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RESEARCH ARTICLE

Asymmetric causality between renewable energy consumption and economic growth: fresh evidence from some emerging countries

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Abstract
Renewable energy is an important alternative energy source in terms of both sustainable growth and climate change. In this paper, the causality nexus between renewable energy consumption and economic growth is analyzed in 15 emerging countries covering the period from 1990 to 2015. The paper adopts the bootstrap panel causality test which is developed by (Kónya, Econ Model 23:978–992, 2006) to consider the cross-sectional dependence. The results of (Kónya, Econ Model 23:978–992, 2006) prove the validity of the neutrality hypothesis in all countries. Then, we analyze asymmetric causality among the variables. Asymmetric test denotes a causality from negative shocks of economic growth to negative shocks of renewable energy consumption in South Africa, Thailand, and Turkey. Thus, a negative shock in economic growth hampers renewable energy consumption in these countries. Our results demonstrate the consequences of the application of disaggregated data in the analyses.

Keywords Renewable energy · Asymmetric causality · Economic growth · Panel data · Emerging countries

Introduction

Energy sources are very important in terms of economic and social development. After the Industrial Revolution, demand for energy resources has increased, and this increase continues day by day. Technological developments, industrialization, and the rise in the world population also rapidly increase the energy demand. Energy, which is the main input in production, is a necessary element for the increase of the welfare of societies. Most of the energy needed in the world is met from fossil resources (coal, oil, and natural gas). Fossil fuels have found widespread use due to both their cheapness and developments in production technology. International efforts to prevent global warming caused by using fossil fuels have accelerated policies that support and increase the use of renewable energy resources (hydroelectric, geothermal, solar, wind, biomass, etc.), which are cleaner.

There is a strong relationship between energy use, environmental impacts, and growth in terms of development. For sustainability, it is necessary to increase the use of renewable energy resources, reduce environmental pollution, and use energy resources efficiently. Greenhouse gases generated as a result of the use of energy sources based on fossil fuels such as oil, natural gas, and coal cause global warming. This situation inevitably leads to climate change and a decrease in biological diversity. Thus, to meet the energy needs, renewable energy investments are made by many countries around the world to benefit more from renewable energy sources instead of non-renewable energy resources. Another reason that enables the development of renewable energy sources is the emergence of environmental awareness. This awareness has led to the realization that traditional energy production and consumption have direct negative effects on the environment and natural resources at local, regional, and global levels, and it has led to the support of renewable energy sources as clean sources.

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Although the traditional economic growth (EG) theories have largely neglected the impact of energy consumption (EC) on EG, researchers have made significant efforts to discover the potential relationship between EC and EG over the last few decades (Jakovac 2018). Economic activities that determine EG and development performances of countries such as production and consumption are highly dependent on energy use. An increase in economic activities rapidly promotes energy demand.

According to BP (2019), primary EC increased by 2.9% in 2018 and reached its highest rate since 2010. In 2018, all types of fuel grew faster than their average in the last 10 years. The highest rate of increase in EC was seen in natural gas, while renewable energy was holding the second-highest growth rate after natural gas. Despite the increasing importance and use of renewable energy in recent years, its share in primary EC has been at 4% which can be assessed as a very low level in EC (BP 2019). This indicates that the energy portfolio is still dominated by non-renewable energy resources.

In 2018, the shares of natural gas, crude oil, and coal respectively were 34%, 27%, and 24% in primary EC. Although the proportion of fossil fuels in primary EC is high, renewable energy consumption (REC) can be expected to increase in the future. The rapid increase in carbon dioxide (CO_2) emissions, global warming, and climate change, excessive volatility in oil prices, and concerns about energy security have made it essential to replace non-renewable energy resources with renewable energy (Burke and Stephens 2018). The need for energy, which is the main input of social and economic development in the world, and the limited energy resources of the world have led countries to reconsider their energy policies and to use energy effectively. Another issue that makes the use of renewable resources important is population growth, rapid urbanization, and environmental pollution that comes with the ensuing intense energy demand. The negative effects of rapid urbanization, which is accepted as one of the main causes of global warming, can be prevented to some extent by using renewable energy.

Renewable energy is a domestic energy resource that can reduce the dependence on foreign energy sources and facilitate the creation of independent energy policies at the national level (Aslan and Ocal 2016). Countries are trying to develop strategic plans and making some arrangements in energy markets to expand the use of renewable energy by increasing public interest in renewable energy (Strunz et al. 2016). Also, governments are trying to encourage renewable energy investments through financial incentives such as tax cuts and credit facilities (Apergis and Payne 2014a).

The dissemination of REC will affect improving environmental quality. In this context, it is very important to explore the relationship between REC and EG comprehensively. This framework can provide important information for policymakers in formulating policies in the fields of energy, environment, and growth. Determining the interactions between REC and EG and which of these variables is the cause leading to another will increase the compliance and success of energy and growth policies to be implemented. Also, revealing the linkages between REC and EG will give clues about the dissemination of renewable energy which plays a strategic role in reducing environmental degradation.

This paper aims to examine the causal linkages between REC and EG in 15 emerging countries for the period 1990–2015. Renewable energy investments are rapidly increasing in the countries due to the advantages it provides in terms of environmental quality and energy security. Emerging market economies all over the world, especially the E-7 countries, have achieved a significant growth performance since the 1990s (Uzar 2021a, b). The rapid evolution of the traditional production structure of these countries, such as agriculture and raw materials, into the industrial sector, increases the energy needs of these countries in the last few decades. Therefore, emerging economies are trying to reduce their high dependence on fossil fuels by increasing their renewable energy investments (Ozcan and Ozturk 2019).

According to the Renewables Global Status Report (2019), emerging economies surpassed developed countries in renewable energy investments in 2015. They maintained their status in 2017 and 2018 as well. In this regard, countries featured in the global renewable energy investments are China, India, Brazil, Turkey, and Indonesia. In 2018, China, India, and Brazil accounted for 38% of global investments. All these developments increase the importance of linkage between REC and EG in emerging markets.

