Application of Bootstrap Panel Granger Causality Test in Determining the Relationship between Renewable and Non-Renewable Energy Consumption and Economic Growth: a Case Study of OPEC Countries

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Abstract

The purpose of this article was to investigate the relationship between renewable and non-renewable energy consumption on economic growth in 10 oil-exporting countries for the period 1980 to 2018. To get to this purpose, the bootstrap panel causality test has been deployed. According to the findings of this study on renewable energy consumption, the results of the causality test showed that the growth hypothesis for Ecuador is well grounded. Besides, the conservation hypothesis is valid for Algeria and Iran. The feedback hypothesis based on a two-way relationship between renewable energy consumption and economic growth in Saudi Arabia and the UAE has also been confirmed, while there was evidence of the neutrality hypothesis for Angola, Iraq, Nigeria, Venezuela, and Congo. Regarding non-renewable energy consumption, the feedback hypothesis has been confirmed for Ecuador, UAE, Iran, Saudi Arabia, Nigeria, Venezuela, and Congo. The conservation hypothesis was observed for Iraq and Algeria. Also, there has been no causal relationship between non-renewable energy consumption and economic growth for Angola, and the neutrality hypothesis is confirmed.

Keywords Renewable energy consumption · Non-renewable energy consumption · Economic growth · Bootstrap panel causality · Oil exporting countries

Introduction

Renewable energies are energies that do not require a long time to access and are available or produced immediately or in a short time. Sources of this type of energy can be renewed or regenerated in a short period. The six most commonly used renewable energy sources include biomass energy, hydropower, geothermal energy, wind energy, solar energy, tidal energy, and wave energy. Increasing the share of renewable energy in the world today is accepted as the main need for sustainable development. Non-renewable energy sources are taken to

be the influential agents of global warming and climate change. In addition to environmental concerns, the negative effects of fossil fuel price fluctuations on investment in various countries, as well as the depletion of fossil fuel resources, have increased the global popularity of renewable energy alternatives. On the other hand, maintaining sustainable economic growth is critical to the development of the renewable energy sector. However, the economic growth of most countries, especially OPEC¹ members, is based on non-renewable energy. Therefore, reducing the production and consumption of non-renewable energy without harming economic activities is necessary. Based on the listed benefits of renewable energy, investment in this sector is growing rapidly around the world. In addition, forecasts show that renewable energy consumption will increase by 3% annually between 2018 and 2050. OPEC reference scenario forecast shows that demand for renewable energy such as wind, photovoltaic solar, and thermal and geothermal solar energy will increase from 3 million barrels per day of crude oil equivalent in 2014 to 18 million barrels in 2040.

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However, the impact of investment in the renewable energy sector on the economic growth of countries is unclear. Therefore, this study aimed to investigate the role of renewable and non-renewable energy consumption in OPEC member countries and compare the performance of both energy sources on economic growth and determine the efficiency of investments in the renewable energy sector. For this purpose, the bootstrap panel Granger causality model was used.

The structure of the present article consists of six sections. In the following and the second part, the theoretical foundations and background of the research are stated. The third section is devoted to examining the state of renewable energy consumption in the world. The research method is described in the fourth section. Empirical results are presented in the fifth section and finally, the conclusion is presented in the final section.

Literature Review

In the process of economic growth, energy is the driving force to accelerate this process, but the degree of importance of energy in different patterns is different. In this regard, different assumptions have been made regarding the relationship between energy and economic growth. Ozturk [27] and Bowden and Payne [9] reviewed the results of studies by Soytaş and Sari [38], Lee [26], Ewing et al. [15] and presented four testable hypotheses about the causal relationship between energy and economic growth [14]. These hypotheses are growth hypothesis, conservation hypothesis, feedback hypothesis, and neutrality hypothesis.

The growth hypothesis indicates a one-way causality from energy consumption to economic growth. In such circumstances, energy consumption directly or as a complement to capital and labor has a vital role in the process of economic growth, and conservation policy in energy consumption will have negative effects on economic growth.

The conservation hypothesis means that economic growth will lead to increased energy consumption. This hypothesis is confirmed if there is a one-way causality from economic growth to energy consumption. In this case, energy conservation policies that may prevent the increasing use of energy are not detrimental to economic growth.

The feedback hypothesis indicates a two-way causality between energy consumption and economic growth. Under such circumstances, a policy of reducing energy consumption can reduce economic growth, and so changes in economic growth can be reflected in energy consumption.

