# Renewable Energy Consumption-Economic Growth Nexus in Saudi Arabia: Evidence from a Bootstrap ARDL Bounds Testing Approach

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*Abstract:* The paper investigates the relationship between Saudi economic growth, renewable energy consumption and trade openness during the 1980-2017 period. By using the Bootstrap Autoregressive Distributed Lag (BARDL) approach and the Granger causality analysis, the results prove the existence of a cointegration relationship between the considered variables. In order to test for Granger causality in the presence of cointegration among the variables, the results indicate that there is a short-run unidirectional causality running from GDP to trade openness. Thus, a bidirectional causality is detected both between (REC-TOP) and between (PIB-REC). In contrast, in the long run, there is a one-way causal relationship running from renewable energy consumption, trade openness to economic growth. These new findings will help policymakers and government officials better understand the role of renewable energy and economic growth in Saudi Arabia's development.

*Keywords:* Trade openness, Renewable energy consumption, Economic growth, Bootstrap ARDL, Saudi Arabia.

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## 1 Introduction and Literature Review

Today, global warming, which is caused by the accumulation of greenhouse gases, is one of the major environmental concerns. Indeed, the energy sector, based on the consumption of fossil fuels- which are the main cause of these gases- has been undergoing structural changes for several years in terms of energy efficiency and the introduction of renewable energies. Guaranteeing access for all to reliable, sustainable, modern and affordable energy services, The United Nations Development Program (UNDP, 2015) is one of the seventeen Sustainable Development Goals endorsed in September 2015 by the General Assembly United Nations to succeed the Millennium Development Goals. For this to be achieved, it is recommended to double the rate of improvement in energy efficiency and to promote the energy transition by 2030.

The Kingdom of Saudi Arabia has for some years started an energy strategy aimed at the deployment of renewable energies. Indeed, the country has known for years a growing energy demand, and has been forced to meet it by importing energy given its lack of conventional energy resources. The Kingdom's interest in the deployment of renewable energies is therefore motivated by several factors. Indeed, the main objective of this new strategy is to participate in the reduction of greenhouse emissions and to respect international commitments in terms of environmental protection, but also to be able to reduce energy dependence by stimulating the production of clean energies, to ensure energy security and to allow widespread access to energy in rural areas. As for Saudi economic growth, this is mainly volatile. This volatility is linked to the concentration of production in a small number of sectors, namely those of raw materials and agriculture, which are highly dependent on world markets and weather vagaries.

Given the need to design efficient energy policies, the causal link between energy consumption and economic growth could be a decisive element. Indeed, in recent years, the debate on the causal link between the consumption of renewable energies and economic growth, closely followed by advances in econometric theory, energy economics and the economy of the environment, caused a lot of ink to flow. However, despite all this research, the state of knowledge still remains undetermined and controversial. Indeed, the study by [1], [2], in which the authors examined the causality of the relationship between energy consumption and economic growth for the United States of America, represents the pioneering study which served as a wealth of empirical research using different econometric methodologies and variables.

Indeed, four possible hypotheses concerning the direction of the causal link between the consumption of renewable energies and economic growth are possible: (I) The hypothesis of neutrality or absence of causality: this hypothesis maintains that there is no causal relationship between GDP growth and energy consumption. This implies that energy consumption is not correlated with GDP growth and therefore policies of energy scarcity and conservative energy use do not affect economic growth. (II) The conservation hypothesis: according to this hypothesis, there is a unidirectional causality going from GDP growth to energy consumption. This assumption implies that GDP growth drives energy consumption. It also suggests that an economy that operates in such a relationship is less dependent on energy; therefore, any conservation policy regarding energy consumption will have little or no negative effect on economic growth. (III) The Growth Hypothesis: this hypothesis implies that there is a unidirectional causality running from energy consumption to GDP. This implies that energy consumption drives GDP growth. The growth hypothesis suggests that the abundant availability of energy sources at a reasonable price promotes economic growth. In this sense, while increasing energy consumption can contribute to further economic growth, a reduction in energy consumption can have negative effects on growth. (IV) The feedback hypothesis: according to this hypothesis, there is a bidirectional causality between GDP and energy consumption. Energy use drives GDP growth, and that same growth drives energy use.