The paper intends to contribute to the existing literature with the following aspects. Firstly, Ozcan and Ozturk (2019) stated that the causal relationship between REC and EG has not been investigated for emerging market economies. Sadorsky (2009), Destek and Aslan (2017), and Ozcan and Ozturk (2019) are limited studies examining the causal nexus between REC and EG in emerging countries. Therefore, the findings of this paper are important to enrich the limited empirical literature on emerging markets and guide policymakers in the policy design process. Secondly, Ozturk (2010) stated that it is not beneficial to apply the same method and the same variables to different periods in the energy-growth literature. Thus, the literature needs to obtain better and more reliable results by adopting different perspectives and different methods. As far as we know, this paper is one of the first attempts to assess the linkages between REC and EG in terms of asymmetric causality.

Asymmetric causality provides a detailed investigation of the nexus between variables. Variables may not produce similar responses to positive and negative shocks. In this

context, asymmetric causality analysis reveals the causal relationship among the positive and negative components of the series, so this analysis allows the discovery of asymmetric connections between the variables. This helps in detailed observation of the causal trade-off between REC and EG, increases the robustness of the analysis, and enables stronger policies to be established.

The remainder of the study is structured as follows. Section 2 summarizes the earlier literature. Section 3 explains the data and methods. Section 4 indicates empirical findings and their interpretation. Section 5 debates the findings. Lastly, Sect. 6 provides concluding remarks and policy recommendations.

Literature review

Since the pioneering attempt of Kraft and Kraft (1978), the interaction among EC and EG has been extensively studied. Most of the studies focused on the nexus between EC and EG (Sari and Soytas 2007; Wolde-Rufael 2009; Apergis and Payne 2009; Belke et al. 2011; Gardiner and Hajek 2020; Khan et al. 2021). The number of studies examining the nexus between REC and EG is enhancing because of the increasing importance of renewable energy in recent years (e.g., Sadorsky 2009; Apergis and Payne 2014a, b; Aslan and Ocal 2016; Ozcan and Ozturk, 2019; Kasperowicz et al. 2020; Uzar and Eyuboglu 2021). On the other hand, comparative studies are examining the linkages among REC, non-REC, and EG (Payne 2009; Pao and Fu 2013; Ohlan 2016; Magazzino 2017; Destek and Aslan 2017; Magazzino and Brady 2018).

Although there is an extensive literature, there is no consensus on the direction of causality between EC and EG. The most important reason for this is that the countries, regions, periods, variables, and methodologies studied differ from each other. Furthermore, as Ozturk (2010) states, the different economic/political preferences and cultural structures of the countries are some of the important reasons for the differentiation of the EG-EC relationship.

The causality nexus between EC and EG growth can be tested by four different hypotheses: growth, conservation, feedback, and the neutrality hypothesis (Ozturk 2010). First, the growth hypothesis suggests that there is one-way causality from EC to EG. Within the framework of this hypothesis, energy conservation policies adversely affect EG because EC is an influential determinant of EG. Second, the conservation hypothesis denotes one-way causality from EG to EC. In this hypothesis, energy conservation policies do not adversely affect EG because the dependence of EG on energy is low. Third, the feedback hypothesis defines bidirectional causality between EC and EG. In this case, energy conservation policies can undermine EG. Additionally, developments in EG also affect EC. Finally, the neutrality hypothesis states that there is no causal linkage between EC and EG. If this hypothesis is valid, the decrement in EC does not influence EG.

The lack of consensus on the direction of the causal linkages between REC and EG has increased the interest in this issue. Researchers have continued to investigate the nexus between EC/REC and EG by employing more sophisticated econometric methods. For example, Sadorsky (2009) examined the linkages between renewable energy incomes in 18 emerging market economies for the period 1994–2003. Panel cointegration results showed that the increase in per capita income affects the REC positively and the conservation hypothesis is valid. Payne (2009) analyzed the nexus between REC and non-REC and EG in the USA covers the period 1949–2006. Results support the neutrality hypothesis in the USA. Menyah and Wolde-Rufael (2010) tested the causal nexus among CO_2 emissions, nuclear energy, REC, and EG in the USA during the period 1960–2007. Unlike Payne (2009), the causality findings prove the validity of the conservation hypothesis in the USA. Apergis and Payne (2010) investigated the nexus among REC and EG in 13 Eurasian countries for the period 1992–2007 by using the Pedroni cointegration test, fully modified ordinary least square (FMOLS), and panel causality analysis. The results showed that there is a nexus between those variables in the long term. Also, causality analysis supported the feedback hypothesis in both the long and short term.

Apergis and Payne (2011) focused on the nexus between REC and EG during the period 1980–2006 in 6 Central American countries. According to the findings, the variables are cointegrated. Also, it is concluded that there is a bidirectional causal nexus among REC and EG. Apergis and Payne (2014b) investigated the interactions among REC and EG in 25 "Organization for Economic Co-operation and Development" (OECD) countries cover the period 1980–2011 through cointegration and causality analyses. The findings prove the validity of the feedback hypothesis in OECD countries. Tugcu et al. (2012) investigated the trade-off among REC, non-REC, and EG in G-7 countries, by applying Autoregressive Distributed Lag Model (ARDL) and Toda-Yamamoto causality. Results showed that there is bidirectional causality between REC and EG in all countries. Chang et al. (2015) analyzed G-7 countries. In the study, heterogeneous causality analysis was used; the results are like Tugcu et al. (2012). Ocal and Aslan (2013) investigated the interactions between REC and EG covering the period 1990–2010 in Turkey. The findings denoted that REC negatively affects EG. On the other hand, causality results pointed out that the conservation hypothesis is valid in Turkey.

