectional causality exist between renewable energy and GDP.

**Key words**: Environmental quality, economic growth, renewable energy, trade openness.

## Introduction

From the past to now, energy has been an important production factor and we can say it is one of the most important driving factors of economic growth. Therefore, exploring the relation between energy consumption and economic growth has been considered by economists and policy-makers in recent decades. In particular, the volatility of energy price in recent years has an obvious effect on world economy. But in the last two decades, the reliance on traditional energy sources has created great concern, one of which is finishing realization of traditional energy sources and fossil fuels. And other is the adverse environmental impact, greenhouse gas emissions and global warming. Among the greenhouse gases, carbon dioxide ($CO_2$) has the greatest effects on global warming.

Nowadays, these issues have been caused to find an alternative energy source for fossil fuel energy sources. Renewable energy resources such as solar, wind, hydropower and geothermal energy are the best alternative to traditional energy sources. So, researchers, governments and international organizations attempt to increase renewable energy production and mitigate the adverse environmental impacts and global warming. To meet this goal, various policies have been adopted by different countries such as carbon taxes, feed-in tariffs, premium payments, quota systems, auctions and cap and trade systems (de Arce et al., 2016). These incentives reduced the production costs of renewable

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energy and in many countries renewable energy has become competitive with conventional energy (Koçak and Şarkgüneşi, 2017).

Many studies have investigated the relationship between energy consumption and economic growth. But in recent years, with attention to the above issues, considering the relationship between renewable energy source, economic growth and $CO_2$ emissions have been more interested. However, studies done about renewable energy are limited and there are no common consensus among the different studies, so studying in this topic is still interested. The lack of common consensus can be due to the different countries, time periods, data sources and econometric method have been used in different studies. The main goal of the present study is to examine the relationship between $CO_2$ emission as an indicator of environmental quality, economic growth, renewable energy and trade openness for two panels of developing countries over the period 2000-2014 by employing the Panel-VECM causality framework. To this end, the rest of the paper is organized as follows: second section presents the literature review of empirical studies, followed by a section which discusses the model and data, the next section presents the methodology and empirical results and the final Section presents conclusion.

## Literature Review

Sebri and Ben-Salha (2014) examined the causal relationship between economic growth, renewable energy, trade openness and $CO_2$ emissions for BRICS countries over the 1971-2010 periods. Empirical finding of ARDL bounds testing and vector error correction model reveal the bidirectional causality between economic growth and renewable energy. Furthermore, the results indicate the significant effect of trade openness and $CO_2$ emission in promoting the renewable energy consumption.

Begum et al. (2017) investigated the relationship between energy consumption and $CO_2$ emissions in Malaysia during 1980 to 2011 years by employing time series approach. They highlighted that the positive and linear relationship between $CO_2$ emission and energy consumption indicates that Malaysia's higher rate of energy consumption leads to the increased $CO_2$ emissions whereas a high growth of GDP and increasing population might cause increased energy consumption.

Aïssa et al. (2014) explored the relationship between renewable energy, trade and GDP for a panel of 11 African countries over the 1980 to 2008 years by using panel cointegration approach. The results of panel error correction causality framework reveal that there is evidence of bidirectional causality between GDP and exports and between GDP and imports in both the short and long-run. However, in the short run, they can't find evidence of causality between GDP and renewable energy and between trade and renewable energy. Furthermore, in the long-run, there is no causality from GDP or trade to renewable energy.

The empirical study of Dogan and Seker (2016) examined the effect of real income, renewable energy consumption, non-renewable energy consumption, trade openness and financial development on $CO_2$ emissions by considering an EKC model for the top countries listed in the Renewable Energy Country Attractiveness Index. The results of FMOLS and the DOLS estimator indicate that increases in renewable energy consumption, trade openness and financial development will cause decrease in carbon emissions while increases in non-renewable energy consumption contribute to the level of emissions, and the EKC hypothesis is supported for the top renewable energy countries.

