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Renewable energy consumption-economic growth nexus in emerging countries: A bootstrap panel causality test

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ABSTRACT

In this study, we analyzed the relationship between renewable energy consumption and economic growth in 17 emerging countries, spanning the period of 1990–2016. The bootstrap panel causality test, allowing for dependence across countries and heterogeneity in slope parameters, developed by Kónya (2006) [1] was employed. The results indicated that the neutrality hypothesis does hold for all of the markets studied except for Poland, which confirmed the growth hypothesis. As such, because of the nonexistence of causality running from renewable energy demand to economic growth, energy saving (mitigation) policies do not have any detrimental influence on the growth rates of these 16 emerging economies. For Poland; however, energy conservation policies may have detrimental effects on the country's economic performance level.

1. Introduction

All countries are heavily dependent on the energy sector in their development processes, and the world's demand for energy is increasing day by day. According to the British Petroleum [2], primary energy consumption grew about 2.2% in 2017, which is the fastest increase since 2013. Among fuel types, natural gas had the largest increment in energy consumption, followed by renewables and then oil. Despite its rising importance and usage level, renewable energy still does not have a large share in the world's energy portfolio compared to non-renewable sources. For instance, oil is the most important non-renewable source and remains the world's leading fuel, constituting 34.2% of global energy consumption in 2017 [2]. However, in 2016, modern renewable energy sources excluding traditional usage of biomass accounted for only ten percent of total final energy consumption [3]. It is expected that this percentage will go up in the future when countries reduce their high usage rates of fossil-based energy sources.

Some important events and developments worldwide have accelerated the transition from non-renewable sources to renewables. These developments include growing concerns over energy security, climate change, political and social pressure to curb greenhouse gases (GHGs) emissions, high and volatile oil prices, and high dependency on foreign energy sources [4]. As a result of these concerns, renewable energy sources such as wind, solar, geothermal, biomass, wave, and so on have become the focus of attention [4–8] Many countries are now investing more in their clean energy sectors and supporting them with various national policies such as tax credits for renewable energy supply, discounts for installing renewable energy mechanisms, renewable energy portfolio measures, and creating markets for renewable energy certificates to secure the energy supply and to diversify the energy mix [5,9,10]

Searching for the relationship between renewable energy demand and economic growth will render important evidence to design appropriate national environmental and energy policies. Based on the research findings, national policy-makers can develop successful development strategies, which produce a harmony among energy, environment and economy. Therefore, we aimed at analyzing the causality linkages between renewable energy use and economic performance in 17 emerging market economies over the period of 1990–2016. Many emerging countries, much like their developed counterparts, have decided to reduce their high dependency ratios for fossil fuels by improving investments in renewable energy. The investments of emerging countries in clean energy have increased from 18% to 42% of global investments since 2004. China, Brazil, and India shared, respectively, the ranks of first, fifth, and eighth in renewable energy investments, accounting for 37% of global clean energy investments [3]. In the literature, there is not enough study exploring the causality linkages between renewable energy demand and economic growth for emerging markets [see, inter alia [6,11,12]]. We differ from the available studies and contribute to the related literature by

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employing the bootstrap panel causality approach proposed by Konya [1]. This causality test is superior to others as it allows for both dependence across countries and heterogeneity in slope parameters.

The rest of the study is designed as follows: Section 2 includes a short literature review. Section 3 explains the material and methods used while Section 4 presents empirical findings with discussion. Finally, Section 5 concludes the paper with some policy suggestions.

2. Literature review

Although the causality relationship between renewable energy consumption and economic growth has attracted significant interest in recent studies, there is not unanimity among scholars about the direction of causality. There exist four essential hypotheses, namely the growth hypothesis, conservation hypothesis, feedback hypothesis, and the neutrality hypothesis, concerning the causality issue between energy use and economic growth. First, the growth hypothesis suggests that energy consumption has a direct or indirect effect on economic growth as it complements to labor and capital. The presence of a unidirectional causality running from energy use to economic growth verifies the growth hypothesis. In this situation, energy saving policies targeting to decrease energy consumption may adversely affect economic performance level by causing a fall in output and a rise in unemployment [13]. The growth hypothesis confirming the positive impact of energy in the development phases of nations assumes that energy is a repulsive factor to economic growth [14]. Second, the conservation hypothesis is supported if there exists a unidirectional causality running from economic growth to energy usage. The conservation hypothesis asserts that energy saving policies planned to curb energy demand may not negatively affect economic performance. Therefore, precautions such as cutting GHGs emissions, increasing energy efficiency or management of energy demand will probably have just a small influence on economic growth because economy is relatively less dependent on energy [15]. Third, regarding the feedback hypothesis, there is a complementarity and interdependence between energy use and economic performance. This hypothesis is confirmed in the presence of a bidirectional (mutual) relationship between energy demand and economic performance. In this case, energy saving policies lessening energy demand are likely to have adverse influences on economic growth. In this situation, energy policy should be carefully arranged given that one-sided policy implementation is likely to be harmful for economic performance and thus a diversified policy, e.g. sectorial policies, should be implemented [14]. Last, the neutrality hypothesis does not assume a significant causality linkage between energy demand and growth because energy consumption doesn't contribute much to the production process [16]. In this scenario, energy mitigation policies would not negatively affect economic growth.

To conserve space, we will not explain all studies in detail; however, we have provided a detailed summary of the literature in Tables 1, 2. The first research strand includes multi-country studies in a panel data framework. Some of these scholars investigated both the renewable energy-income and non-renewable energy-income nexuses (see [4,6,10,17]). Salim et al. [10] found evidence confirming the feedback hypothesis for the link of economic growth-non-renewable energy use in the short-run, while the growth hypothesis was confirmed in the case of economic growth and renewable energy consumption in the short-run. In this research strand, in the case of economic growth and renewable electricity consumption, Apergis and Payne [6] confirmed the conservation hypothesis in the short-run and the feedback hypothesis in the long-run. Furthermore, the feedback hypothesis was supported for the non-renewable electricity demand-economic performance case in both the short- and long-run. In another study, Apergis and Payne [4] analyzed the relationship between renewable and non-renewable energy use and economic growth for 80 countries. The authors confirmed the feedback hypothesis in the case of renewable and non-renewable energy consumption and economic growth in both the short- and long-run. For the nine South American economies, Apergis and Payne [17] confirmed the feedback hypothesis between renewable and non-renewable electricity consumption, respectively and economic growth in both the short- and long-run.