Pao and Fu (2013) explored the causal linkages among four different types of energy and real gross domestic product (GDP) in Brazil during the period 1980–2010. They

found that total REC has a positive and significant effect on real GDP. The results of the Granger causality analysis indicated that there is a bidirectional relationship between REC and EG. Al-Mulali et al. (2013) investigated the nexus between REC and EG through a comprehensive data set consisting of high, upper-middle, and lower-middle-income countries during the period 1949–2009. FMOLS results denoted the hypothesis of feedback for 79%, neutrality for 19%, and conservation for 2% of the analyzed countries to be valid. Sebri and Ben-Salha (2014) investigated the nexus among REC, trade openness, EG, and CO_2 emissions in Brazil, Russia, India, and China (BRIC) countries. The causality results support the feedback hypothesis in BRIC countries. Aslan and Ocal (2016) tested the linkages between REC and EG in 7 European Union (EU) countries. Although REC positively affected EG in all countries, only statistically significant results were found in Bulgaria, Estonia, Poland, and Slovenia. Causality results denoted that the neutrality hypothesis is valid in Cyprus, Estonia, Hungary, Poland, and Slovenia. For the Czech Republic and Bulgaria, conservation and growth hypotheses are valid respectively.

Sugiawan and Managi (2016) investigated the validity of the EKC in Indonesia covers the period 1971 to 2010 and concluded that there is cointegration between REN and EG. Ohlan (2016) analyzed the effect of energy use on EG in India during the period 1971–2012. Findings showed that the REC has no significant effect on EG. The results of the vector error correction model (VECM) show that there is one-way causality from REC to EG in the short term. Inglesi-Lotz (2016) tested the impact of REC on EG for the period 1990–2010 in 34 OECD countries. The results indicated that the REC has a positive effect on EG. Destek and Aslan (2017) analyzed the nexus among REC, non-REC, and EG during the period 1980–2012 in 17 emerging countries. The results proved the validity of the neutrality hypothesis for most of the countries. Wang et al. (2018) analyzed the linkages among REC, EG, and human development in Pakistan. VECM results denote those linkages among the variables exist in neither the short nor long term. Ozcan and Ozturk (2019) analyzed the interaction between the two variables in the 17 emerging countries for the period 1990–2016. Similar to Destek and Aslan (2017), they explored the validity of the neutrality hypothesis in 16 countries. Akadiri et al. (2019) tested the nexus among REC, EG, and environmental sustainability in 28 EU countries during the period 1995–2015. The linkages among these variables are analyzed by Dumitrescu and Hurlin causality test, and it is concluded that the feedback hypothesis is valid.

Chen et al. (2019) tested the trade-off among CO_2 emissions, REC, non-REC, and foreign trade in China covering the period 1980–2014. The results showed that the variables are cointegrated. On the other hand, causality results indicated that the conservation hypothesis is valid in China. Zafar et al. (2019) focused on the linkages among REC, non-REC, R&D spending, and EG in the Asia-Pacific Economic Cooperation countries during the period 1990–2015. They explored that the linkages between the two variables are explained by the feedback hypothesis. Rahman and Velayutham (2020) investigated the trade-off among EG, REC, and non-REC for the period 1990–2014 in 5 South Asian countries. The findings showed that a 1% rise in REC raises EG by 0.66%. Dumitrescu and Hurlin causality results support the conservation hypothesis. In the studies summarized above, researchers investigated the linkage between two variables with both time series and panel data. The results of these studies denote that there is no consensus on the direction of causality between the variables as like the nexus between total energy and growth. Le and Sarkodie (2020) examined the impact of both non-renewable and REN on EG in 45 emerging economies for the period 1990–2014. They found bidirectional causality between the variables.

The nexus between REN and EG maintains its importance in current studies. The relationship between REN and EG for both developed and developing countries continues to be examined by researchers. For example, Magazzino et al. (2021) examined the trade-off between REN and EG in Brazil during the Covid-19 pandemic. The findings showed that the use of REN will help offset the negative effects of the epidemic and support EG. Yilanci et al. (2021) analyzed the economic effects of REN in 17 developing countries. They explored that the growth hypothesis was valid in some of the countries examined, while the conservation hypothesis was valid in some other countries. Asiedu et al. (2021) investigated the causality between REN and EG for the period 1980–2018 in 26 European countries. The causality results showed that the feedback hypothesis was valid. Doytch and Narayan (2021) examined the effect of REN on EG in 107 countries in different income groups at the sectoral level. GMM analysis indicated that REN increases EG in the services sector in high-income countries and the manufacturing sector in middle-income countries. Bouyghrissi et al. (2021) tested the economic effects of Morocco's REN during the period 1990–2014. Findings from ARDL and Granger causality analysis showed that REN supports EG. Finally, Asif et al. (2021) examined the effect of REN on EG in 99 countries in different income groups during the period 1995–2017. They found that REN enhances EG. Table 1 presents the studies focusing on the causality between REC and EG.

In the earlier and current studies, the direction of causality among the variables was mostly examined with causality tests such as VECM, Toda-Yamamoto, Konya, Dumitrescu, and Hurlin. This study aims to reveal asymmetric causal relationships between negative and positive components of variables. In this respect, this paper differs from the studies in the literature.