Findings from the literature on the relationship between energy consumption and economic growth therefore support four possible conclusions regarding the direction of the causal link. Recently, other studies have also looked at the relationship between renewable energy consumption and economic growth. Indeed in [3], the authors examined the causal link between renewable energy consumption and economic growth in South Africa for the period 1990-2014. The authors used the ARDL model to explore the long-term relationship between the variables and the vector error correction model to determine the direction of causality. The authors also incorporated carbon dioxide emissions, capital formation, and trade openness as additional variables to form a multidimensional framework. The results of the study validated the existence of a long-run relationship between the variables. Moreover, a unidirectional causality running from renewable energy consumption to economic growth was confirmed for the long run. On the other hand, the short-run results suggest unidirectional causality running from economic growth to renewable energy consumption. The results then confirm that all the variables are co-integrated and support the validity of the long-run growth hypothesis and the short-run conservation hypothesis.

In [4], the authors investigated the long-run causal relationship between renewable energy consumption and economic growth in different countries. Indeed, the authors classified the various countries studied into four categories: low-income countries, lower-middle-income countries, upper-middle-income countries and high-income countries. However, study results are mixed across countries. The results revealed that the long-run bidirectional relationship between the variables is more significant in high-income countries. Indeed, 79% of countries were found to have a positive, long-run, bidirectional relationship between renewable energy consumption and economic growth, thus confirming the feedback hypothesis.

However, 19% of the countries showed no long-run relationship between the variables, thus confirming the neutrality hypothesis. Since renewable energy consumption plays an important role in GDP growth for most of the countries studied, the authors then underlined the importance of investments in the sector, and underlined the role of the latter in strengthening energy security, thanks to its contribution to the reduction of imported fossil fuels. The authors also highlighted the role of renewable energy in job creation.

In [5], the authors studied the short- and long-run relationships as well as the direction of Granger causality between energy consumption from non-renewable and renewable sources and economic growth in MENA countries for the period 1980-2012. They included capital and labor as explanatory variables. The empirical results support the existence of a long-run relationship between economic growth, renewable and non-renewable energy consumption, labor and capital. Granger's causality results confirm the feedback hypothesis between the two types of energy used and economic growth. This suggests that both energy sources are vital for economic growth. Meanwhile, in [6], the authors assessed the impact of renewable energies on the economic growth of 15 West African countries over the period 1995-2014. The results of the study demonstrated that the consumption of renewable energy slows down these countries' economic growth. Indeed, the authors attribute these results to the fact that biomass, which is generally impure and highly polluting, is the most widespread source of energy in these countries; unlike solar or wind energy, which are much less used in West Africa. The study therefore recommends the use of an increased share of other renewable energy sources such as solar, wind and geothermal. In [7], the authors analyzed and compared the short- and long-term causality between renewable energy consumption and economic growth in 12 European Union countries, using a vector error correction model and the Granger causality test for the 1990 to 2014 period. The results of the study indicate the presence of a unidirectional causality from economic growth to renewable energy consumption in the short run. However, in the long run, the results of the study support the existence of a bidirectional relationship between the variables in question and therefore confirm the feedback hypothesis between the long-run variables.

In [8], the authors studied the effects of renewable energy consumption on economic growth from 1991 to 2012 in a sample of 38 countries. The results of the study indicate that the consumption of renewable energy has a positive and significant impact on the economic output of 57% of the selected countries. The authors believe that these results are because these countries could not effectively use renewable energy sources in the production process, which therefore has almost no impact on economic production. In [9], the authors relied on the ARDL approach to examine the causal link between economic growth, renewable energy consumption, capital and labor for the new EU member countries for the period 1990-2009. The results of the study confirm that the consumption of renewable energy has positive effects on the economic growth of all the countries studied. However, the impact on economic growth is only statistically significant for Bulgaria, Estonia, Poland and Slovenia. On the other hand, no causal link was found and therefore the neutrality hypothesis was confirmed for Cyprus, Estonia, Hungary, Poland and Slovenia. For the Czech Republic, the conservation hypothesis- stating that there is a unidirectional causality from economic growth to renewable energy consumption- was confirmed. Also, the causality from renewable energy consumption to economic growth was confirmed for Bulgaria. The growth hypothesis is therefore confirmed for this country.

In [10], the authors analyzed the causal link between renewable energy consumption and economic growth in 17 emerging countries from 1990 to 2016. The results of the study demonstrated that the neutrality hypothesis is valid for all the countries studied, with the exception of Poland, thus the growth hypothesis is confirmed. The authors estimate that energy saving policies have no harmful influence on the growth rates of these 16 emerging economies. However, for Poland, energy saving policies can have adverse effects on the country's economic performance level. According to the authors, the absence of causality does not necessarily imply that renewable energies do not represent a crucial contribution to economic growth. This indicates, however, that the level of investment in the renewable energy sector is not yet sufficient to drive these economies' economic growth rates. This also indicates that there is a given threshold beyond which renewable energy consumption will begin to stimulate economic growth.