Jebli et al. (2016) investigated the relationship between $CO_2$ emissions, GDP, renewable and non-renewable energy consumption, and international trade for a panel of 25 OECD countries over the period 1980–2010. The finding of short-run Granger causality tests show the existence of bidirectional causality between: renewable energy consumption and imports, renewable and non-renewable energy consumption, non-renewable energy and trade; and unidirectional causality running from: exports to renewable energy, trade to $CO_2$ emissions, output to renewable energy. Furthermore, the results of FMOLS and DOLS estimates reveal that U-shaped environmental Kuznets curve (EKC) hypothesis is verified for this sample of OECD countries.

Zaidi et al. (2017) employed panel data of 17 developed and 12 developing countries to examine the relationship between $CO_2$ emissions, energy consumption and economic growth over the 1960 to 2008 periods. The main findings show a strong relationship between the variables. The results of model with inverse function transformation indicate that more than 84% of $CO_2$ emission can be explained by GDP and energy consumption.

Zoundi (2017) investigated short- and long-run impacts of renewable energy on $CO_2$ emissions for a panel of 25 selected African countries, over the period 1980-2012 by using panel cointegration method. $CO_2$ emissions are found to increase with economic growth.

The estimations results reveal that renewable energy, with a negative effect on $CO_2$ emissions, is an efficient substitute for the traditional energy sources.

Jebli and Youssef (2015b) examined the causal relationship between output, renewable and non-renewable energy consumption, and international trade for a sample of 69 countries during the period 1980–2010. The empirical finding show that there is a bidirectional causality between output and trade, a bidirectional causality between non-renewable energy and trade, and a one way causality running from renewable energy to trade.

Ozturk and Acaravci (2016) examined the long-run and causal relationship between economic growth, carbon emissions, energy consumption, foreign trade ratio, and employment ratio in Cyprus and Malta over the 1980 to 2006 years, by employing ARDL bounds testing approach and error correction based Granger causality models. The empirical finding indicates the existence of long-run relationship between the variables only for Malta. The results of Granger causality test show that the causality runs from carbon emissions, energy consumption, foreign trade ratio, and employment ratio to economic growth but not vice versa in Malta.

Jebli and Youssef (2015a) examined the relation between economic growth, renewable and non-renewable energy, per capita $CO_2$ emissions and international trade for Tunisia over the 1980 to 2009 years. The empirical finding of ARDL bound testing and vector error correction Granger causality method indicates the existence of a short-run unidirectional causality from trade, GDP, $CO_2$ emission and non-renewable energy to renewable energy consumption. The results of long-run estimate reveal that negative impact of renewable energy consumption to the $CO_2$ emissions.

Apergis and Payne (2014) studied the determinants of renewable energy consumption per capita for a panel of seven Central American countries over the period 1980 to 2010. The empirical findings reveal a long-run cointegration relationship between renewable energy consumption per capita, real GDP per capita, $CO_2$ emissions per capita, real coal prices, and real oil prices with the respective coefficients positive and statistically significant.

The study of Sek (2017) attempted to reveal how energy consumption can affect economic growth directly and indirectly through its impact on environmental quality in China over the 1966 to 2015 years. The results of linear and threshold cointegration test indicate significant long-run relationship in model and estimation results show that energy consumption has directly positive effect on economic growth. But, this effect is relatively small, compared to the strong negative effect of $CO_2$ emissions (indirect effect of energy consumption) on economic growth.

Omri et al. (2015) examined the causal relationship between nuclear energy, renewable energy, economic growth and $CO_2$ emission for a panel of 17 developed and developing countries by employing panel data models over the 1990-2011 years. The results indicate mixed direction of causality for different countries.

Aliprandi et al. (2016) presented a model to simulating the operational characteristics of a national grid similar to the Italian one, with relevant shares of wind and photovoltaic energy, and estimate $CO_2$ emissions with a level of penetration. The results show that the reduction of $CO_2$ emissions is lower than expected considering the amount of energy produced from renewable sources, and is related to the level of RE penetration and the season of the year; in summer the reduction is slightly greater, because of the higher production by Combined Cycle Gas Turbines (CCGTs) and the consequent decrease of that generated by the more pollutant coal power plants.