Some panel studies only examined the relationship between renewable energy demand and economic performance (see [5–7,12,31–34]). Out of these studies, the feedback hypothesis was verified in both the short- and long-run by Apergis and Payne [32] for 80 countries, Apergis and Payne [31] for 13 Eurasian countries, Apergis and Payne [6] for six Central American countries, and Apergis and Payne [5] for 20 OECD countries. However, Kula [34] supported the conservation hypothesis for 19 OECD countries, while Menegaki [33] affirmed the neutrality hypothesis for 27 European countries. Sadorsky [12] verified the neutrality hypothesis in the short-run and the feedback hypothesis in the long-run for 18 emerging economies.

Apart from the panel studies, there exists a second research strand that includes country-specific studies. These studies generally use the Toda-Yamamoto causality test [36] (see [8,9,14,23,24,26]) or the bootstrap causality test of Hatemi-J [37] (see [14,30]) and forecast error of variance decomposition analysis (see [21,27,29]) to reveal the direction of causality among certain variables. Some of the studies examined both the renewable and non-renewable energy use and economic growth links. For instance, Tugcu et al. [30] confirmed the feedback hypothesis for both the renewable-growth nexus and the non-renewable-growth nexus for all G7 countries by using classical production function; but they found mixed results for each country in case of the augmented production function. Payne [8] confirmed the neutrality hypothesis for both the renewable energy consumption-real GDP and non-renewable energy consumption-real GDP nexuses for the US. Another study by Payne [26] supported the growth hypothesis for the biomass-GDP nexus in the US while Ocal and Aslan [23] obtained evidence of the conservation hypothesis for Turkey.

Furthermore, some country-specific studies used disaggregate data (see Bowden and Payne [9] for the US; Ewing et al. [21] for the US; Pao and Chia [25] for Brazil; Sari and Soytas [27] for Turkey; Sari et al. [28] for the US; Yildirim et al. [14] for the US) to define the direction of causality between renewable energy use and economic performance. Additionally, some of the studies in this strand revealed the impact of renewable energy consumption on CO_2 emissions, controlling for GDP and other variables (see [24,29]). Besides, the third research strand consists of time series studies using methods other than causality tests and variance decomposition analysis (see [18–20,22]). The fourth research strand includes studies employing both panel data and time series data methods (see [11]).

3. Material and methods

3.1. Data and sample

Following the studies of Apergis and Payne [4–6,31,32,35], we examined the causality linkages between renewable energy use and economic growth, controlling for measures of capital and labor to prevent omitted variable bias. Data on total renewable electricity consumption defined in billions of kilowatt hours are from the EIA [38] while data on real GDP measured in billions of constant 2005 U.S. dollars, total labor force defined in millions, real gross fixed capital formation defined in billions of constant 2005 U.S. dollars are sourced from the World Bank [39]. Additionally, all variables are expressed in their natural logarithmic forms. The models are defined in Eqs. (8) and (9).

The sample consists of seventeen emerging markets namely, Brazil, Chile, China, India, Indonesia, Egypt, Greece, Hungary, Malaysia, Mexico, Peru, Philippines, Poland, South Africa, South Korea, Thailand and Turkey over the period 1990–2016. We used the Morgan Stanley Capital International (MSCI) classification [40] to select emerging markets. We excluded Colombia, Czech Republic, Russia, and Taiwan

Table 1
Summary of literature (panel data studies).

Authors	Countries	Period	Methods	Variables	Results
Apergis and Payne [31]	13 Eurasian countries	1992–2007	Pedroni's panel cointegration tests, panel FMOLS estimator, PVEC	REC, GDP, L, K	GDP ⇔ REC (in short- and long-run)
Apergis and Payne [5]	20 OECD countries	1985–2005	Pedroni's panel cointegration tests, panel FMOLS estimator, PVEC	REC, GDP, L, K	GDP ⇔ REC (in short- and long-run)
Apergis and Payne [16]	6 Central American countries	1980–2006	Pedroni's panel cointegration tests, panel FMOLS estimator, PVEC	REC, GDP, L, K	GDP ⇔ REC (in short- and long-run)
Apergis and Payne [35]	16 emerging market economies	1990–2007	Pedroni's panel cointegration tests, panel FMOLS estimator, PVEC	NREC, REC, GDP, L, K	GDP ⇔ REC (in short- and long-run) GDP ⇔ NREC (in short- and long-run)
Apergis and Payne [4]	80 countries	1990–2007	Pedroni's panel cointegration tests, panel FMOLS estimator, PVEC	NREC, REC, GDP, L, K	GDP ⇔ REC (in short- and long-run) GDP ⇔ NREC (in short- and long-run)
Apergis and Payne [32]	80 countries	1990–2007	Pedroni's panel cointegration tests, panel FMOLS estimator, PVEC	REC, GDP, L,K	GDP ⇔ REC (in short- and long-run)
Apergis and Payne [17]	Nine South America	1990–2007	Larsson et al.'s panel cointegration test, PEVC	NREC, REC, GDP, L, K	GDP ⇔ REC (in short- and long-run) GDP ⇔ NREC(in short- and long-run)
Kula [34]	19 OECD	1980–2008	Pedroni's cointegration tests and panel DOLS, PVEC	REC, GDP	GDP → REC
Menegaki [33]	27 European countries	1997–2007	Random effect model	GDP, REC, final energy consumption, greenhouse gas emissions and L	GDP ≠ REC
Sadorsky [12]	18 emerging economies	1994–2003	Pedroni's panel cointegration tests, panel FMOLS, DOLS, OLS, and PVEC	REC, GDP, L, K	GDP ≠ REC (in the short-run) GDP ⇔ REC (in the long-run)
Sadorsky [7]	G7	1980–2005	Panel cointegration test, FMOLS, DOLS, PVEC	REC, GDP per capita, CO_2 emissions per capita, oil prices.	a 1% increase in GDP leads to 8.44% increase in REC
Salim and Rafiq [11]	Brazil, China, India, Indonesia, Philippines and Turkey	1980–2006	Panel cointegration test, FMOLS, DOLS, ARDL approach, Granger causality test	REC, GDP, oil price, CO_2 emissions.	REC ⇔ income (in the short-run)
Salim et al. [10]	29 OECD countries	1980–2011	Panel cointegration test and PVEC model	REC, NREC, L, K,GDP and industrial output	Industrial output ⇔ REC and NREC(in short- and long-run) GDP ⇔ NREC (in the short-run), REC → GDP (in the short-run)