This article therefore aims to provide empirical results on the impact of renewable energy consumption on economic growth in Saudi Arabia, highlighting the role of capital and labor in the deployment of the sector.

The rest of the paper is structured as follows. Methodology, data and sources are presented in section 2. Results and discussion of findings are presented in section 3. The last section concludes and suggests some policy implications.

# 2 Data and Methodology

## 2.1 Data

The variables used in this study are gross domestic product per capita (GDP), renewable energy consumption per capita (REC), trade openness (TO) and human capital (HC).

These variables are examined for the case of Saudi Arabia during the period 1980-2017. Table 1 presents the data sources and measurement for this study.

Table 1. Description and source of the variables

| Variables | Description | Sources |
|---|---|---|
| GDP per capita (GDPP) | GDP per capita (constant 2015 US$) | [11] |
| Renewable energy consumption (REC) | Renewable energy consumption (% of total final energy consumption) | [11] |
| Gross fixed capital formation for capital (HC) | gross fixed capital formation in billions of constant 2010 U.S. dollars for capital | [11] |
| Trade Openness | Trade (% of GDP) | [11] |

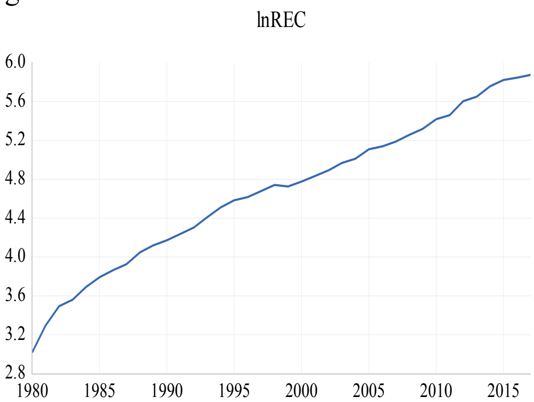
To provide an overall understanding of the chosen variables, Table 2 below presents the descriptive statistics and the relative correlation relationship between the different variables. Table 2 shows that the GDP per capita is on average 19,381.26 US$ with a maximum value of 21,399.11 US$. Renewable energy consumption ranges between 20.45 and 77.6% of total final energy consumption. Trade openness ranges between 56.088% and 96.102% of economic growth. The development of human capital increases by 21.2% with a maximum value of 2.667, which means that the growth rate of human capital development is related to the consumption of renewable energy.

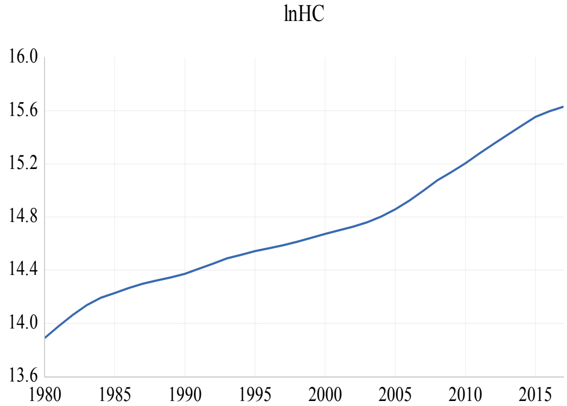
The analysis of the correlation matrix in this table indicates that the highest correlation is between economic growth and renewable energy consumption. In addition, the latter is positively correlated with human capital and trade openness, which means that an increase in renewable energy consumption leads to promoting economic growth without deteriorating the environment.

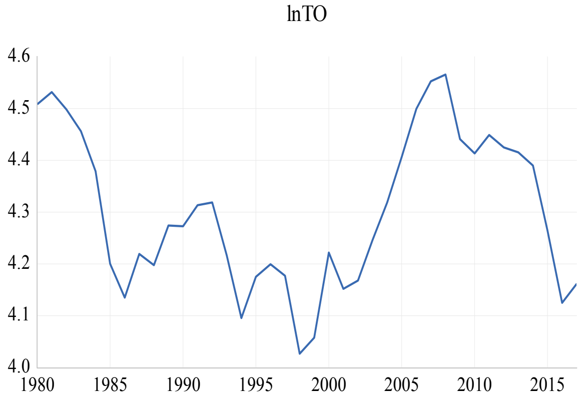
Table 2. Summary statistics and correlations