The neutrality hypothesis connotes that the causal relationship between energy consumption and economic growth cannot be validated. Providing the validity of this hypothesis, the conservation and protection policy of energy resources will not affect economic growth.

By and large, in experimental studies, different methods have been used to examine the relationship between energy consumption and economic growth. In this section, these studies are presented in detail.

Payne [32] examined the role of renewable and non-renewable energy consumption in economic growth in the United States for the period 1949 to 2006 using the Toda-Yamamoto causality approach. The study outcome unveiled that there is no causal relationship among renewable energy and non-renewable energy consumption and economic growth, which point out the neutrality hypothesis.

Apergis and Payne [6] examined the effect of renewable and non-renewable energy consumption on economic growth in 16 emerging countries for the period 1990–2007 using the panel cointegration of Pedroni method. The results showed a two-way causal relationship between renewable and non-renewable energy consumption and economic growth in the long run.

In another research study, Apergis and Payne [4] studied the relationship among renewable energy consumption, non-renewable energy consumption, and economic growth in 80 countries for the period 1990 to 2007 using the panel cointegration method and the panel error correction model and concluded that the feedback hypothesis is valid.

Tugcu et al. [42] examined the causal relationship between renewable, non-renewable energy consumption, and economic growth in the G7 for the period 1980–2009. Based on the findings of this research, the growth hypothesis was valid in Japan. The neutrality hypothesis was valid for other G7 countries utilizing non-renewable energy. Moreover, the feedback hypothesis was conducted for Britain and Japan. The conservation hypothesis was confirmed in Germany, and the neutrality hypothesis was confirmed in France, Canada, Italy, and the United States in the case of renewable energy consumption.

Tiwari et al. [40] studied the performance of renewable energy and non-renewable energy on economic growth in 12 African countries for the period 1971 to 2011. They got to the point that there is a one-way causal relationship between renewable and non-renewable energy consumption and economic growth.

Jebli and Youssef [24] deployed the panel cointegration and panel Granger causality method and to investigate the relationship between renewable energy consumption, non-renewable energy, and economic growth in 69 countries for the period 1980 to 2010. They reached the point that there is a two-way causality between renewable energy consumption, non-renewable energy consumption, and economic growth.

Bhattacharya et al. [10] evaluated the relationship between renewable energy consumption, non-renewable energy, and economic growth in 38 countries for the period 1991–2012 using the panel heterogeneous causality method. The outcome showed that there is a one-way causality from non-renewable energy consumption to economic growth and there is not a

causal relationship between renewable energy consumption and economic growth. Moreover, the results of dynamic ordinary least squares showed that economic growth is influenced by the consumption of renewable and non-renewable energy.

Destek and Aslan [14] assessed the relationship between renewable energy consumption, non-renewable energy, and economic growth in 17 emerging economies for the period 1980–2012 utilizing the bootstrap panel causality method. The results of this study indicated that the growth hypothesis for renewable energy was valid for Peru. The conservation hypothesis was conducted for Colombia and Thailand. The results back up the feedback hypothesis for Greece and South Korea. The neutrality hypothesis was also confirmed for the other 12 emerging economies. There was also a two-way causal relationship between non-renewable energy consumption and economic growth for Turkey. For China, Colombia, Mexico, and the Philippines, there is a one-way causal relationship between energy consumption and economic growth. However, there was a one-way causal relationship between economic growth and non-renewable energy consumption for Egypt, Peru, and Portugal.

Tuna and Tuna [41] in a study analyzed the asymmetric relationship between energy consumption and economic growth in ASEAN countries in the period 1980–2015. The research uses Hacker and Hatemi-J [18] tests for symmetric causality analysis and Hatemi-j [19] test to examine asymmetric causality. According to the findings of this study, economic growth and renewable energy consumption in ASEAN countries are not related, but there is a significant relationship between non-renewable energy consumption and economic growth.

Rahman and Velayutham [36] in a study assessed the relationship between non-renewable energy consumption and economic growth for South Asian countries in the period 1990–2014. This research uncovers positive effects of renewable and non-renewable energy consumption and fixed capital formation on economic growth. It has also been unveiled that there is a unidirectional causality proceeding from economic growth to renewable energy consumption. Based on the come by-results, the conservation hypothesis is valid for the South Asian countries.