Notes: FMOLS, DOLS, ARDL, PVEC, REC, NREC, L and K denote the fully modified ordinary least squares, dynamic ordinary least squares, Autoregressive distributed lag model, Panel vector error correction model, renewable energy consumption, non-renewable energy consumption, labor and capital, respectively.

Table 2
A brief summary of literature (time series studies).

Authors	Countries	Period	Methods	Variables	Results
Al-Mulali et al. [18]	high income, upper middle income, lower middle income	Differ over the period 1949–2009 for each country	FMOLS	REC, GDP	GDP⇔REC: 79% of the countries GDP‡REC: 19% of the countries GDP→REC and REC→ GDP: 2% of the countries
Bowden and Payne [9]	US	1949–2006	TY causality test	GDP, REC and NREC for commercial, industrial, and residential sectors, L, K	Commercial GDP‡ REC Industrial GDP‡REC Commercial NREC⇔GDP Residential NREC⇔GDP Residential REC→GDP Industrial non-renewable→GDP
Chien and Hu [19]	45 economies	2001–2002	DEA	GDP, L, K, traditional energy	The more renewable energy consumption, the more technical efficiency.
Chien and Hu [20]	116 economies	2003	SEM	GDP, REC	REC had a positive indirect effect on GDP
Ewing et al. [21]	US	2001:1–2005:6	Generalized forecast error variance decomposition technique	disaggregate categories of the energy consumption, L, industrial production	REC explains less than 2.5% of the forecast error variance of industrial production
Fang [22]	China	1978–2008	OLS and SPSS software	REC, GDP, GDP per capita, per capita income of urban and rural households	a 1% increase in REC increases: Real GDP by 0.120%, GDP per capita by 0.162%,
Ocal and Aslan [23]	Turkey	1990–2010	ARDL approach, TY causality test	REC and waste % of total energy, GDP, L, K	GDP→REC
Menyah and Wolde-Rufael [24]	US	1960–2007	TY causality test	CO_2 emissions, REC and nuclear energy consumption and real GDP	GDP→REC
Pao and Fu [25]	Brazil	1980–2010	Johansen cointegration test and VEC model	Real GDP, NHREC, TREC, NREC, TEC	NHREC→GDP, TREC⇔GDP GDP→NREC and TEC
Payne [8]	US	1949–2006	TY causality test	REC, NREC, L, K	GDP‡REC GDP‡NREC
Payne [26]	US	1949–2007	TY causality test	Biomass, real GDP, L, K	REC→GDP
Sari and Soytas [27]	Turkey	1969–1999	Generalized forecast error variance decomposition technique	GDP, L and energy consumption at disaggregate level	Lignite, waste, oil and hydraulic power explain about 25%, 17%, 15% and 10%, respectively of the forecast error variance of GDP.
Sari et al. [28]	US	2001:1–2005:6.	ARDL approach	Industrial output, L, disaggregate categories of the energy consumption	Mixed results were obtained based on energy source.
Tiwari et al. [29]	India	1960–2009	SVAR approach and variance decomposition analysis	REC, GDP growth, and CO_2 emissions	REC explain a significant part of the forecast error variance of GDP
Tugcu et al. [30]	G7	1980–2009	ARDL cointegration test, Hatemi-J causality test	Classical function: (REC, NREC, L, K) Augmented function: (REC, NREC, L, K, R&D and human capital	GDP⇔REC and GDP⇔NREC in classical function Mixed results in the case of augmented function.
Yildirim et al. [14]	US	Differ over the period 1949–2010 based on energy types.	TY causality test and Hatemi-J causality test	Total REC, biomass, hydropower, biomass-wood-derived REC	Biomass-waste-derived REC→real GDP No causality result for the other energy types.

Notes: FMOLS, DOLS, TY, DEA, SEM, ARDL, SVAR, SPSS, OLS, VEC, REC, NREC, NHREC, TREC, TEC, L, K, and R&D denote the fully modified ordinary least squares, dynamic ordinary least squares, Toda-Yamamoto causality test, data envelopment analysis, structural equation model, Autoregressive distributed lag model, structural vector autoregressive model, Statistical package for the social sciences, ordinary least squares, vector error correction, renewable energy consumption, non-renewable energy consumption, non-hydro- renewable energy consumption, total renewable energy consumption, total energy consumption, labor, capital, and research and development, respectively.

due to insufficient data.