Table 1 Earlier and current studies (REC-EG)

Authors	Countries	Period	Methods	Finding
Sadorsky (2009)	18 emerging market countries	1994–2003	Panel cointegration, FMOLS, Granger causality	Conservation
Payne (2009)	USA	1949–2006	Toda-Yamamoto causality	Neutrality
Apergis and Payne (2010)	13 Eurasian countries	1992–2007	Pedroni cointegration, FMOLS, panel causality	Feedback
Menyah and Wolde-Rufael (2010)	USA	1960–2007	Granger causality	Conservation
Apergis and Payne (2011)	6 Central American countries	1980–2006	Pedroni cointegration, FMOLS, panel causality	Feedback
Tugcu et al. (2012)	G-7 countries	1980–2009	ARDL, Hatemi-J causality	Feedback
Pao and Fu (2013)	Brazil	1980–2010	Johansen cointegration, Granger causality	Feedback
Ocal and Aslan (2013)	Turkey	1990–2010	ARDL, Toda-Yamamoto causality	Conservation
Al-mulali et al. (2013)	High income, upper-middle-income, and lower-income countries	1949–2009	FMOLS	Feedback (79%) Neutrality (19%) Conservation (2%)
Apergis and Payne (2014b)	25 OECD countries	1980–2011	Pedroni cointegration, FMOLS, panel causality	Feedback
Sebri and Ben-Salha (2014)	BRICS	1971–2010	ARDL Bound test, VECM causality	Feedback
Chang et al. (2015)	G-7 countries	1990–2011	Granger causality	Feedback
Aslan and Ocal (2016)	7 EU countries	1990–2009	ARDL, Hatemi-J causality	Neutrality
Ohlan (2016)	India	1971–2012	Bayer-Hanck cointegration, ARDL, VECM causality	Growth
Sugiawan and Managi (2016)	Indonesia	1971–2010	ARDL test	Growth
Magazzino (2017)	Italy	1970–2007	Johansen cointegration, Toda and Yamamoto	Growth
Inglesi-Lotz (2016)	34 OECD countries	1990–2010	Pedroni cointegration	Growth
Destek and Aslan (2017)	17 emerging market countries	1980–2012	Bootstrap panel causality	Growth: Peru, Conservation: Thailand, Feedback: Greece and South Korea
Wang et al. (2018)	Pakistan	1990–2014	VECM causality	Neutrality
Akadiri et al. (2019)	28 EU countries	1995–2015	ARDL, Dumitrescu-Hurlin causality	Feedback
Chen et al. (2019)	China	1980–2014	ARDL, VECM causality	Conservation
Ozcan and Ozturk (2019)	17 emerging market countries	1990–2016	Bootstrap panel causality	Neutrality (Only Poland=Growth)
Zafar et al. (2019)	Asia-Pacific Economic Cooperation countries	1990–2015	FMOLS, Dumitrescu-Hurlin	Feedback
Rahman and Velayutham (2020)	5 South Asian Countries	1990–2014	Pedroni cointegration, FMOLS, Dumitrescu-Hurlin causality	Conservation
Kasperowicz et al. (2020)	29 European countries	1995–2016	Kao, Pedroni cointegration, FMOLS, DOLS	Growth
Le and Sarkodie (2020)	45 Emerging market countries	1990–2014	Heterogeneous panel data and Dumitrescu-Hurlin causality	Feedback
Magazzino et al. (2021)	Brazil	Covid-19 Era	Artificial neural networks (ANNs)	Growth
Yilanci et al. (2021)	17 Emerging countries	1980–2016	Bootstrap panel causality test	Growth Conservation
Asiedu et al. (2021)	26 European countries	1990–2018	Granger causality	Feedback
Doytch and Narayan (2021)	107 countries	1984–2019	GMM	Growth
Bouyghrissi et al. (2021)	Morocco	1990–2014	ARDL, Granger causality	Growth
Asif et al. (2021)	99 countries	1995–2017	FMOLS, DOLS	Growth

Data and methodology

We tested the symmetric and asymmetric causal impact of REC and EG on each other in 15 emerging countries (Argentina, Brazil, Chile, India, Indonesia, Malaysia, Mexico, Nigeria, Pakistan, Philippines, Poland, Russia, South Africa, Thailand, and Turkey) during the period from 1990 to 2015. The panel data is selected because data on renewable energy consumption have only recently been collected in most emerging countries, and this covers a rather short time. Data are sourced from the World Bank database. Each country has enough available data. We used log of both variables. The model utilized in the paper is specified as below:

$$\ln EG_{it} = f\left(\ln REC_{it}\right) \tag{1}$$

In the equation, EG_{it} and REC_{it} symbolize GDP per capita (constant 2010 US$) and REC (% of total final energy consumption) respectively. We utilized Kónya (2006)[1] and Yilanci and Aydin (2017) bootstrap panel tests to reveal causal linkages between the variables. In case that panel data variables are stationary or non-stationary, Konya panel causality produces consistent and reliable results. It also allows dependence across countries and heterogeneity in slope parameters.

Emerging countries have various policies due to differences in their economic structures. Thus, we utilized a causality test that allows both dependence across countries and heterogeneity in slope parameters. Hence, it is not mandatory to utilize unit root or cointegration tests (Eyuboglu and Eyuboglu 2020). In the study, the cross-sectional dependence (CD) is investigated by utilizing Pesaran (2004) CD and Pesaran et al. (2008) LM_{adj} tests.

OLS estimators are not reliable if there is CD among countries. It can be removed by employing the SUR estimator as suggested by Zellner (1962). Kónya (2006) panel causality considers the bootstrap table critical values for each country. If the estimated Wald test statistics exceeds the table critical values, the existence of the causality is approved (Pata 2018).

Granger and Yoon (2002) emphasized that negative and positive components of the variables may give different responses to the positive and negative shocks. Hence, a new test by Yilanci and Aydin (2017)[2] based on Kónya (2006) can investigate asymmetric causality among the series. Thus, asymmetric causality reveals the causality between series in more detail by revealing asymmetric relationships. Asymmetric causality can be estimated as below:

$$\begin{aligned}
X_{1,t}^{+} &= a_{2,1} + \sum_{j=1}^{ly_2} \beta_{2,1,j} Y_{1,t-j}^{+} + \sum_{j=1}^{lx_2} \delta_{2,1,j} X_{1,t-j}^{+} + \varepsilon_{2,1,t}^{+} \\
X_{2,t}^{+} &= a_{2,2} + \sum_{j=1}^{ly_1} \beta_{2,2,j} Y_{2,t-j}^{+} + \sum_{j=1}^{lx_1} \delta_{2,2,j} X_{2,t-j}^{+} + \varepsilon_{2,2,t}^{+} \\
&\cdot \\
X_{N,t}^{+} &= a_{2,N} + \sum_{j=1}^{ly_2} \beta_{2,N,j} Y_{N,t-j}^{+} + \sum_{j=1}^{lx_2} \delta_{2,N,j} X_{N,t-j}^{+} + \varepsilon_{2,N,t}^{+}
\end{aligned} \tag{2}$$