| | GDPP | HC | TOP | REC |
|---|---|---|---|---|
| Mean | 19409.09 | 1.25E+11 | 74.637 | 60.109 |
| Median | 19315.07 | 1.34E+11 | 71.765 | 51.712 |
| Maximum | 21399.11 | 2.09E+11 | 96.102 | 77.610 |
| Minimum | 16696.41 | 4.75E+10 | 56.088 | 20.452 |
| Std. Dev. | 1344.880 | 5.84E+10 | 11.207 | 10.063 |
| GDPP | 1 | | | |
| HC | 0.890 | 1 | | |
| TOP | 0.912 | 0.863 | 1 | |
| REC | 0.966 | 0.963 | 0.925 | 1 |

Indeed, the temporal evolutions of the series can change the results of the unit root test. Therefore, it is important to conduct several tests that take into consideration the structural break and the integration of trend at the level of the series. Figure 1 shows if there are any structural breaks. Obviously, the graphs show the absence of trend in all the variables except the log of renewable energy consumption (LnREC) and the log of human capital (LnHC) which maintain a constant upward trend during the period studied. However, there is evidence that affirms the existence of structural breaks in the series given their upward and downward movements. The breaks are associated with periods of political and economic events in the country such as global efforts towards efficient energy use and environmental sustainability. In particular, the decrease in TOP during the 1980s could be explained by the oil price shock in 1985 which reduced the growth rate in Saudi Arabia. However, the increase in capital during the 2000s could be attributed to steady economic growth resulting from increased individual consumption of goods and services.



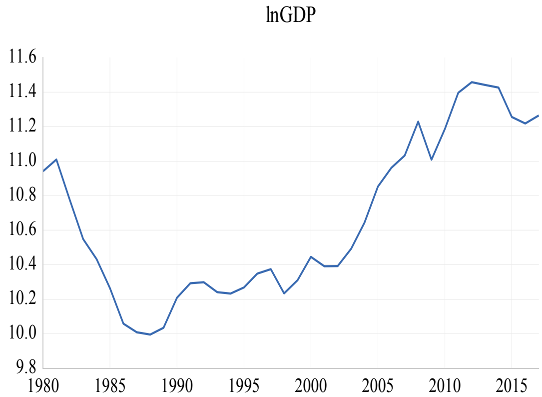




Fig.1: The series time profiles

## 2.2 Methodology

Our objective is to highlight the relationship between renewable energy consumption and sustainable development over the period 1980-2017 in Saudi Arabia.

To do this, we use GDP as a well-being indicator and we start from the following relationship:

$$\ln GDP_t = \mu + \alpha \ln REN_t + \beta \ln X_t + \varepsilon_t \quad (1)$$

Where $lnGDP_t$ and $lnRen_t$ denote respectively economic growth and renewable energy consumption expressed in natural logarithm. $X_t$ is a vector of control variables including human capital and trade openness ; $\varepsilon_t$ denotes the error term and $\mu$, $\alpha$ and $\beta$ are the cointegrating parameter vectors to be estimated.

The long-run relationship between trade openness, human capital, renewable energy consumption and economic growth is then examined by applying the autoregressive distributed delay (BARDL) bootstrap test proposed by [12].

The ARDL model is presented as follows:

$$y_t = \sum_{i=1}^{m} \mu_i y_{t-i} + \sum_{j=0}^{k} \nu_j x_{t-j} + \sum_{j=0}^{k} \gamma_j z_{t-j} + \sum_{r=0}^{q} \delta_r \sigma_{t,r} + \varepsilon_t \quad (2)$$

$i$ and j are the indicators of the lag period, $i = 1, 2, 3, ..., m$; $j = 0, 1, 2, ..., k$; $r = 0, 1, 2, ..., q$. $t$ designs time $t = 1, 2, 3, ..., T$. The $y_t$ in the equation is the explanatory variable, $x_t$ and $z_t$ are the explanatory variables; and $\sigma_t$ is a dummy variable. The parameters $\mu_i$, $\nu_j$, and $\gamma_j$ are the coefficients of the lag of $y_t$, $x_t$, and $z_t$. The error term is $\varepsilon_t$. Equation (1) is developed in the equation below:

$$\Delta y_t = \beta_1 y_{t-1} + \beta_2 x_{t-1} + \beta_3 z_{t-1} + \sum_{i=1}^{m-1} \eta_i y_{t-i} + \sum_{j=1}^{k-1} \tau_j x_{t-j} + \sum_{j=1}^{k-1} \theta_j z_{t-j} + \sum_{r=1}^{q} \upsilon_r \sigma_{t,r} + \omega_t \quad (3)$$