López-Menéndez et al. (2014) attempts to study the impact of economic growth on $CO_2$ emissions for a panel data set of 27 European Union countries during the 1996-2010 periods by estimation of an Environmental Kuznets Curve (EKC). Empirical findings reveal the significant impacts of renewable energies on $CO_2$ emissions, suggesting the existence of an extended EKC.

Bölük and Mert (2014) investigated the EKC hypothesis by considering the relationship between $CO_2$ emissions, income, renewable energy and fossil fuel energy consumption for panel of 16 European Union countries over the 1990-2008 years. The results show that renewable energy consumption contributes around 1/2 less per unit of energy consumed than fossil energy consumption in terms of greenhouse gas emissions in EU countries.

Apergis and Payne (2015) analyzed the long-run and causal relationship between renewable energy consumption per capita, real gross domestic product per capita, carbon dioxide emissions per capita, and real oil prices for a panel of South American countries from 1980 to 2010 period. The results of long-run estimate indicated positive and significant impact of real GDP per capita, $CO_2$ emissions per capita and oil price to renewable energy. Furthermore, the empirical finding of panel causality test indicates bidirectional relationship between the variables. The error correction terms in each of the equations are statistically significant, indicating that shocks to any one of the equations will be temporary in nature returning to the long-run equilibrium.

Menyah and Wolde-Rufael (2010) examined the causal relationship between nuclear and renewable energy, economic growth and $CO_2$ emissions for the US over the 1960-2007 period. The results show a unidirectional causality from nuclear energy consumption to $CO_2$ emissions, but no causality from renewable energy to $CO_2$ in this time period.

The study of Apergis et al. (2010) examined the causal relationship between $CO_2$ emissions, nuclear energy consumption, renewable energy consumption, and economic growth for a panel of 19 developed and developing countries over the period 1984–2007. The results of panel Granger causality tests suggest that in the short-run nuclear energy consumption plays an important role in reducing $CO_2$ emissions whereas renewable energy consumption does not contribute to reductions in emissions. This may be due to the lack of adequate storage technology to overcome intermittent supply problems; as a result electricity producers have to rely on emission generating energy sources to meet peak load demand.

Pao and Tsai (2011) studied the impact of economic growth and financial development on environmental degradation for a panel of BRIC countries (Brazil, Russian Federation, India and China) by using a panel cointegration approach over the 1980 and 2007 period. The result indicates bidirectional causality between $CO_2$ emissions and FDI and unidirectional causality from GDP to FDI. Additionally, there exists output-emissions and output-energy consumption bidirectional causality, while there is unidirectional causality from energy consumption to $CO_2$ emission.

## Model and Data

According to relative literature on the relationship between renewable energy, economic growth and $CO_2$ emissions, we use the following regression model:

$$CO_{2it} = \alpha_0 + \alpha_{1i} Y_{it} + \alpha_{2i} RE + \alpha_{3i}\, \mathrm{TOPEN} + u_{it} \quad (1)$$

where $CO_{2it}$ is the total $CO_2$ emissions from fuel combustion (million tonnes of $CO_2$), $Y$ is the real gross domestic product (GDP) of constant 2010 U.S. dollars, RE is the total renewable electricity net generation (billion kilowatt-hours) as a proxy for renewable energy, TOPEN is the trade openness and defined as the sum of imports and exports divided by the GDP measured by constant 2010 U.S. dollars. The data sources of $CO_2$, $Y$ and $RE$ respectively are the International Energy Agency (EIA), World Development Indicators (WDI) and U.S. Energy Information Administration (EIA), Also the data source of trade openness is WDI, all variable presented in natural logarithmic form.

Baltagi (2005) points out several benefits of employing panel data: controlling for individual heterogeneity and giving more informative data, more variability, less collinearity among the variables, more degrees of freedom and more efficiency. With respect to these benefits this study used panel data of $CO_2$ emission, GDP, renewable energy, and trade openness for two panels of developing countries over the 2000 to 2014 years—one panel of six European developing countries including: Albania, Belarus, Bulgaria, Croatia, Poland and Romania and another panel of nine Asian developing countries including: Bangladesh, Indonesia, India, Iran, Malaysia, Pakistan, Philippines, Srilanka and Thailand.