Ivanovski et al. [23] evaluated the relationship among renewable energy consumption, non-renewable energy, and economic growth in OECD² and non-OECD panels from 1990 to 2015 through deploying the nonparametric method. The results recommend that non-renewable energy consumption makes a positive and significant impact on economic growth all through OECD countries. The influence of renewable energy consumption on economic growth, however, is statistically indistinguishable from zero in these countries for most of the study period. Both renewable and non-renewable

energy consumption develop economic growth in non-OECD countries.

Wang et al. [43] in a study assessed the relationship between renewable energy consumption and economic growth for China from 1977 to 2017. This study delves into the long-term and short-term impacts of economic growth and financial development on renewable energy consumption. The causality test results exhibit that the unidirectional causality relationships lie in financial development onto renewable energy consumption. Moreover, economic growth unidirectionally causes renewable energy consumption in China.

Brini [12] examines the dynamic causal relationship between renewable and non-renewable energy consumption, economic growth and climate change for 16 African countries from 1980 to 2014. The practical analysis attests the existence of long-run cointegration relationship among variables. In the long-run; non-renewable energy consumption and economic growth are found to have a harmful impact on the climate change, while, renewable energy consumption has a beneficial [climate change effect](#). In the short-run, results manifest a bidirectional causality relationship running from non-renewable energy consumption to climate change, supporting the feedback hypothesis, while, a unidirectional causality relationship running from climate change to renewable energy consumption is proven Tables 1 and 2.

Investigating the State of Renewable Energy Consumption in the World

According to IEA³ [20, 21] forecasts, due to the reduced cost of producing renewable energy and its cost-effectiveness, improving the competitiveness of this fuel worldwide compared to other fuels, environmental considerations, and the development of technologies related to wind and solar energy, the share of renewable energy in the composition of primary energy will increase. As can be seen in the diagram below, renewable energy is the leading source of energy among other primary energies. Forecasts show that renewable energy consumption will increase by 3% annually between 2018 and 2050 Fig. 1 and 2.

Hydropower accounts for the largest share of total primary energy supply, followed by geothermal, wind, tidal, and solar. Despite the high share of hydropower in relation to solar and wind energy, forecasts show that the highest growth rate of renewable energy consumption during the outlook period (2040) is related to solar energy and then wind. In the field of wind energy, we will see an increase in installation capacity, which will reduce the average cost of capital. Forecasts show that despite the current high share of hydropower due to new technologies in the field of renewable energy, which is

² The Organisation for Economic Co-operation and Development

³ International Energy Agency

Table 1 literature summary of on renewable and non-renewable energy consumption and economic growth

Study	period	Countries	Methodology	Supported hypothesis
Payne [30]	1949–2006	USA	Toda-Yamamoto causality	Neutrality
Apergis, Payne [5]	1985–2005	OECD countries	VECM	Feedback
Bowden, Payne [9]	1949–2006	USA	Toda-Yamamoto causality	Feedback, Growth, Neutrality
Apergis, Payne [3]	1990–2007	Emerging market	Panel error correction model	Feedback, Growth
Apergis, Payne [4]	1990–2007	80 countries	Vector error correction model	Feedback
Tugcu et al. [42]	1980–2009	G7 countries	Panel vector autoregressive model	Feedback
Al-mulali et al. [1]	1980–2010	Latin American countries	Vector error correction model	Feedback, Growth
Jebli and Youssef [24]	1980–2010	69 countries	Panel Granger causality test	Feedback
Bhattacharya et al. [10]	1991–2012	38 countries	Heterogeneous panel causality test	Neutrality
Inglesi-Lotz [22]	1990–2010	OECD countries	Panel co-integration method	Growth
Ohlan [29]	1971–2012	India	Vector error correction model	Feedback
Aneja et al. [7]	1990–2012	BRICS countries	Panel error correction model	Conservation
Destek and Aslan [14]	1980–2012	emerging market countries	Bootstrap panel causality	Feedback, Growth, And Neutrality
Adams et al.[2]	1980–2012	Sub-Saharan African countries	Pairwise heterogeneous panel causality test	Neutrality
Tugcu and Topcu [39]	1980–2014	G7 countries	A nonlinear ARDL ¹ model	Feedback
Aydin [8]	1980–2015	OECD countries	Dumitrescu-Hurlin panel causality test and Frequency Domain panel causality test	Feedback
Fan and Hao [17]	2000–2015	China	Granger causality test	Neutrality
Tuna and Tuna [41]	1980–2015	ASEAN countries	Hacker and Hatemi-J [18] and Hatemi- J [19] causality tests	Neutrality
Rahman and Velayutham [36]	1990–2014	South Asian countries	panel Fully Modified Ordinary Least Squares and panel Dynamic Ordinary Least Squares	conservation
Brini [12]	1980–2014	African countries	Panel ARDL	Feedback