Where $\beta_1 = -1 + \sum_{i=1}^{m} \mu_i$, $\beta_2 = \sum_{j=0}^{k} \nu_j$ and $\beta_3 = \sum_{j=0}^{k} \gamma_j$ ; other parameters are the function values of the original parameters. The authors in [12] present the bootstrap method to ARDL cointegration tests and propose a cointegration that requires testing the following three hypotheses:

The $F_{statistic}$ test which is based on all the relevant error-correction terms:

$$F_{statistic} \begin{cases} H_0 : \beta_1 = \beta_2 = \beta_3 = 0 \\ H_1 : \beta_1 \neq \beta_2 \neq \beta_3 \neq 0 \end{cases}$$

The $F_{indep}$ test which is based on all of the explanatory variable s' terms:

$$F_{indep} \begin{cases} H_0 : \beta_2 = \beta_3 = 0 \\ H_1 : \beta_2 \neq \beta_3 \neq 0 \end{cases}$$

The $t_{dep}$ which is based on the lagged dependent variable:

$$t_{dep} \begin{cases} H_0 : \beta_1 = 0 \\ H_1 : \beta_1 \neq 0 \end{cases}$$

After testing the long-term relationships, we conclude that the short-term causal relationship will be determined by Granger causality tests if there is no cointegration relationship between $x_t$, $y_t$ and $z_t$. We used the Granger causality test to $x_t$ and $z_t$, which should include the delayed difference on $x_t$ or $z_t$, and we tested $\tau_j = 0$ or $\theta_j = 0$ in equation (3). On the other hand, if the dependent variable and the independent variable are cointegrated, then a fixed linear combination will be determined between these variables. In this case, the short-run relationship test should include the hysteresis difference of $x_t$ or $z_t$ and the hysteresis level of $x_t$ or $z_t$, i.e., test $\beta_2$ and $\tau_j$ or $\beta_3$ and $\theta_j$.

## 3 Results and Discussion

Testing the stationarity of the variables is a necessary step before any cointegration test. To ensure this, we will apply the Augmented Dickey-Fuller, [13], and Phillips Perron, [14], tests to study the properties of the unit root of each series. The results presented in Table 3 show that the series TOP and HC are stationary in level while GDP and REC are stationary in first difference, and consequently none of them is integrated of order 2. This confirms our choice of the ARDL model.

Table 2. Unit Roots tests

| Variable | Augmented Dickey Fuller (ADF) | | PP | |
|---|---|---|---|---|
| | Levels | First difference | Levels | First difference |
| TOP | -5.145* | _ | -10.655* | _ |
| HC | -7.235** | _ | -12.364 | _ |
| GDP | 0.128 | -2.364** | -3.928 | -8.099* |
| REC | 0.556 | -2.927** | -3.310 | -5.365* |

**Note:** * and ** symbolize statistical significance at the 1% and 5% thresholds, respectively.

In the second step of our analysis, the bootstrap ARDL bound test for cointegration was performed. The empirical results of this test are reported in Table 4. Using the bootstrap ARDL test, the diagnostic tests indicate that the adopted specifications are globally satisfactory. The Jarque-Bera (JB) normality tests do not allow us to reject the errors normality hypothesis. The Breusch-Godfrey LM tests make it possible to reject the null hypothesis of the absence of serial autocorrelation in the 4 regressions. Thus, according to the tests studied, we conclude that the 4 dependent variables are stable over time (Fig. 2 and Fig. 3). The delay number is selected with Akaike Information Criteria (AIC).

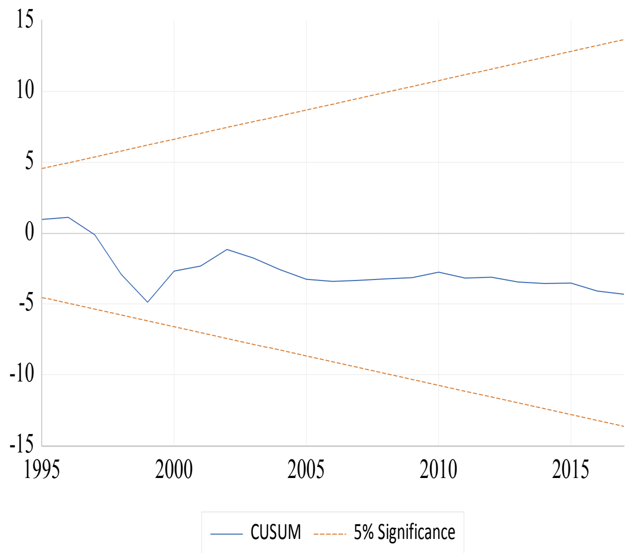



Fig. 2: CUSUM.