## Methodology and Empirical Results

The econometric methodology of this paper follows three steps. First, we test for a panel unit root. Prompted by the existence of unit roots in the series, long-run cointegration relationship between variables was tested by using the panel cointegration test. Conditional on finding cointegration, the causal link between variables have been explored by employing a panel VECM Granger causality framework.

### Panel Unit Root Test

Several panel unit root tests have been presented for understanding stationary properties of panel data. We have employed the tests proposed by Levin et al. (LLC, 2002), Im et al. (IPS, 2003), Breitung (2000) and Fisher-type test proposed by Maddala and Wu (1999) and Choi (2001) to test the null hypothesis of the existence of a unit root.

Following Dickey and Fuller (1979, 1981), Levin and Lin (1993), and Levin et al. (2002), consider a panel extension of the null hypothesis that each individual time series in the panel contains a unit root against the alternative hypothesis that all individual series are stationary (Hsiao, 2003). The adjusted $t$-statistic of LLC is:

$$t^*_\rho = \frac{t_\rho - N\tilde{T}\hat{S}_N \hat{\sigma}_{\tilde{\varepsilon}}^{-2} \hat{\sigma}(\hat{\rho}) \mu^*_{m\tilde{T}}}{\sigma^*_{m\tilde{T}}}$$

where $\mu^*_{m\tilde{T}}$ and $\sigma^*_{m\tilde{T}}$ are the mean and standard deviation adjustments provided by Table 2 of LLC. Levin et al. show that is asymptotically distributed as $N$ (0, 1).

The test of Im, Pesaran and Shin (IPS, 2003) allow for a heterogeneous coefficient of $y_{it-1}$ and propose an alternative testing procedure based on averaging individual unit root test statistics. IPS suggests an average of the ADF tests when $u_{it}$ is serially correlated with different serial correlation properties across cross-sectional units. The $t$-statistic of IPS is given as follows:

$$t_{\text{IPS}} = \frac{\sqrt{N}\left(\bar{t} - \frac{1}{N}\sum_{i=1}^{N} E[t_{iT} \mid \rho_i = 0]\right)}{\sqrt{\frac{1}{N}\sum_{i=1}^{N} \text{var}[t_{iT} \mid \rho_i = 0]}} \Rightarrow N(0,1)$$

Values of $E[t_{iT}| \rho_i = 0]$ and $\text{var}[t_{iT}| \rho_i = 0]$ are obtained from the results of Monte Carlo simulations carried out by IPS.

Maddala and Wu (1999) and Choi (2001) proposed a Fisher-type test of unit root, which combines the $p$-values from unit root tests for each cross-section $i$ to test for unit root in panel data. The Fisher test is nonparametric and distributed as chi-square with two degrees of freedom:

$$p\lambda = -2\sum \log_e \pi_i$$

The results of panel unit root tests show the existence of unit roots in level for $CO_2$, $Y$, $RE$ and TOPEN in both Asian developing panel and European developing panel. But the results of panel unit root tests in the first difference indicate that all variables become stationary after first difference. In other words, data series are integrated of order one I (1).

**Panel Cointegration Test**

On the basis of the panel unit root test results, which imply that the data series are non-stationary in level, at the second step, we proceed to test for the existence of a long-run relationship between variables by using panel cointegration test. Granger (1981) showed that when if some series are integrated of order one (they become stationary after first differencing), but a linear combination of them is already stationary without differencing, they are said to be cointegrated, which implies the existence of a long-run relationship between the series.

**Table 1: Panel unit root tests—Asian developing countries**

| *Variable* / *Test* | *$CO_2$* | | *Y* | | *RE* | | *TOPEN* | |
|---|---|---|---|---|---|---|---|---|
| | *Levels* | *1st differences* | *Levels* | *1st differences* | *Levels* | *1st differences* | *Levels* | *1st differences* |
| LLC (2002) | -1.48 | -6.84*** | -0.74 | -6.34*** | -0.58 | -10.45*** | -0.86 | -8.76*** |
| IPS (2003) | 0.70 | -6.43*** | 1.25 | -3.55*** | 0.51 | -7.63*** | 1.34 | -6.85*** |
| ADF-Fisher | 18.95 | 56.45** | 28.34 | 52.63*** | 24.76 | 92.34*** | 24.36 | 85.47*** |
| PP-Fisher | 22.37 | 76.82*** | 32.21 | 59.72** | 32.45 | 105.61*** | 30.78 | 99.25*** |

*Note:* *** and ** denote statistical significance at the 1 and 5% levels.