Autoregressive Distributed Lag

now a major global industry, wind, and solar energy will experience high growth in the future. Forecasts show that despite declining fossil fuel prices, the strength of the dollar, and the instability and weakness of the European economy, global investment in renewable energy will increase and the cost of producing each unit of energy through wind energy and solar photovoltaics (PV) will decrease so that investment in renewable energy is expected to outperform an investment in fossil fuels to increase capacity. In this regard, according to the IEA forecast, the share of renewable energy in the composition of

primary energy in the new policy scenario will increase from 8% in 2014 to 16% in 2040. By 2040, the cost of generating electricity from renewable energy is expected to be competitive with the average cost of generating electricity in fossil fuel power plants. According to the EIA [16], electricity generation from renewable energy will increase by an average of 3.8% per year from 2012 to 2040. Accordingly, the IEA forecast shows that the share of renewable energy in electricity generation will increase from 23% in 2015 to 37% in 2040. It is also expected that 60% of the increase in electricity

Table 2 Cross-Sectional dependence and homogeneity test

	lnGDP	lnREN	lnNREN
Cross-Sectional dependence			
LM	38.2922***	25.3693***	19.3632***
CD	17.3691***	29.3987***	24.3632***
LM _{adj}	32.1484***	28.9656***	21.4877***
Homogeneity			
$\Delta^{\wedge}$	19.6326***	25.3635***	22.1147***
Δ_{adj}	24.3636***	22.6893***	19.6985***

Note: *** indicates significance at 1% level

Fig. 1 Renewable energy consumption trends. Source: International Energy Outlook 2019 with projections to 2050

generation capacity (reaching 1705 GW in 2040) by 2040 will be provided by renewable energy. As a result, this energy will become the largest source of increasing electricity generation capacity.

As you can see most of the growth in electricity generation is fueled by renewables and natural gas. Renewables (including hydropower) are the fastest-growing source of electricity generation during the 2018 to 2050 period, rising by an average of 3.6% per year.

By 2025, renewables surpass coal as the primary source for electricity generation, and by 2050, renewables account for almost half of total world electricity generation.

As the forecast shows wind and solar dominate growth in renewable generation. Among renewable energy sources, electricity generation from wind and solar resources increase the most between 2018 and 2050, reaching 6.7 trillion and 8.3 trillion kilowatt-hours (kWh), respectively. By 2050, wind and solar account for over 70% of total renewables generation (Fig. 3).

Data and Methodological Framework

The data used in this study for the period 1980 to 2018 are related to 10 OPEC member countries including Ecuador, UAE,⁴ Iran, Algeria, Angola, Iraq, Saudi Arabia, Nigeria, Venezuela, and Congo [28].

Electricity generation is done with renewable energy such as wind, geothermal, biomass and waste, tides, waves, and solar, and with non-renewable energy such as coal, gas, and oil. GDP per capita was in constant 2010 US dollars.

To investigate the relationship between renewable and non-renewable energy consumption and economic growth, the bootstrap Granger causality method provided by Konya was used. In the method presented by Konya [25], there is no need to perform a causality test jointly for all sections and the

existence of causality can be examined for all sections separately. The advantage of this method over the Granger causality method in the time series framework (causality study separately for each section) is that in the Konya method, the synchronous correlation that may exist in the panel data frame between sections⁵ is used, and the use of this additional information leads to better results. In the following, it is explained that Konya uses the SUR⁶ method to estimate this information. The advantage of this method is that it also pays attention to the information of the variance-covariance matrix, which makes the estimates more efficient. Another advantage of this method is that unlike the traditional method of causality test, in which variables must be at a static or cointegrated level, this method does not require static variables (or cointegration of variables) and does not test for static or cointegration of variables.

For the Konya method to be superior to the traditional Granger causality method, there must be a concurrent correlation between the sections for this method to achieve more efficient results.

Therefore, one of the presuppositions of using the Konya method is that there is a simultaneous correlation between sections. Fortunately, there are tests that allow us to examine the existence of such a correlation. Also, since this method examines the causality of Granger separately for each section, there must be a compelling reason for such a distinction. This issue can also be examined through the Slope Homogeneity Test. To clarify the issue, we will first refer to the Konya method and then to the cross-correlation and homogeneity tests.