3.2. Cross-sectional dependence tests

Cross-sectional dependence is of importance among panel members, particularly if the panel consists of countries in a similar category such as developed countries, emerging countries, and transition countries. Due to globalization, financial integration, and international trade, a shock affecting one economy can affect other economies, as well [41–43]. Therefore, searching for the presence of cross-sectional dependence is our first step. There exist four cross-sectional dependence tests. The Lagrange multiplier (LM) test, which is suitable in situations where N is smaller than T, which was developed by Breusch and Pagan [44]. Based on Eq. (1), we constructed the LM test statistic:

$$y_{it} = \alpha_i + \beta_i x_{it} + u_{it} \; i = 1, \ldots\ldots, N \text{ and } t = 1, \ldots\ldots, T \tag{1}$$

where y_{it} is a dependent variable, x_{it} is a $kx1$ vector of independent variables, and the subscripts i and t represent cross-section and time dimensions, respectively; α_i and β_i are, respectively, the country-specific intercepts and slope coefficients. In this context, the null hypothesis of cross-sectional independence—H_0: $Cov(u_{it}, u_{jt}) = 0$ for all t and $i \neq j$ —is tested against the alternative hypothesis of cross-sectional dependence—H_1: $Cov(u_{it}, u_{jt}) \neq 0$ —for at least one pair of $i \neq j$. Besides, the LM test statistic can be computed as in Eq. (2).

$$LM = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij} \rightarrow_d \chi^2_{N(N-1)/2} \tag{2}$$

where $\hat{\rho}_{ij}$ represents a sample estimate of the pair-wise correlation of the residuals. However,

the LM statistic is not appropriate when N is large; in this case, Pesaran [45] suggested the following Lagrange multiplier test statistic (CD_{lm}) that is the scaled version of the LM test statistic:

$$CD_{lm} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T\hat{\rho}_{ij}^2 - 1\right) \tag{3}$$

Under the cross-sectional independence null hypothesis with first $T \to \infty$ and then $N \to \infty$, CD_{lm} test statistic follows an asymptotic standard normal distribution (see [41–43]). In the case of large N relative to T, the CD_{lm} test has substantial size distortions. Therefore, Pesaran [45] suggested to utilize the following CD test, which is appropriate when N is larger than T.

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \tilde{\rho}_{ij} \tag{4}$$

The CD test has a standard normal distribution asymptotically under the null hypothesis of cross-sectional independence with $T \to \infty$ and then $N \to \infty$ in any order [41]. However, the CD test has the following drawback: where the population average pair-wise correlations is zero, even though the underlying individual population pair-wise correlations are non-zero, CD test will lose power. Therefore, Pesaran et al. [46] proposed a bias-adjusted version of the LM test, LM_{adj}, which utilizes the exact mean and variance of the LM statistic in case of large panels where first $T \to \infty$ and then $N \to \infty$. The bias-adjusted LM test statistic is defined as

$$LM_{adj} = \sqrt{\left(\frac{2}{N(N-1)}\right)} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \frac{(T-k)\hat{\rho}^2{}_{ij} - \mu_{Tij}}{\upsilon^2{}_{Tij}} \rightarrow_d N\left(0, 1\right) \tag{5}$$

where k refers to the number of regressors, μ_{Tij} and υ_{Tij}^2 indicate the exact mean and variance of $(T-k)\hat{\rho}_{ij}^2$, respectively.

3.3. Slope homogeneity tests

Although there is likely to be a strong dependence across countries, each country follows different methods in their development stages by designing different policies, making it crucial to test for slope heterogeneity across countries [43]. As such, the next step is to search for the heterogeneity in slope coefficients in Eqs. (8) and (9). To this purpose, we used the Delta tests ($\tilde{\Delta}$, $\tilde{\Delta}_{adj}$), which were suggested by Pesaran and Yamagata [47]. There are four types of Delta tests ($\tilde{\Delta}$, $\tilde{\Delta}_{adj}$, $\hat{\Delta}$, and $\hat{\Delta}_{adj}$), but Pesaran and Yamagata [47] state that $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ tests have better size properties compared to $\hat{\Delta}$ and $\hat{\Delta}_{adj}$ tests. Therefore, we applied $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ tests, which are defined in Eqs. (6) and (7).

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}}\right) \tag{6}$$

where k, $\tilde{S}$ and N indicate the number of exogenous regressors, Swamy's [48] test statistic, and the cross-section dimension, respectively. The small sample properties of the $\tilde{\Delta}$ test could be improved under the normally distributed errors based on the following mean and variance bias-adjusted version of $\tilde{\Delta}$:

$$\tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - E(\tilde{z}_{iT})}{\sqrt{Var(\tilde{z}_{iT})}}\right) \tag{7}$$

where $E(\tilde{z}_{iT}) = k$ and $Var(\tilde{z}_{iT}) = \frac{2k(T-k-1)}{T+1}$.

3.4. The bootstrap panel causality test

We utilized the bootstrap panel causality test developed by Konya [1] that utilizes the seemingly unrelated regression (SUR) systems and reports Wald test statistics with individual-specific bootstrap critical values. This test is not based on the assumption of panel homogeneity, meaning that testing for Granger causality on each cross-section unit is possible. First, we estimated the following system of equations via SUR method:

$$\begin{aligned}
\ln REC_{1,t} &= \alpha_{1,1} + \textstyle\sum_{l=1}^{mly_1} \beta_{1,1,l} \ln REC_{1,t-l} + \sum_{l=1}^{mlx_1} \theta_{1,1,l} \ln Y_{1,t-l} \\
&\quad + \textstyle\sum_{l=1}^{mlz_1} \omega_{1,1,l} \ln K_{1,t-l} + \sum_{l=1}^{mlw_1} \phi_{1,1,l} \ln L_{1,t-l} + \varepsilon_{1,1,t} \\
\ln REC_{2,t} &= \alpha_{1,2} + \textstyle\sum_{l=1}^{mly_1} \beta_{1,2,l} \ln REC_{2,t-l} + \sum_{l=1}^{mlx_1} \theta_{1,2,l} \ln Y_{2,t-l} \\
&\quad + \textstyle\sum_{l=1}^{mlz_1} \omega_{1,2,l} \ln K_{2,t-l} + \sum_{l=1}^{mlw_1} \varphi_{1,2,l} \ln L_{2,t-l} + \varepsilon_{1,2,t} \\
&\vdots \\
\ln REC_{N,t} &= \alpha_{1,N} + \textstyle\sum_{l=1}^{mly_1} \beta_{1,N,l} \ln REC_{N,t-l} + \sum_{l=1}^{mlx_1} \theta_{1,N,l} \ln Y_{N,t-l} \\
&\quad + \textstyle\sum_{l=1}^{mlz_1} \omega_{1,N,l} \ln K_{N,t-l} + \sum_{l=1}^{mlw_1} \phi_{1,N,l} \ln L_{N,t-l} + \varepsilon_{1,N,t}
\end{aligned} \tag{8}$$