$$\begin{aligned}
Y_{1,t}^{+} &= a_{1,1} + \sum_{j=1}^{ly_1} \beta_{1,1,j} Y_{1,t-j}^{+} + \sum_{j=1}^{lx_1} \delta_{1,1,j} X_{1,t-j}^{+} + \varepsilon_{1,1,t}^{+} \\
Y_{2,t}^{+} &= a_{1,2} + \sum_{j=1}^{ly_1} \beta_{1,2,j} Y_{2,t-j}^{+} + \sum_{j=1}^{lx_1} \delta_{1,2,j} X_{2,t-j}^{+} + \varepsilon_{1,2,t}^{+} \\
&\cdot \\
Y_{N,t}^{+} &= a_{1,N} + \sum_{j=1}^{ly_1} \beta_{1,N,j} Y_{N,t-j}^{+} + \sum_{j=1}^{lx_1} \delta_{1,N,j} X_{N,t-j}^{+} + \varepsilon_{1,N,t}^{+}
\end{aligned} \tag{3}$$

where N, t, and j symbolize the number of countries, time period, and optimal lag length respectively. Asymmetry in variables means that variables can make different responses to positive and negative shocks. Disregarding these dissimilarities cannot show the possible relationship that exists among the series. If we consider the asymmetry, the possible asymmetric relationships among series can be discovered (Yilanci and Aydin 2017).

Findings

Descriptive statistics are shown in Table 2 for each of those 15 emerging countries. Based on Table 2, we determined that Pakistan and Chile have the lowest and highest mean levels of EG, and Russia and Nigeria have the lowest and highest mean levels of REC respectively. Moreover, we also observed that the average EG during the sample period was 9.05 and that the average REC was 2.31.

Table 3 shows the CD of the panel. The results indicate that CD is valid in the panel. Thus, we made our analyses by using Kónya (2006) panel causality test which takes into account CD.

We firstly analyzed the causal linkages between the series by using Kónya (2006) panel causality tests. The results are presented in Table 4. The symmetric Kónya (2006) causality test results show that 2 variables do not have any effect on each other in 15 emerging countries. In other words, the neutrality hypothesis is valid in the countries. Thus, it can be concluded that REC is not a critical factor for EG. Therefore, energy-saving policies may

[1] In accordance with Konya (2006) to solve the problem of deciding the optimal lag length, the model is estimated for each possible lag by supposing from 1 lag to 4 lags. Then, the optimal lag length is selected that minimizes Akaike Criterion.

[2] For the detailed information see Yilanci and Aydin (2017).

Table 2 Descriptive statistics

	Variables	Mean	Max.	Min.	Std. dev.	Skewness	Kurtosis
Panel	EG	9.05	9.29	8.73	0.15	−0.07	1.95
	REC	2.31	2.48	2.02	0.13	−0.14	2.68
Argentina	EG	9.05	9.29	8.73	0.16	−0.07	1.95
	REC	2.31	2.58	2.02	0.13	0.14	2.68
Brazil	EG	9.15	9.39	8.96	0.14	0.40	1.75
	REC	3.81	3.90	3.72	0.05	−0.01	1.85
Chile	EG	9.21	9.59	8.68	0.26	−0.30	2.07
	REC	3.44	3.65	3.21	0.09	−0.16	3.20
India	EG	6.85	7.46	6.35	0.34	0.18	1.78
	REC	3.86	4.07	3.58	0.15	−0.55	1.91
Indonesia	EG	7.82	8.24	7.44	0.22	0.33	2.09
	REC	3.79	4.07	3.60	0.14	0.54	2.06
Malaysia	EG	8.90	9.29	8.42	0.23	−0.27	2.31
	REC	1.82	2.48	1.34	0.34	0.50	1.99
Mexico	EG	9.09	9.21	8.95	0.07	−0.47	2.05
	REC	2.39	2.66	2.19	0.15	0.18	1.50
Nigeria	EG	7.46	7.84	7.20	0.23	0.38	1.60
	REC	4.45	4.48	4.41	0.01	−0.51	2.74
Pakistan	EG	6.78	6.98	6.60	0.11	0.22	1.55
	REC	3.90	4.06	3.79	0.07	0.41	2.09
Philippines	EG	7.48	7.86	7.27	0.18	0.63	2.16
	REC	3.54	3.95	3.31	0.18	1.05	2.92
Poland	EG	9.11	9.59	8.61	0.31	−0.08	1.72
	REC	1.91	2.47	0.72	0.45	−1.37	4.54
Russia	EG	9.02	9.36	8.61	026	−0.17	1.53
	REC	1.27	1.39	1.17	0.06	−0.01	−1.04
South Africa	EG	8.77	8.93	8.61	0.11	0.17	1.36
	REC	2.84	2.95	2.74	0.05	0.07	1.98
Thailand	EG	8.28	8.65	7.82	0.23	−0.10	1.98
	REC	3.13	3.51	2.99	0.14	1.59	4.62
Turkey	EG	9.10	9.53	8.81	0.22	0.41	1.96
	REC	2.84	3.19	2.45	0.25	0.06	1.53

Table 3 Cross-sectional dependence

CD tests	Statistic	*p* values
CD test	20.168	0.000
Bias-corrected scaled LM	7.0583	0.000

not affect EG performance. Findings are similar to Payne (2009), Destek and Aslan (2017), Wang et al. (2018), and Ozcan and Ozturk (2019).