**Table 2: Panel unit root tests—European developing countries**

| *Variable* / *Test* | *$CO_2$* | | *Y* | | *RE* | | *TOPEN* | |
|---|---|---|---|---|---|---|---|---|
| | *Levels* | *1st differences* | *Levels* | *1st differences* | *Levels* | *1st differences* | *Levels* | *1st differences* |
| LLC (2002) | -2.08 | -7.14*** | -0.54 | -5.94*** | -0.69 | -11.35*** | -0.78 | -8.54*** |
| IPS (2003) | 0.87 | -6.78*** | 1.45 | -3.95*** | 0.74 | -6.93*** | 1.73 | -7.15*** |
| ADF-Fisher | 20.45 | 62.35*** | 25.87 | 49.73*** | 22.96 | 102.14*** | 27.45 | 89.37*** |
| PP-Fisher | 24.67 | 79.81** | 28.24 | 54.72** | 30.25 | 112.71*** | 32.78 | 97.35*** |

*Note:* *** and ** denote statistical significance at the 1 and 5% levels.

Several tests are proposed to examine the existence of cointegration in panel data. We use Pedroni (1999, 2004) and Kao (1999) panel cointegration test.

Kao (1999) introduced parametric residual-based panel cointegration. He expanded four DF-types and one ADF-type tests for testing the null hypothesis of no cointegration. The tests are based on the spurious Least Squares Dummy Variable (LSDV) panel regression equation with one single regressor.

Pedroni (1999) considers the following time series panel regression:

$$y_{i,t} = \alpha_i + \delta_i t + \beta_{1i} x_{1i,t} + \beta_{2i} x_{2i,t} + \ldots + \beta_{Mi} x_{Mi,t} + e_{i,t} \quad (2)$$

For $t = 1, \ldots, T$; $i = 1, \ldots, N$; $m = 1, \ldots, M$

where $T$ refers to the number of observations over time, $N$ refers to the number of individual members in the panel, and $M$ refers to the number of regression variables. Pedroni presented seven statistics for testing the null hypothesis of no cointegration versus cointegration in panel data. Four statistics, called panel cointegration statistics, are based on pooling along what is commonly referred to as the within-dimension. In addition to them, three statistics called group-mean panel cointegration statistics, are based on pooling along what is commonly referred to as the between-dimension.

Table 3 presents the result of Kao panel cointegration tests and reveals the existence of cointegration relationship between variables. Also, the results of Pedroni panel cointegration test, presented in Table 4, support the existence of cointegration between the series.

**Table 3: Kao panel cointegration test**

| *Panel group/ Statistics* | *European developing countries* | *Asian developing countries* |
|---|---|---|
| $DF_\rho$ | -0.86* | -1.21** |
| $DF_t$ | -3.46*** | -2.85** |
| $DF_\rho^*$ | -4.97*** | -5.34*** |
| $DF_t^*$ | -2.40** | -2.98*** |
| *ADF* | -1.82** | -1.90*** |

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

**Table 4: Pedroni panel cointegration test**

| *Panel group/ Statistics* | *European developing countries* | *Asian developing countries* |
|---|---|---|
| Panel *v*-statistic | 7.08*** | 5.04*** |
| Panel *ρ*-statistic | -9.30*** | -12.43** |
| Panel non-parametric (PP) *t*-statistic | -4.37* | -5.26 |
| Panel parametric (ADF) *t*-statistic | -85.92*** | -104.64*** |
| Group *ρ*-statistic | -15.51*** | -14.18*** |
| Group non-parametric *t*-statistic | -4.91** | -5.21*** |
| Group parametric *t*-statistic | -4.39** | -4.26*** |

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

## Panel Causality Test

The finding of cointegration implies that there exists a causal relationship between the series, but it does not indicate the direction of causality. Engle and Granger (1987) showed that if non-stationary variables are cointegrated, a vector autoregression (VAR) in first differences will be misspecified, because of the removed long-run information in the first differencing, but a vector error correction model (VECM) can avoid this shortcoming. In addition, unlike the usual Granger causality test, VECM can identify sources of causation and can distinguish between a long-run and a short-run relationship in the series.