and

$$\begin{aligned}
\ln Y_{1,t} &= \alpha_{2,1} + \textstyle\sum_{l=1}^{mly_2} \theta_{2,1,l} \ln Y_{1,t-l} + \sum_{l=1}^{mlx_2} \beta_{2,1,l} \ln REC_{1,t-l} \\
&\quad + \textstyle\sum_{l=1}^{mlz_2} \omega_{2,1,l} \ln K_{1,t-l} + \sum_{l=1}^{mlw_2} \phi_{2,1,l} \ln L_{1,t-l} + \varepsilon_{2,1,t} \\
\ln Y_{2,t} &= \alpha_{2,2} + \textstyle\sum_{l=1}^{mly_2} \theta_{2,2,l} \ln Y_{2,t-l} + \sum_{l=1}^{mlx_2} \beta_{2,2,l} \ln REC_{2,t-l} \\
&\quad + \textstyle\sum_{l=1}^{mlz_2} \omega_{2,2,l} \ln K_{2,t-l} + \sum_{l=1}^{mlw_2} \varphi_{2,2,l} \ln L_{2,t-l} + \varepsilon_{2,2,t} \\
&\vdots \\
\ln Y_{N,t} &= \alpha_{2,N} + \textstyle\sum_{l=1}^{mly_2} \theta_{2,N,l} \ln Y_{N,t-l} + \sum_{l=1}^{mlx_2} \beta_{2,N,l} \ln REC_{N,t-l} \\
&\quad + \textstyle\sum_{l=1}^{mlz_2} \omega_{2,N,l} \ln K_{N,t-l} + \sum_{l=1}^{mlw_2} \phi_{2,N,l} \ln L_{N,t-l} + \varepsilon_{2,N,t}
\end{aligned} \tag{9}$$

where $\ln REC$ is renewable energy consumption, $\ln Y$ is real GDP, $\ln K$ is the real gross-fixed capital formation, and $\ln L$ is the labor. N is the number of countries ($i = 1, 2, \ldots.., 17$), t is the time period ($t = 1990, \ldots.., 2016$), and l is the lag length. While testing for causality between $\ln Y$ and $\ln REC$, we treated $\ln K$ and $\ln L$ as auxiliary variables and did not directly involve them in the Granger causality test.

With regard to the causality chain between $\ln Y$ and $\ln REC$ for country i, there are four possible causality chains: (i) there exists a one-way Granger causality running from $\ln Y$ to $\ln REC$ if in Eq. (8) not all $\theta_{1,i}$ s are zero but in Eq. (9) all $\beta_{2,i}$ s are zero; (ii) there exists a one-way Granger causality running from $\ln REC$ to $\ln Y$ if in Eq. (8) all $\theta_{1,i}$ s are zero but not all $\beta_{2,i}$ s are zero in Eq. (9); (iii) there exists a two-way

Granger causality between ln REC and ln Y if neither all $\theta_{1,i}$ s nor all $\beta_{2,i}$ s are zero; and (iv) there is not a Granger causality between ln REC and ln Y if all $\theta_{1,i}$ s and $\beta_{2,i}$ s are zero (see [1]).

The above system has two distinct features. First, each equation consists of different predetermined variables. There is a cross correlation within the system and this is the only possible link between individual regressions. Thus, this system of equations refers to SUR systems instead of VAR. Because of the contemporaneous correlations across countries, the OLS is not an efficient estimator. In this situation, we stacked the Eqs. (8) and (9) and estimated these two stacked equations individually via a SUR estimator suggested by Zellner [49]. Second, the variables of interest are not supposed to be stationary since country-specific bootstrap critical values[1] are used. Thus, there is no need to test for the unit root properties of variables of interest.

Before applying the causality test, the numbers of optimal lags must be defined because causality test results could be sensitive to the number of lag. On the one hand, few lags are likely to cause omitted variable problem in the model, which, in turn, creates bias in the retained regression coefficients. On the other hand, many lags cause another specification error due to extra observation loss. In this case, standard errors of the estimated coefficients increase, resulting in less precise results (see [1]). We estimated the system for each possible pair of lags that range from 1 to 4 and then use the combinations minimizing the Akaike and Schwarz Information Criteria.[2]

4. Results and discussions

4.1. Results of cross-sectional dependence and slope homogeneity

As shown in Table 3, the null hypothesis of cross-sectional independence could be rejected in three out of four tests (LM,CD_{lm} and CD tests) in the case of Eq. (1). Likewise, in the Eq. (2), three out of four tests (LM, CD_{lm} and LM_{adj} tests) rejected the null hypothesis of cross-sectional independence. As most tests supported cross-sectional dependence, we can assert that there is a high dependence among emerging countries. In regard to the issue of slope heterogeneity, both Delta tests ($\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$) provided strong evidence of slope heterogeneity in both Eqns. The result of heterogeneity in the slope coefficients was expected because emerging markets have different policy designs and tools due to differences in their economic structures. Based on these results, we carried out a causality test that allows for both dependence across countries and heterogeneity in slope parameters.

4.2. Results of the bootstrap panel causality test

As tabulated in Table 4, there is no relationship between renewable energy consumption and economic growth in any direction for 16 out of the 17 countries because the bootstrap critical values are smaller than χ^2 test statistics except for Poland. In other words, renewable energy consumption and real GDP do not have any significant impact on each other in emerging markets. Only in Poland does renewable energy consumption affect GDP positively at the 10% significance level as the coefficient of the test statistic is positive.

Therefore, there is a one-way causality running from renewable energy consumption to real GDP in Poland. This result verified the growth hypothesis for Poland. In other words, more energy consumption will cause more economic growth in Polish economy. This outcome indicates that energy saving policies targeted to reduce energy demand may have detrimental effects on Polish economic performance. According to the IEA [50], the Polish government has set its renewable energy targets as 15% of gross final energy consumption and 10% of transport fuels by 2020. Market-based mechanism, i.e. the quota obligation system with tradable green certificates introduced in 2005, became successful in accelerating investment in renewable energy technologies and supporting renewable electricity production [50]. However, for the remaning16 emerging economies, the neutrality hypothesis was supported for the nexus of renewable energy consumption and economic growth, implying that economic growth and renewable energy consumption do not have any reciprocal causality linkage. As such, energy saving policies may not adversely affect economic performance levels of these 16 countries.