According to Konya [25] in the framework of the panel data of the equation, Granger causality of renewable and non-renewable energy consumption and economic growth for each section separately can be explained according to Eq. 1. The appropriate method for estimating this system of

⁵ Cross-Sectional Dependence

⁶ Seemingly Unrelated Regression

⁴ United Arab Emirates

Fig. 2 Share of net electricity generation by fuel. Source: International Energy Outlook 2019 with projections to 2050

equations depends on the properties of the error component. If there is no cross-sectional correlation, this system of equations can be easily estimated by the ordinary least squares method (of course, taking into account the static and cointegration considerations of the variables). But if there is a cross-sectional correlation, the OLS estimate will no longer work

because it does not use the information in the variance-covariance matrix. The method that can use this information and lead us to a more efficient estimate is the SUR method proposed by Zellner [44]. The SUR system is in the form of Eq. 1:

$$\begin{cases}
 GDP_{1t} = \alpha_{11} + \sum_{i=1}^{P1} \beta_{11i} GDP_{1t-i} + \sum_{i=1}^{P1} \delta_{11i} EC_{11t-i} + \varepsilon_{11t} \\
 GDP_{Nt} = \alpha_{1N} + \sum_{i=1}^{P1} \beta_{1Ni} GDP_{Nt-i} + \sum_{i=1}^{P1} \delta_{1Ni} EC_{Nt-i} + \varepsilon_{1Nt} \\
 EC_{1t} = \alpha_{21} + \sum_{i=1}^{P2} \beta_{21i} GDP_{1t-i} + \sum_{i=1}^{P1} \delta_{21i} EC_{21t-i} + \varepsilon_{21t} \\
 EC_{Nt} = \alpha_{2N} + \sum_{i=1}^{P2} \beta_{2Ni} GDP_{Nt-i} + \sum_{i=1}^{P2} \delta_{2Ni} EC_{Nt-i} + \varepsilon_{2Nt}
 \end{cases} \quad (1)$$

Fig. 3 Wind and solar dominate growth in renewables generation. Source: International Energy Outlook 2019 with projections to 2050

Where GDP is the real gross domestic product and EC is the consumption of renewable and non-renewable energy. N represents the number of countries and T represents the desired period and I represent the optimal interval length. The optimal lags of the equations are determined based on Akaike or Schwartz's information criteria.

Determining the optimal lag is the only test that needs to be done before using the Bootstrap Granger causality method. Determining the optimal lag is important in that it can strongly influence the causal results, and must be done before estimating the above equations. The optimal case is that the lags are not for common sections and are determined separately for each section. However, because this requires a lot of calculations, it was assumed that the lag structure is the same for all sections. The optimal lag in this study will be determined based on the proposed information statistics of Konya. Akaike (AIC) and Schwartz (SC) statistics are:

$$AIC_k = \ln|W| + \frac{2N^2q}{T} \quad (2)$$

$$SC_k = \ln|W| + \frac{N^2q}{T} \ln(T) \quad (3)$$

Where W is the covariance matrix of the model error statements and T , N , q are the number of equations, sample size, and the number of coefficients per equation, respectively. To investigate the causality of Granger in the system of Eqs. 1, the significance of regression coefficients is considered.

To investigate the causality of Granger in the system of Eqs. 1, the significance of regression coefficients is considered. It is said that in the i th country, Granger causality is one-way from EC to GDP when all δ_{1i} are non-zero but β_{2i} are zero. There is also a one-way relationship from GDP to EC if all δ_{1i} are zero and all β_{2i} are non-zero. Finally, there will be a two-way causality between GDP and EC when neither δ_{1i} and β_{2i} are zero, and conversely, there will be no causal relationship between GDP and EC when both δ_{1i} and β_{2i} are zero.

The Wald test can be used to perform the Granger causality test as described. The Wald statistic distribution normally follows the standard chi-square distribution.

When there is a cross-sectional correlation, the research variables are unstable or there is cointegration between them, the critical values extracted from the chi-square distribution cannot be used to test the hypothesis. In such cases (when there is a cross-sectional correlation or the variables are unstable or cointegrated), it is necessary to re-extract the Wald test statistic distribution either analytically (algebraically) or experimentally (simulation). Konya [25] suggests that it is better to use the bootstrap simulation method to obtain the distribution of test statistics. This method was also used in this study.