We specify a model with a dynamic error-correction representation. This means that the VAR model is augmented with one period lagged error correction term (ECT), which is obtained from the estimated residuals of the cointegrated model. The panel-VECM framework for examining the causality between $CO_2$ emissions, economic growth, renewable energy, and trade openness can be written as follows:

$$\Delta CO_{2it} = c_{1i} + \sum_{i=1}^{k} \alpha_{1ik}\, \Delta CO_{2it-k} + \sum_{i=1}^{k} \beta_{1ik}\, \Delta Y_{it-k} + \sum_{i=1}^{k} \gamma_{1ik}\, \Delta RE_{it-k} + \sum_{i=1}^{k} \lambda_{1ik}\, \Delta TOPEN_{it-k} + \varphi_{1i} ECT_{t-1} + \varepsilon_{it} \quad (3)$$

$$\Delta Y_{it} = c_{2i} + \sum_{i=1}^{k} \alpha_{2ik}\, \Delta CO_{2it-k} + \sum_{i=0}^{k} \beta_{2ik}\, \Delta Y_{it-k} + \sum_{i=1}^{k} \gamma_{2ik}\, \Delta RE_{it-k} + \sum_{i=1}^{k} \lambda_{2ik}\, \Delta TOPEN_{it-k} + \varphi_{2i} ECT_{t-1} + \varepsilon_{it} \quad (4)$$

$$\Delta RE_{it} = c_{3i} + \sum_{i=1}^{k} \alpha_{3ik}\, \Delta CO_{2it-k} + \sum_{i=1}^{k} \beta_{3ik}\, \Delta Y_{it-k} + \sum_{i=1}^{k} \gamma_{3ik}\, \Delta RE_{it-k} + \sum_{i=1}^{k} \lambda_{3ik}\, \Delta TOPEN_{it-k} + \varphi_{3i} ECT_{t-1} + \varepsilon_{it} \quad (5)$$

$$\Delta TOPEN_{it} = c_{4i} + \sum_{i=1}^{k} \alpha_{4ik}\, \Delta CO_{2it-k} + \sum_{i=1}^{k} \beta_{4ik}\, \Delta Y_{it-k} + \sum_{i=1}^{k} \gamma_{4ik}\, \Delta RE_{it-k} + \sum_{i=1}^{k} \lambda_{4ik}\, \Delta TOPEN_{it-k} + \varphi_{4i} ECT_{t-1} + \varepsilon_{it} \quad (6)$$

where Δ is the first difference operator; $ECT_{t-1}$ is the lagged error correction term; $k$ is the lag length; and $\varepsilon_{it}$, $\upsilon_{it}$ and $\in_{it}$ are the serially uncorrelated error terms.

The direction of panel causations can be identified by testing for the significance of the coefficient of dependent variables in Eqs. (3–6). We test $H_0$: $\beta_{1ik} = 0\ \forall i, k$ and $H_0$: $\gamma_{1ik} = 0\ \forall i, k$ and $H_0$: $\lambda_{1ik} = 0\ \forall i, k$ to determine short-run Granger causality from GDP, renewable energy, and trade openness to $CO_2$ emissions, respectively; $H_0$: $\alpha_{2ik} = 0\ \forall i, k$ and $H_0$: $\gamma_{2ik} = 0\ \forall i, k$ $H_0$: $\lambda_{2ik} = 0\ \forall i, k$ to determine short-run Granger causality from $CO_2$ emissions, renewable energy, and trade openness to GDP; and $H_0$: $\alpha_{3ik} = 0\ \forall i, k$ and $H_0$: $\beta_{3ik} = 0\ \forall i, k$ and $H_0$: $\lambda_{3ik} = 0\ \forall i, k$ to indicate short-run Granger causality from $CO_2$ emissions, GDP, and trade openness to renewable energy. We also test $H_0$: $\alpha_{4ik} = 0\ \forall i, k$ and $H_0$: $\beta_{4ik} = 0\ \forall i, k$ and $H_0$: $\gamma_{4ik} = 0\ \forall i, k$ to indicate short-run Granger causality from $CO_2$ emissions, GDP, and renewable energy to trade openness. Finally, for long-run causality, we test $H_0$: $\varphi_i = 0\ \forall i, k$ in each Eq. (3-6). (Notice: the null hypothesis implies no Granger causality.)