Table 3
Results of cross-sectional dependence and slope homogeneity.

Tests	Eq. (8)	Eq. (9)
LM test	172.250[b] (0.019)	291.917[a] (0.000)
CD_{lm} test	2.198[b] (0.014)	9.454[a] (0.000)
CD test	− 1.308[c] (0.095)	− 0.444 (0.329)
LM_{adj} test	− 4.751 (1.000)	15.386[a] (0.000)
$\tilde{\Delta}$ test	11.408 (0.000)	18.902 (0.000)
$\tilde{\Delta}_{adj}$ test	12.895 (0.000)	21.367 (0.000)

Notes: Probability values are reported in parentheses. [a], [b] and [c] indicate the rejection of null hypotheses, i.e. the rejection of the no cross-sectional dependence and the slope homogeneity null hypotheses in cross-sectional dependence and slope homogeneity tests, respectively. Eqs. (8) and (9) refer to Eqs. (8) and (9), respectively.

As sum, the results of this study provided strong evidence in support of the neutrality hypothesis in many emerging countries. There are many efforts to spur the renewable energy sector in emerging countries due their high energy consumption rates. It appears that the renewable energy sector is not well developed and needs time to develop in many emerging countries. After it reaches a threshold level, renewable energy consumption may begin to boost economic performance in these countries. Emerging markets still have high dependence rates on non-renewable energy sources such as oil and coal due to their rapid population growth and urbanization rates. Additionally, economic growth does not seem to affect renewable energy consumption, either. Increases in real income appear to be used in other priority sectors such as industry, transportation, and non-renewable energy.

If we compare our results with those of other studies related to emerging markets, the findings are in sharp contrast to those of Apergis and Payne [35], who obtained evidence of the conservation hypothesis for 16 emerging markets; Sadorsky [12], who found evidence of the feedback hypothesis for 16 emerging countries; Salim and Rafiq [11], who attained support for the feedback hypothesis for six emerging markets; Pao and Fu [25], who supported the feedback hypothesis for Brazil; and Ocal and Aslan [23], who obtained evidence of the conservation hypothesis for Turkey. However, our results are in line with those of Payne [8] for the US, Menegaki [33] for 27 European countries, Bowden and Payne [9] for the commercial and industrial sectors of the US, and Sadorsky [12] for emerging markets in the short-run.

5. Conclusion and policy implications

This study aims at analyzing the causality dynamics between renewable energy use and economic growth for 17 emerging markets from 1990 to 2016. As a testing methodology, the causality test of Konya [1], allowing for heterogeneity in slope parameters and dependence across countries, is utilized. The results indicated that the neutrality hypothesis was confirmed in 16 emerging market economies while the growth hypothesis was supported only for Poland. However,

[1] To produce the bootstrap critical values and bootstrap samples, there are four steps in the bootstrap sampling method. See Konya [1] for a detailed explanation on bootstrap sampling.

[2] We did not report the results of the lag selection method to save space; however, it is available upon request from the author. Additionally, following Konya [1], we assumed that $mlx_1 = mlz_1 = mlw_1$ in Eq. (8) and that $mlx_2 = mlz_2 = mlw_2$ in Eq. (9). The minimum values for both the Akaike and Shcwarz information criteria were obtained in the lag lengths as $mlx_1 = 1$ and $mly_1 = 1$ in Eq. (8) and $mlx_2 = 1$ and $mly_2 = 1$ in Eq. (9).

Table 4
Results of the bootstrap panel causality test.

	REC does not cause to Y					Y does not cause REC				
Countries	Coefficients	Statistics	Critical values			Coefficients	Statistics	Critical values		
			10%	5%	1%			10%	5%	1%
Mexico	− 0.013	0.175	40.256	65.164	148.342	− 3.601	8.310	36.006	55.656	121.738
Brazil	0.101	5.152	37.045	58.286	127.652	0.768	8.935	60.405	94.544	191.915
Chile	0.055	16.072	31.048	47.969	108.864	0.534	3.242	39.427	60.252	120.961
Peru	0.084	1.924	48.524	78.389	182.986	0.692	12.218	22.379	33.453	74.228
Greece	− 0.017	0.878	29.722	46.520	109.075	3.190	12.825	34.360	52.153	107.390
Hungary	0.016	4.753	31.067	47.788	98.529	2.128	6.425	22.878	37.347	82.824
Poland	0.149	47.542[c]	46.975	73.813	168.460	0.899	11.499	27.825	44.754	103.551
Turkey	0.078	8.686	26.842	41.231	89.923	0.509	1.040	28.126	41.912	82.755
Egypt	0.048	5.770	24.582	36.973	72.903	1.612	29.373	47.324	70.078	142.011
South Africa	− 0.010	15.666	52.241	81.915	170.892	− 5.717	3.313	34.114	51.868	107.278
China	0.159	26.277	57.607	85.918	180.512	0.631	5.017	21.740	33.169	68.422
India	0.018	0.221	31.869	50.857	107.737	− 0.221	0.405	27.750	42.853	91.665
Indonesia	0.173	43.860	68.780	110.875	244.669	2.073	4.854	35.292	55.162	115.277
South Korea	0.802	0.285	45.495	68.757	153.863	1.223	1.354	29.628	44.349	94.397
Malaysia	0.065	14.491	53.947	82.150	162.234	3.508	14.426	40.694	61.256	133.943
Philippines	− 0.017	2.018	36.509	55.418	111.233	− 0.526	7.363	22.055	34.108	62.568
Thailand	− 0.077	12.674	45.265	66.881	133.082	1.088	17.927	89.118	124.746	226.149

Notes: Constant and tend terms were included in regressions. Critical values were based on 10,000 bootstrap replications; [c] denotes statistical significance at 10% level.

there is not an empirical support both for the conservation and feedback hypotheses.