The applied econometric methods are generally symmetric in earlier studies. The main problem in these tests is that negative and positive components are assumed to respond to the shocks similarly. But Granger and Yoon (2002) emphasized that the effects of negative and positive shocks may be different. They recommended that variables should be divided into their components.

The Yilanci and Aydin (2017) test results are reported in Table 5. Firstly, when the asymmetric causality between positive shocks is examined, it is found that bootstrap critical values are higher than Wald statistics. In other words, no asymmetric causality is found between the positive components of REC and EG. Thus, the results are consistent with the symmetric causality findings and support the neutrality hypothesis, meaning that a positive shock in REC will not affect EG in the 15 emerging countries. Also, the positive development of EG will not be able to increase REC.

Table 6 presents the causality linkages between the negative components of the variables. In terms of negative shocks, no asymmetric causality was found between

Table 4 Konya panel causality test (1990–2015)

Countries	H_0: EG does not cause REC				H_0: REC does not cause EG			
	Wald stat.	Bootstrap critical values			Wald stat.	Bootstrap critical values		
		1%	5%	10%		1%	5%	10%
Argentina	0.67	231.58	96.26	57.97	29.76	268.43	144.56	100.53
Brazil	0.15	730.75	312.01	161.16	21.67	441.78	217.49	143.66
Chile	0.07	903.65	365.79	226.55	1.02	298.71	140.02	91.30
India	2.29	362.15	157.13	119.18	15.36	290.79	158.64	116.79
Indonesia	1.36	363.83	161.19	124.03	13.60	308.01	165.67	119.35
Malaysia	0.00	234.43	104.39	66.00	7.03	330.35	161.33	115.70
Mexico	0.32	215.33	110.69	74.77	6.98	277.01	144.59	101.76
Nigeria	0.93	223.11	116.65	81.41	12.53	232.10	115.46	78.59
Pakistan	0.00	242.00	134.51	97.73	18.89	268.78	147.27	103.12
Philippines	0.00	211.58	119.93	87.59	24.58	253.37	145.80	103.85
Poland	0.22	136.03	75.65	52.36	18.96	365.08	189.83	132.85
Russia	0.08	124.23	66.11	47.51	11.41	367.24	191.51	136.54
South Africa	1.26	150.21	75.27	50.89	2.36	222.28	124.73	90.97
Thailand	1.47	175.02	76.44	51.49	14.61	188.33	116.92	88.24
Turkey	1.84	105.60	50.13	34.26	14.95	184.77	112.51	85.39

Table 5 Yilanci and Aydin (2017) causality test (+, +) (1990–2015)

Countries	H_0: EG ↛REC				H_0: REC ↛EG			
	Wald stat.	Bootstrap critical values			Wald stat.	Bootstrap critical values		
		1%	5%	10%		1%	5%	10%
Argentina	3.19	184.61	89.54	58.63	0.66	531.72	232.47	147.76
Brazil	3.36	162.84	73.14	45.57	0.04	472.34	239.38	158.98
Chile	1.40	259.30	90.80	58.82	0.08	448.55	215.68	132.73
India	1.31	220.53	84.41	52.97	0.06	892.37	451.10	272.89
Indonesia	1.79	591.96	271.94	160.60	1.22	635.42	311.06	201.32
Malaysia	0.02	694.43	285.03	186.86	2.72	118.32	55.09	34.84
Mexico	12.42	404.26	221.18	156.79	0.26	257.58	121.77	79.27
Nigeria	5.54	352.13	177.51	121.56	0.12	362.32	157.31	99.25
Pakistan	8.40	377.09	212.47	147.07	0.25	271.83	119.37	76.80
Philippines	10.17	410.02	200.95	133.59	0.04	132.60	65.83	42.46
Poland	22.68	480.04	206.16	138.94	1.02	189.87	101.54	63.64
Russia	0.97	337.47	125.71	78.10	0.70	397.92	188.08	116.89
South Africa	3.41	268.02	125.08	78.86	0.93	152.31	68.31	41.82
Thailand	2.37	467.45	196.47	116.17	0.44	63.90	28.80	18.13
Turkey	64.55	543.17	239.25	154.76	1.44	51.57	23.82	15.95

the negative components of REC and EG for 12 out of 15 emerging countries.

In other words, it is concluded that the neutrality hypothesis is valid in terms of negative shocks in these countries. On the other hand, a one-way asymmetric causality is determined in South Africa, Thailand, and Turkey from negative components of EG to negative components of REC. In other words, the conservation hypothesis is valid for negative components in South Africa, Thailand, and Turkey. This indicates that reducing REC will not adversely affect EG performance. In other words, economic activities are less dependent on renewable energy.

Since the asymmetric effect was not examined, this result was not mentioned in previous studies. However, this finding partly supports the findings of Sadorsky (2009), Menyah and Wolde-Rufael (2010), Ocal and Aslan (2013), Chen et al. (2019), Rahman and Velayutham (2020).

Table 6 Yilanci and Aydin (2017) causality test (−, −) (1990–2015)

Countries	H_0: EG ↛REC				H_0: REC ↛EG			
	Wald stat.	Bootstrap critical values			Wald stat.	Bootstrap critical values		
		1%	5%	10%		1%	5%	10%
Argentina	12.52	75.87	35.64	21.59	3.75	172.03	85.29	51.12
Brazil	8.55	156.92	65.01	36.80	10.30	283.17	122.84	80.46
Chile	6.12	133.03	62.53	37.40	23.31	261.02	117.80	76.82
India	1.42	100.96	49.19	30.46	9.54	229.43	115.52	71.44
Indonesia	0.67	114.78	48.74	32.56	9.98	235.03	117.63	76.77
Malaysia	0.11	95.17	42.30	26.85	9.14	222.90	108.08	70.16
Mexico	1.74	74.42	38.65	26.78	36.55	181.20	96.09	63.17
Nigeria	3.06	110.01	53.45	35.19	17.55	346.16	187.73	120.11
Pakistan	1.47	96.89	43.13	27.26	12.14	360.23	198.49	141.72
Philippines	3.08	78.35	36.12	23.28	8.01	309.01	165.39	113.04
Poland	1.87	102.68	50.32	32.01	6.09	231.57	134.11	88.01
Russia	8.49	182.21	86.54	55.41	1.77	191.29	93.92	57.86
South Africa	60.59**	120.51	57.03	38.30	0.02	70.82	34.94	22.38
Thailand	34.51*	95.18	47.93	33.04	14.21	137.91	77.75	55.59
Turkey	17.74*	56.39	27.83	16.79	11.60	171.51	97.04	67.80