Empirical Results

First, before examining the causality of Granger between economic growth, renewable and non-renewable energy consumption, the cross-sectional correlation dependency, and slope homogeneity must be examined. The table below shows the results of the cross-sectional correlation test.

The null hypothesis that there is no cross-sectional correlation between countries is rejected. This means that the shock that occurs in one of the OPEC countries may be transmitted to other countries.

In the slope homogeneity test, the null hypothesis is that the slope is homogeneous, which is rejected based on the results, and as a result, the country-specific heterogeneity for OPEC countries was confirmed.

The results of Table 3 show that there is a two-way causal relationship between economic growth and the consumption of non-renewable energy for all countries except Algeria, Iraq, and Angola. Thus, the feedback hypothesis for non-renewable energy is confirmed in Ecuador, UAE, Iran, Saudi Arabia, Nigeria, Venezuela, and Congo. Economic growth in Iraq and Algeria is the cause of non-renewable energy consumption, and there is a one-way relationship from economic growth to non-renewable energy consumption in these two countries. Therefore, the conservation hypothesis is confirmed in these two countries. For Angola, the neutrality hypothesis is also confirmed.

The results of the causality test based on the data in Table 4 show that there is a one-way causal relationship between renewable energy consumption and economic growth for Ecuador. Hence, there is a growth hypothesis for this country regarding the consumption of renewable energy. Economic growth is also the cause of non-renewable energy consumption in Algeria and Iran. Therefore, regarding the consumption of renewable energy, the conservation hypothesis is confirmed in the mentioned countries. The results of Table 4 also show that there is a two-way causal relationship between renewable energy consumption and economic growth in Saudi Arabia and the UAE. Also, there is no causal relationship between these two variables in other OPEC member countries.

Conclusions

The purpose of this article was to investigate the relationship between renewable and non-renewable energy consumption on economic growth in oil-exporting countries for the period 1980 to 2018. The results show that both cross-sectional dependency and country-specific heterogeneity are valid for sample countries, it implies a shock that occurred in one OPEC country may be transmitted to the other OPEC countries.

Table 3 Bootstrap causality results between non-renewable energy consumption and economic growth

Countries	H0:lnNREN dose not cause lnGDP					H0:lnGDP dose not cause lnNREN				
	Statistic	pval	Critical values			Statistic	pval	Critical values		
			90%	95%	99%			90%	95%	99%
Ecuador	6.8	0.08	6.1	9.9	12.6	9.6	0.09	9	13.7	16
Algeria	5.5	0.2	7.9	9.6	12.8	30	0.0	7.6	9.1	12.5
UAE	15.6	0.02	8.2	13.6	18	14	0.0	7.4	11.8	13.2
Iran	9.4	0.04	6.3	8.7	14.5	17	0.0	8.7	11.3	16
ANGOLD	7.3	0.08	7.1	9	11.4	8.3	0.07	6.9	11.5	13.6
IRAQ	3.6	0.7	6.2	8.4	11.7	8.3	0.04	6.85	8.2	12.5
Saudi Arabia	19	0.0	7.3	10.9	15.4	17.8	0.0	7.8	10.9	15
congo	2.6	0.7	9.9	13.7	15.7	1.7	0.7	8.6	14.6	16.8
NIGER	10.3	0.07	8.36	12.8	16.7	13.6	0.02	7.6	11.5	14.8
VENEZ	10.3	0.09	9.4	13.3	17.5	15.3	0.02	9.2	14.3	19

Note: *, **, *** indicate significance at 10, 5 and 1% level respectively. Critical values are based on 10,000 bootstrap replications

In the case of renewable energy consumption, the results of the causality test showed that there is evidence of a growth hypothesis for Ecuador. In addition, the conservation hypothesis that there is a one-way causal relationship between economic growth and the renewable energy consumption is valid for Algeria and Iran. The feedback hypothesis in Saudi Arabia and the UAE were also confirmed.

While there is evidence of the neutrality hypothesis for Angola, Iraq, Nigeria, Venezuela, and Congo. Regarding non-renewable energy consumption, the feedback hypothesis is confirmed for Ecuador, UAE, Iran, Saudi Arabia, Nigeria, Venezuela, and Congo. In other words, in these countries, there is a two-way causal relationship between non-renewable energy consumption and economic growth. In

Iraq and Algeria, the conservation hypothesis is in place. Thus, economic growth in these countries is the cause of non-renewable energy consumption. There is also no causal relationship between unlimited energy consumption and economic growth for Angola, and the neutrality hypothesis is confirmed.