The obtained results signal that there is not any mutual relationship between renewable energy consumption and economic growth in nearly all emerging market economies (except for Poland). This finding is an expected result because the amount of electricity production and consumption from renewables in most emerging market economies is still low compared to developed countries such OECD economies. However, this scenario does not necessarily imply that renewable energy is not a crucial input for the economic growth and development processes of emerging market economies. It does indicate that the investment level in the renewable energy sector is not enough to boost economic growth rates of emerging economies and there is likely an unreached threshold beyond which renewable energy consumption will start to push economic growth. Most emerging economies have high dependence rates on non-renewable energy sources to produce more output. Only for Poland, renewable energy demand contributes to economic growth process. In course of time, Polish government started investing more in renewable energy sector and redesigned its key objectives of energy policy. For instance, the share of renewable energy sources in final energy consumption is aimed to increase to 15% in 2020 and 20% in 2030 [51].

Based on the above-mentioned results, the governments of emerging countries continue to support the renewable energy sector by designing different policy tools. As proposed by Apergis and Payne [31], a multilateral effort to promote renewable energy and energy efficiency needs to be designed, and a cooperation between public and private sector stakeholders could be established for the development of renewable energy markets via sharing information about on-going projects, technologies, financing and investment strategies. Furthermore, thanks to this link between the public and private sectors, the technology transfer process of bringing renewable energy projects to market would be improved [52]. Also, many governments initiatives such as renewable energy production tax credits, renewable energy portfolio standards, rebates for the installation of renewable energy systems, and the establishment of markets for renewable energy certificates would promote the expansion of the renewable energy sector [10,35].

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References

[1] Kónya L. Exports and growth: Granger causality analysis on OECD countries with a panel data approach. Econ Model 2006;23:978–92. https://doi.org/10.1016/j.econmod.2006.04.008.
[2] BP (British Petroleum). BP statistical review of world energy. 67th edition 2018〈https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statisticalreview/bp-stats-review-2018-full-report.pdf〉.
[3] REN21. Renewables 2018 global status report. 2018〈http://www.ren21.net/wp-content/uploads/2018/06/178652_GSR2018_FullReport_web_final_.pdf〉.
[4] Apergis N, Payne JE. Renewable energy consumption and economic growth: evidence from a panel of OECD countries. Energy Policy 2010;38:656–60.
[5] Apergis N, Payne JE. The renewable energy consumption-growth nexus in Central America. Appl Energy 2011;88:343–7. https://doi.org/10.1016/j.apenergy.2010.07.013.
[6] Apergis N, Payne JE. Renewable and non-renewable energy consumption-growth nexus: evidence from a panel error correction model. Energy Econ 2012;34:733–8. https://doi.org/10.1016/j.eneco.2011.04.007.
[7] Sadorsky P. Renewable energy consumption, CO_2 emissions and oil prices in the G7 countries. Energy Econ 2009;31:456–62. https://doi.org/10.1016/j.eneco.2008.12.010.
[8] Payne JE. On the dynamics of energy consumption and output in the US. Appl Energy 2009;86:575–7. https://doi.org/10.1016/j.apenergy.2008.07.003.
[9] Bowden N, Payne JE. Sectoral analysis of the causal relationship between renewable and non-renewable energy consumption and real output in the US. Energy Sources Part B Econ Plan Policy 2010;5:400–8. https://doi.org/10.1080/15567240802534250.
[10] Salim RA, Hassan K, Shafiei S. Renewable and non-renewable energy consumption and economic activities: further evidence from OECD countries. Energy Econ 2014;44:350–60. https://doi.org/10.1016/j.eneco.2014.05.001.
[11] Salim RA, Rafiq S. Why do some emerging economies proactively accelerate the adoption of renewable energy? Energy Econ 2012;34:1051–7. https://doi.org/10.1016/j.eneco.2011.08.015.
[12] Sadorsky P. Renewable energy consumption and income in emerging economies. Energy Policy 2009;37:4021–8. https://doi.org/10.1016/j.enpol.2009.05.003.
[13] Bozoklu S, Yilanci V. Energy consumption and economic growth for selected OECD countries: further evidence from the Granger causality test in the frequency domain. Energy Policy 2013;63:877–81. https://doi.org/10.1016/j.enpol.2013.09.037.
[14] Yildirim E, Sarac S, Aslan A. Energy consumption and economic growth in the USA: evidence from renewable energy. Renew Sustain Energy Rev 2012;16:6770–4. https://doi.org/10.1016/j.rser.2012.09.004.
[15] Jakovac P. Causality between energy consumption and economic growth: literature review. In: Proceedings of the 5th international conference on education and social sciences. Istanbul, Turkey; 2018.
[16] Apergis N, Payne JE. Energy consumption and economic growth in Central America: evidence from a panel cointegration and error correction model. Energy Econ 2009;31:211–6. https://doi.org/10.1016/j.eneco.2008.09.002.
[17] Apergis N, Payne JE. Another look at the electricity consumption-growth nexus in South America. Energy Sources Part B Econ Plan, Policy 2013;8:171–8. https://doi.