**, * symbolize significance at 5% and 10%

Table 7 Emirmahmutoglu and Kose (2011) causality test (1990–2015)

	EG↛REC	REC↛EG	EG^+↛REC^+	REC^+↛EG^+	EG^-↛REC^-	REC^-↛EG^-
Argentina	0.740	0.483	1.686	0.539	2.913	0.158
Brazil	0.133	0.211	1.809	0.033	3.846	0.239
Chile	0.715	0.046	1.119	0.138	3.523	0.434
India	0.693	1.167	0.871	0.029	1.580	1.327
Indonesia	0.575	1.309	1.064	0.854	0.243	2.908
Malaysia	0.001	0.651	0.371	2.018	0.43	3.071
Mexico	0.007	0.464	1.654	1.668	3.894	3.702
Nigeria	0.077	2.380	3.698	0.589	2.118	2.909
Pakistan	0.055	2.107	3.012	0.966	3.286	3.277
Philippines	0.049	2.278	3.243	1.038	3.583	2.632
Poland	0.069	2.675	3.708	0.064	0.975	3.465
Russia	0.007	1.477	1.806	0.157	0.317	0.735
S. Africa	0.216	0.339	2.119	0.57	6.656*	0.718
Thailand	0.461	0.304	1.141	0.082	4.303**	0.893
Turkey	1.084	0.473	2.254	1.480	2.988*	0.358

**, * symbolize significance at 5% and 10%

Although Konya panel causality results confirm the asymmetric causality is running from negative components of EG to negative components of REC, we also use Emirmahmutoglu and Kose (2011)[3] causality test to check the robustness of our results. Table 7 shows that there is no causality from EG to REC and vice versa in aggregated and disaggregated (positive) data.

Similar to the Konya test, Emirmahmutoglu and Kose (2011) test results denote that there are causalities from EG to REN in South Africa, Thailand, and Turkey in terms of negative components. Thus, we can conclude that our results are robust. This finding highlights the importance of considering asymmetric causality between REC and EG.

[3] Emirmahmutoğlu and Köse (2011) test does not claim that the series are stationary, and therefore it can be used for panels consisting of stationary, non-stationary, cointegrated, and non-cointegrated series (Seyoum et al. 2014). It also considers possible slope heterogeneity and cross-sectional dependency in the panel. For the detailed information, see Emirmahmutoglu and Kose (2011). We found all series have no unit root at their first difference by using CADF test.

Discussion

The results of the symmetric Konya causality test support the validity of the neutrality hypothesis in all emerging countries. In other words, there is no causal relationship between REC and EG. These findings are similar to Payne (2009), Aslan and Ocal (2016), Alper and Oguz (2016), Destek and Aslan (2017), and Wang et al. (2018). Despite the significant increase in renewable energy investments of emerging market economies in recent years, the amount of renewable energy production and consumption is not at the level of developed countries (Ozcan and Ozturk 2019). This indicates that the energy required by the EG and development process in emerging market economies is still based on fossil fuels such as coal and oil. The fact that fossil-based fuels are cheaper and more storable than renewable energy resources can reduce the EG costs of these countries.

Zhao and Luo (2017) state that traditional fossil-based energy companies have significant employment capacity. Increasing the unemployment rate in emerging market economies will cause a serious loss of production. Therefore, governments may not want to reduce the activities of these companies by making some arrangements in the energy market. Attempts to expand REC through regulations in the energy market may reduce the employment provided by traditional energy companies in short and medium terms. This may be another reason why those economies are still dependent on fossil-derived energy types.

Cadoret and Padovano (2016) and Sequeira and Santos (2018) point out that the lobbying activities of traditional energy companies cause an insufficient increase in renewable energy investments. Although there have been some positive developments in the institutional sense in recent years, institutional quality in emerging countries is still not high compared to developed countries. Inadequate institutional quality may accelerate such lobbying activities. All these developments can be the reasons why REC in emerging market economies cannot trigger EG.

Also, the symmetric causality test showed that EG does not cause REC for all countries. This indicates that the renewable energy sector has not benefited sufficiently from EG. This shows that income growth and capital accumulation provided by EG are channeled to different areas rather than the renewable energy sector. In this context, Ozcan and Ozturk (2019) stated that industry, transportation, and non-renewable energy sectors are priority areas in emerging market economies, and the authors emphasized that financial gains from EG are transferred to such areas. As mentioned, it is a fact that the development goal is still more dominant than environmental concerns affecting the distribution and optimization of scarce resources in these countries. Therefore, the renewable energy sector, which is not a priority area, cannot benefit sufficiently from the gains generated by EG.

Since symmetric causality analysis did not reveal asymmetric nexus between variables, the responses of the variables to positive and negative shocks are determined through asymmetric causality analysis. For the positive components, like symmetric results, no asymmetric causality between variables could be discovered. This result proves that, as mentioned above, the gains from EG are channeled to different areas rather than renewable energy investments. Thus, the positive shocks in REC in these countries, which are mainly dependent on fossil-based fuels, do not seem to stimulate EG.

On the other hand, in terms of negative components, a similar result was found in 12 out of 15 emerging countries. However, an asymmetric causality has been explored from negative components of EG to negative components of REC in South Africa, Thailand, and Turkey. In this context, negative EG affects REC in these 3 countries. In other words, economic contraction affects the renewable energy sector in South Africa, Thailand, and Turkey.