Thus, according to the findings of this article, the consumption of non-renewable energy in most energy-exporting countries has an impact on economic growth, while this is not the case with renewable energy, because the share of renewable energy consumption in OPEC countries is lower. The reasons for this can be considered the initial cost and high cost, insufficient investment, and lack of supportive policies.

Table 4 Granger causality results between renewable energy consumption and economic growth

Countries	H0:lnREN dose not cause lnGDP					H0:lnGDP dose not cause lnREN				
	Statistic	pval	Critical values			Statistic	pval	Critical values		
			90%	95%	99%			90%	95%	99%
Ecuador	8.1	0.07	7	9.2	13.6	4.8	0.5	7.6	11.7	13.4
Algeria	7	0.2	7.7	9.3	12.8	13.4	0.0	6.3	10.7	13
UAE	19	0.0	8.3	14.7	17.3	18.6	0.0	9	12.5	17
Iran	5.5	0.3	7	8.6	12.5	8.6	0.09	8.2	11.4	15
ANGOLA	4.9	0.5	8.9	10.4	13.6	5.2	0.2	7.2	10.9	13
IRAQ	2.6	0.7	6.3	9.4	12.9	5	0.5	6.5	9.1	13.3
Saudi Arabia	22	0.0	10.4	14.8	18.6	19	0.0	8.3	12.7	15.3
congo	1.4	0.8	10.4	14.6	16.9	1.6	0.9	9.6	14.8	17
NIGER	2.1	0.7	7.9	11.2	15.1	5.4	0.5	8.9	12.8	15.2
VENEZO	1.8	0.9	7.2	12.9	15.8	3.1	0.7	8.1	12.8	16.5

Note: *, **, *** indicate significance at 10, 5 and 1% level respectively. Critical values are based on 10,000 bootstrap replications

So overall, environmental policies to reduce non-renewable energy consumption could be detrimental to economic growth in most OPEC countries. However, the emphasis can be on optimizing the consumption of non-renewable energy in these countries. Also, considering that in half of the OPEC member countries there is a causal relationship between the consumption of renewable energy and economic growth, investment in the renewable energy sector is necessary. In this regard, tax exemptions related to the production of renewable energy and the expansion of the financial support system to facilitate investment to develop the renewable energy sector can be proposed.

Appendix

Bootstrap Panel Granger Causality is based on SUR systems and Wald tests with country specific bootstrap critical values. This approach has two advantages. On the one hand, it does not assume that the panel is homogeneous, so it is possible to perform Granger-causality tests on each individual panel member separately. However, since contemporaneous correlation is allowed across countries, it makes it possible to exploit the extra information provided by the panel data setting. On the other hand, this approach does not require pretesting for unit roots and cointegration, though it still requires the specification of the lag structure.

The procedure to generate bootstrap samples and country specific critical values consists of the following five steps [25]:

- (i) Estimate Eq. (1) under the null hypothesis of no-causality from EC to GDP by imposing $\delta_{ij} = 0$ for all j and i and obtain the residuals.
- (ii) Re-sample these residuals. In order to preserve the contemporaneous cross-correlation structure of the error terms in (1), do not draw the residuals for each country one-by-one, but rather randomly select a full column from the $[e_{H0,i,t}]$ matrix at a time. Denote the selected bootstrap residuals as $e_{H0,i,t}^*$ where $t = 1, \dots, T^*$ and T^* can be greater than T .
- (iii) Generate the bootstrap sample of GDP under the assumption of no-causality from EC to GDP as $GDP_{it}^* = \hat{\alpha}_{1i} + \sum_{j=1}^{p1} b_{1ij} GDP_{it-1}^* + e_{H0,i,t}^*$
- (iv) Substitute GDP_{it}^* for GDP_{it} , estimate Eq. (1) without any parameter restrictions and then carry out the Wald test for each country to test for the null of no-causality.
- (v) Develop the empirical distributions of the Wald test statistics repeating the steps 2–4 many times and generate the bootstrap critical values by selecting the appropriate percentiles of these sampling distributions.

Cross-sectional correlation tests

As explained earlier, for the SUR method to be more efficient than the OLS⁷ method, there must be a simultaneous correlation between the error statements of the equation system. Simultaneous correlation can occur for several reasons: there may be a common factor affecting all sections that are ignored in the regression; It may be due to the spatial effects overheads or it may be due to the interaction of sections [13].