org/10.1080/15567249.2011.653474.
[18] Al-Mulali U, Fereidouni HG, Lee JY, Sab CNBC. Examining the bi-directional long run relationship between renewable energy consumption and GDP growth. Renew Sustain Energy Rev 2013;22:209–22. https://doi.org/10.1016/j.rser.2013.02.005.
[19] Chien T, Hu JL. Renewable energy and macroeconomic efficiency of OECD and non-OECD economies. Energy Policy 2007;35:3606–15. https://doi.org/10.1016/j.enpol.2006.12.033.
[20] Chien T, Hu JL. Renewable energy: an efficient mechanism to improve GDP. Energy Policy 2008;36:3035–42. https://doi.org/10.1016/j.enpol.2008.04.012.
[21] Ewing BT, Sari R, Soytas U. Disaggregate energy consumption and industrial output in the United States. Energy Policy 2007;35:1274–81. https://doi.org/10.1016/j.enpol.2006.03.012.
[22] Fang Y. Economic welfare impacts from renewable energy consumption: the China experience. Renew Sustain Energy Rev 2011;15:5120–8. https://doi.org/10.1016/j.rser.2011.07.044.
[23] Ocal O, Aslan A. Renewable energy consumption–economic growth nexus in Turkey. Renew Sustain Energy Rev 2013;28:494–9. https://doi.org/10.1016/j.rser.2013.08.036.
[24] Menyah K, Wolde-Rufael Y. CO_2 emissions, nuclear energy, renewable energy and economic growth in the US. Energ Policy 2010;38:2911–5. https://doi.org/10.1016/j.enpol.2010.01.024.
[25] Pao HT, Fu HC. Renewable energy, non-renewable energy and economic growth in Brazil. Renew Sustain Energy Rev 2013;25:381–92. https://doi.org/10.1016/j.rser.2013.05.004.
[26] Payne JE. On biomass energy consumption and real output in the US. Energy Sources Part B Econ Plan Policy 2011;6:47–52. https://doi.org/10.1080/15567240903160906.
[27] Sari R, Soytas U. Disaggregate energy consumption, employment and income in Turkey. Energy Econ 2004;26:335–44. https://doi.org/10.1016/j.eneco.2004.04.014.
[28] Sari R, Ewing BT, Soytas U. The relationship between disaggregate energy consumption and industrial production in the United States: an ARDL approach. Energy Econ 2008;30:2302–13. https://doi.org/10.1016/j.eneco.2007.10.002.
[29] Tiwari AK. A structural VAR analysis of renewable energy consumption, real GDP and CO_2 emissions: evidence from India. Econ Bull 2011;31:1793–806.
[30] Tugcu CT, Ozturk I, Aslan A. Renewable and non-renewable energy consumption and economic growth relationship revisited: evidence from G7 countries. Energy Econ 2012;34:1942–50. https://doi.org/10.1016/j.eneco.2012.08.021.
[31] Apergis N, Payne JE. Renewable energy consumption and growth in Eurasia. Energy Econ 2010;32:1392–7. https://doi.org/10.1016/j.eneco.2010.06.001.
[32] Apergis N, Payne JE. A global perspective on the renewable energy consumption-growth nexus. Energy Sources Part B Econ Plan Policy 2012;7:314–22. https://doi.org/10.1080/15567249.2011.601530.
[33] Menegaki AN. Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis. Energy Econ 2011;33:257–63. https://doi.org/10.1016/j.eneco.2010.10.004.
[34] Kula F. The long-run relationship between renewable electricity consumption and GDP: evidence from panel data. Energy Sources Part B Econ Plan Policy 2014;9:156160. https://doi.org/10.1080/15567249.2010.481655.
[35] Apergis N, Payne JE. Renewable and non-renewable electricity consumption–-growth nexus: evidence from emerging market economies. Appl Energy 2011;88:5226–30.
[36] Toda HY, Yamamoto T. Statistical inference in vector autoregressions with possibly integrated processes. J Econ 1995;66:225–50.
[37] Hatemi-j A. Asymmetric causality tests with an application. Empir Econ 2012;43:447–56. https://doi.org/10.1007/s00181-011-0484-x.
[38] (EIA) Energy Information Administration. International Energy Statistic; 2018. 〈http//wwwEiaGov/Cfapps/Ipdbproject/IEDIndex3Cfm?Tid = 6&pid = 29&aid = 2〉.
[39] World Bank. World Development Indicators; 2018. 〈http//DatabankWorldbankOrg/Data/Views/VariableSelection/SelectvariablesAspx?Source = world-Development-Indicators〉.
[40] (MSCI) Morgan Stanley Capital International; 2018. 〈http://wwwMsciCom/〉.
[41] Nazlioglu S, Lebe F, Kayhan S. Nuclear energy consumption and economic growth in OECD countries: cross-sectionally dependent heterogeneous panel causality analysis. Energy Policy 2011;39:6615–21. https://doi.org/10.1016/j.enpol.2011.08.007.
[42] Menyah K, Nazlioglu S, Wolde-Rufael Y. Financial development, trade openness and economic growth in African countries: new insights from a panel causality approach. Econ Model 2014;37:386–94. https://doi.org/10.1016/j.econmod.2013.11.044.
[43] Wolde-Rufael Y. Electricity consumption and economic growth in transition countries: a revisit using bootstrap panel Granger causality analysis. Energy Econ 2014;44:325–30. https://doi.org/10.1016/j.eneco.2014.04.019.
[44] Pagan AR. The Lagrange multiplier test and its applications to model specification in econometrics. Rev Econ Stud 1980;XLVII:239–53.
[45] Pesaran MH. General Diagnostic Tests for Cross Section Dependence in Panels; 2004. 〈https://doi.org/10.17863/CAM.5113〉.
[46] Pesaran MH, Ullah A, Yamagata T. A bias-adjusted LM test of error cross-section independence. Econ J 2008;11:105–27. https://doi.org/10.1111/j.1368-423X.2007.00227.x.
[47] Pesaran MH, Yamagata T. Testing slope homogeneity in large panels. J Econ 2008;142:50–93. https://doi.org/10.1016/j.jeconom.2007.05.010.
[48] Swamy PAVB. Efficient inference in a random coefficient regression model. Econometrica 1970;38:311–23.
[49] Zellner A. An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. J Am Stat Assoc 2010;57:348–68.
[50] (IEA) International Energy Agency. Energy Policies of IEA Countries Poland 2011. France: OECD/IEA; 2011. 〈http://www.oecd.org/publications/energy-policies-of-iea-countries-poland-2011-9789264098190-en.htm〉.
[51] APAX Consulting Group. Renewable Energy in Poland; 2009. 〈https://www.paih.gov.pl/files/?id_plik = 12126〉.
[52] Apergis N, Payne JE. Renewable and non-renewable energy consumption-growth nexus: evidence from a panel error correction model. Energy Econ 2012;34:733–8. https://doi.org/10.1016/j.eneco.2011.04.007.