There may be several reasons for this situation. For example, during periods of economic contraction, governments may postpone incentives such as tax relief and credit facilities. Elimination of such incentives may lead to a reduction in the production and consumption of renewable energy because it is a well-known fact that the initial investment in the renewable energy sector is expensive for these countries and renewable energy investments may be harmful on economic activities until it reaches the optimum level (Mehrara et al. 2015; Destek 2016). Therefore, it can be thought that during periods of economic contraction, entrepreneurs postpone such high-cost investment decisions in these 3 countries. Thus, the contraction in renewable energy investments may harm REC.

REC is relatively low in the energy profile of all three countries (BP 2019). Until 2010, South Africa and Thailand had very low renewable energy generation. Although there has been an increase in renewable energy generation after 2010, fossil resources still dominate the energy sector. According to the Renewables Status Report (2019), although there have been improvements in the context of renewable resources in South Africa, uncertainties have also been reported. For example, in the final resource planning of the government for concentrating solar thermal power, it is stated that no resources are allocated for new plants. All these developments point out that if the economy suffers from a negative shock, it may adversely affect the generation of renewable energy.

Renewable energy investments also have begun to increase in Turkey since 2010 (BP 2019). Renewables 2019 Global Status Report argues that Turkey has taken

important steps in the generation of geothermal, hydroelectric, and solar power. All over the world, two-thirds of the geothermal energy capacity creation have been made in India and Turkey in 2018. The report also states that employment in the renewable energy sector has decreased due to reasons such as macroeconomic trends and land scarcity. According to the report released in September, the unemployment rate reached 13.8% in Turkey (TUIK 2019).

Given Turkey's high unemployment rate and the inability of the renewable energy sector to contribute to employment, it is quite negative for macroeconomic stability. Hence, a shock in the economy will increase the unemployment rate, which is already quite high. A serious problem such as unemployment occurred in Turkey, and it is not a surprise to observe an adverse impact of economic distress on the renewable energy sector.

Conclusion

This paper aims to examine the potential causal relationships between REC and EG in 15 emerging countries for the period 1990–2015. For this purpose, firstly, Kónya (2006) symmetric causality analysis, which allows heterogeneity of slope parameters across countries, is used. Afterward, since the symmetric analysis cannot discover asymmetric causal relationships between REC and EG, the series is divided into their positive and negative components and asymmetric causalities are examined by employing asymmetric Kónya (2006) causality analysis. The results from the symmetric causality analysis confirm the validity of the neutrality hypothesis in all countries. On the other hand, no causal trade-off is detected between the positive components of the variables, and the neutrality hypothesis is confirmed for the positive components. Therefore, it can be concluded that symmetric test findings testing REN and EG are generally compatible with the findings of positive shocks for asymmetric tests.

The causality test confirms that there are no causal linkages between REC and EG in emerging countries, except South Africa, Thailand, and Turkey. As mentioned, this situation is not a surprise. This is because EG is largely dependent on fossil-based resources in emerging countries. It is a fact that EG and development is an urgent problem for these countries and fossil-based fuels are preferred in this context. This situation indicates that environmental problems will become increasingly severe. The results should not be inferred that REC is insignificant for EG in emerging countries. Although the current consumption level does not currently support EG, REC may be an important determinant of the EG in these countries after a certain threshold level (Ozcan and Ozturk 2019).

In terms of negative components, no asymmetric causality is found in 12 out of 15 countries, while unidirectional causality from negative components of EG to negative components of REC is discovered in South Africa, Thailand, and Turkey. Thus, it is concluded that the conservation hypothesis is valid in terms of negative components in these countries. It is possible to develop important policy recommendations within the framework of the results obtained from the study. These policy recommendations have the potential to be an important guide for policymakers. These can be listed as follows:

- Considering the findings for positive and negative shocks separately will help these 3 countries to determine more accurate strategies while deciding on energy policies. Policymakers can encourage investors to invest by offering alternative sources of financing to build renewable energy facilities, especially in times of recession, providing tax exemptions, and being guarantors against their debts.
- Making renewable energy investments more attractive to investors is possible by removing market barriers and reducing risks. For this, policymakers and public financial institutions can provide technical assistance and grants for project preparation and development, improve access to finance, and enhance local lending capacity.
- Policymakers can standardize contracts and project documentation processes to facilitate project aggregation while developing guidelines for green bond issuance to mobilize more capital market investment.
- Private investors and lenders can access risk mitigation tools such as foreign exchange hedging instruments and liquidity facilities through public finance institutions.
- Increasing income levels may also trigger REC at some point in these countries. The increase in the income level can enhance the resources allocated for renewable energy investments. Also, people can increase their demand for environmental quality with the effect of income level and welfare increase.
- For renewable energy investments to become widespread, bureaucratic obstacles in licensing and permit issues should be reduced, and government and private sector cooperation should be acted upon in the implementation of projects.
- As Apergis and Payne (2010, 2011) mentioned, coordination between public and private sectors is very important for the development of the renewable energy sector in research and development (R&D), financing, and investment strategies.

In order to ensure sustainable growth, improve living standards, and realize economic activities, it is necessary to meet the increasing energy requirement due to population

growth and economic growth. Energy is an element closely related to all economic, social, and environmental dimensions of sustainable growth. Ensuring energy supply security constitutes one of the most important conditions for sustainable growth and has increasingly become one of the vital interests of the leading actors in the international political scene. In this context, environmental problems should be minimized, energy resources should be reviewed considering the global threat, and alternative solutions should be produced.

In future analysis, including different types of renewable energy sources, a separate analysis of each renewable energy source will make it possible to determine the relative contribution of different energy resources.

Author contribution **KE:** estimates, supervision, results; **UU:** introduction, literature review, policy implications, conclusions, discussion of the results.

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