For example, the global economic downturn is a shock that affects all countries together and affects their production; Such a shock cannot be explained by economic variables. Hence, it appears in regression error sentences and causes a cross-sectional correlation. This is the common factor between sections. If there is a cross-sectional correlation, using the OLS estimator will result in us not using all available information and the estimates will not work. To be able to use the information in the variance-covariance matrix, we can use the SUR method to obtain more efficient estimates. In this study, three LM tests of Breusch-Pagan [11], CD by Pesaran [33], and LM of modified bias of Pesaran et al. [34] will be used.

Breusch-Pagan LM test [11]

The statistics of this test are calculated as follows:

$$LM = \sum_{i=1}^{N-1} \sum_{j=i+1}^N T \rho_{ij}^{\wedge 2} \chi_{\frac{n(n-1)}{2}}^2 \quad (4)$$

where $\rho_{ij}^{\wedge}$ is the correlation between the error sentences of sections i and j . This asymptotic distribution has a chi-square distribution and is for cases where N is constant and $T \rightarrow \infty$. When T is small and N is large, this statistic encounters the problem of size distortion. To solve this problem, Pesaran [33] introduced another statistic. Error sentences are also calculated from the following regression estimates using the ordinary least squares method:

$$y_{it} = \beta_i' x_{it} + e_{it} \quad (5)$$

y_{it} is the vector of the dependent variable and x_{it} is the matrix for the explanatory variables.

Pesaran CD Test (2004)

Pesaran [33] introduced the CD statistic as the following equation to solve the problem of bias in the LM test statistic when N is large.

$$CD = \sqrt{\frac{2}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N T \rho_{ij}^{\wedge 2} \right) \quad (6)$$

⁷ ordinary least squares

He showed that when T is large, $T \rightarrow \infty$, and $N \rightarrow \infty$, the CD test statistic tends to distribute $N(0,1)$. This statistic performs better than LM when N and T are small.

Adjusted LM bias test of Pesaran et al. [34]

When the mean two-to-two correlation of community error sentences is zero, the CD statistic is low. This statistic both solves the problem of LM statistic bias and performs better than CD statistic. The adjusted LM bias statistic is as follows:

$$LM_{adj} = \sqrt{\frac{2}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \rho_{ij}^{\wedge} \frac{(T-k)\rho_{ij}^{\wedge 2} - \mu_{Tij}}{\vartheta_{Tij}} \right) \quad (7)$$

where K represents the number of explanatory variables and μ_{Tij} and ϑ_{Tij} represent the mean-variance $(T-k)\rho_{ij}^{\wedge 2}$, respectively. This asymptotic distribution tends to the $N(0,1)$ distribution.

Slope homogeneity test

As mentioned earlier, in Konya [25] method, the causality of Granger is examined for each section separately. To have a convincing reason for this, the coefficient homogeneity test is used. If the regression coefficients are different for each section (coefficients are heterogeneous) there will be a good reason to use the Konya method. Swamy [37] presented a test that can be used to test the heterogeneity of section coefficients.

$$\tilde{s} = \sum_{i=1}^N \left(\hat{\beta}_i - \tilde{\beta}_{WFE} \right)' \frac{X_i' M_T X_i}{\hat{\sigma}_i^2} \left(\hat{\beta}_i - \tilde{\beta}_{WFE} \right) \quad (8)$$

where $\hat{\beta}_i$ The coefficients estimated by the pooled OLS for each section and $\tilde{\beta}_{WFE}$ is the coefficients obtained by the Weighted Fixed-Effect Pooled Estimation. M_T represents the unit matrix and $\hat{\sigma}_i^2$ also estimates the variance of the error sentences. The test statistics for Swami [37], Pesaran, and Yamagata [35] provide the test as follows.

$$\tilde{\Delta} = \sqrt{N} \left(\frac{N^{-1} \tilde{s} - K}{\sqrt{2K}} \right) \quad (9)$$

where N is the number of sections, K is the number of explanatory variables and $\tilde{s}$ represent the statistics of the Swami test (1970). In addition to this statistic, Pesaran and Yamagata [35] presented another improved test statistic as follows.

$$\tilde{\Delta}_{adj} = \sqrt{N} \left(\frac{N^{-1} \tilde{s} - K}{\sqrt{2K(T-K-1)}} \right) \quad (10)$$

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