Lag-length selection using Schwarz information criterion (SC) and Hannan-Quinn information criterion (HQ) indicated one lag for Asian developing panel and two lags for the European developing panel. The results of panel causality are displayed in Tables 5 and 6.

Empirical finding of panel causality in Asian developing countries in short-run indicates unidirectional causality from renewable energy and trade openness to $CO_2$ emissions and from GDP to renewable energy and bidirectional causality between economic growth and $CO_2$ emissions and economic growth and trade openness. For European developing panel there is evidence of unidirectional causality from renewable energy to $CO_2$ emissions and trade openness and unidirectional causality from trade openness to $CO_2$ emissions and bidirectional causality between GDP and $CO_2$, Renewable energy and GDP, and finally between the trade openness and GDP. Furthermore, there is evidence of long-run causality in any of the VECM vectors for both panels of Asian and European developing countries.

## Conclusion

In the last two decades, the reliance on traditional energy sources has created great concern due to the adverse environmental impact, greenhouse gas emissions and global warming. So, in recent years the

**Table 5: Panel causality—Asian developing panel**

| *Dependent variable* | *Source of causation (independent variables)* | | | | |
|---|---|---|---|---|---|
| | *Short-run* | | | | *Long-run* |
| | *$\Delta CO_2$* | *ΔY* | *ΔRE* | *ΔTOPEN* | *ECT* |
| $\Delta CO_2$ | — | 6.87*** | 20.18*** | 8.95* | 5.14** |
| ΔY | 10.45*** | — | 0.58 | 7.57** | 157.17*** |
| ΔRE | 0.39 | 4.17* | — | 0.53 | 25.46*** |
| ΔTOPEN | 0.46 | 8.49** | 0.37 | — | 23.64** |

*Note:* Table reports F statistics. ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively.

**Table 6:** Panel causality—European developing panel

| *Dependent variable* | *Source of causation (independent variables)* | | | | |
|---|---|---|---|---|---|
| | *Short-run* | | | | *Long-run* |
| | *$\Delta CO_2$* | *ΔY* | *ΔRE* | *ΔTOPEN* | *ECT* |
| $\Delta CO_2$ | — | 7.53*** | 18.25*** | 7.78** | 4.59** |
| ΔY | 11.26*** | — | 3.48* | 9.47*** | 167.28*** |
| ΔRE | 0.39 | 4.17* | — | 0.46 | 29.36*** |
| ΔTOPEN | 0.57 | 7.53** | 2.86* | — | 18.74** |

**Note**: Table reports F statistics. ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively.

relationship between renewable energy consumption and $CO_2$ emissions have been more interested among the researchers. Therefore, the aim of this study is to examine the causal relationship between economic growth, renewable energy, trade openness and $CO_2$ emission as an indicator of environmental quality for two groups of developing countries over the 2000 to 2014 years. For this purpose at first we perform panel unit root test and the results indicate that all variables are integrated of order one. Then we examined the existence of long-run relation by using panel cointegration test and empirical findings support the existence of cointegration between variables for both Asian and European panels.

Finally, panel-VECM causality framework was employed to identify the direction of causality between the series. The results of short-run panel causality test indicates bidirectional causality between GDP and $CO_2$ emissions; bidirectional causality between GDP and trade openness, and unidirectional causality from renewable energy and trade openness to $CO_2$ emissions for both Asian and European panels. Furthermore, there is evidence of unidirectional causality from GDP to renewable energy for Asian panel, while for European panel, bidirectional causality exists between renewable energy and GDP. Also there is evidence of unidirectional causality from renewable energy to trade openness for European panel. Finally, there is evidence of long-run causality in any of the VECM vectors for both panels of Asian and European developing countries.

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