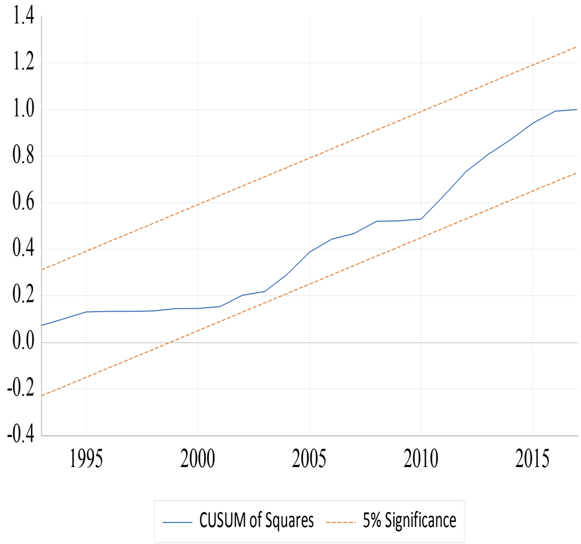



Fig. 3: CUSUM of squares.

Indeed, the results show that their evolutions do not exceed the confidence interval in red. This stability is explained by the presence of the different explanatory variables integrated into this model. In addition, the columns Fstatistic, tdep, $F^{indep}$ present values for the significance level of 1%, and 5%, generated by the ARDL bootstrap procedure. The bootstrap ARDL presents the joint $t_{dep}$, $F_{indep}$, and $F_{statistic}$ tests. The $F_{statistic}$, and $t_{dep}$ tests take into account the values lagged by one period for all the independent variables and the dependent variable, respectively. The $F_{indep}$ test takes into account the one period lagged value for the independent variable. This shows the advantage of bootstrap ARDL over traditional ARDL to study the cointegration relationship between series. Indeed, Table 4 shows that the $F_{statistic}$ and $t_{dep}$, $F_{indep}$ tests can reject the null hypothesis of absence of cointegration between economic growth, renewable energy consumption and trade openness. This indicates that the $F_{statistic}$ and $t_{dep}$, $F_{indep}$ tests show the presence of three cointegrating vectors. The value of $R^2$ varies from 0.756 to 0.867, which shows that all the independent variables simultaneously explain the dependent variables.

Table 5 presents the Granger causality results. We show a unidirectional causality running from renewable energy consumption to real GDP. This result confirms the growth hypothesis that renewable energy consumption contributes in the short run to economic growth in Saudi Arabia. This implies that, alongside other determinants of economic growth, any change in renewable energy consumption will affect economic growth. These results differ from those of in [15] who the authors found evidence of a unidirectional causality from renewable energy consumption to economic growth in Saudi Arabia.

Table 5 also shows the existence of a unidirectional causality running from trade openness to real GDP, which means that trade openness boosts economic growth in Saudi Arabia. This evidence is consistent with several studies, such as [16] for South Korea and Taiwan, [17] for South Korea, Pakistan and Thailand, [18] for Malaysia and Thailand;, [19] for Pakistan; and Rahman and [20] for Australia.

Table 4. Bootstrap ARDL cointegration analysis

| Bounds testing approach to cointegration | | | | | | Diagnostic tests | | | Cointegration Status |
|---|---|---|---|---|---|---|---|---|---|
| Dependent variable/independent variable | Lag length | Break year | $F_{statistic}$ | $t_{dep}$ | $F_{indep}$ | $R^2$ | LM(2) | JB | |
| GDP(REN/HC/TOP) | (1,1,2,2) | 1990 | 20.241* | -4.199* | 6.411* | 0.814 | 0.364 | 1.678 | Cointegration |
| REN(GDP//HC/TOP) | (2,0,2,1) | 1991 | 11.259* | -5.622** | 2.587* | 0.799 | 2.578 | 0.821 | Cointegration |
| HC(GDP/REN/TOP) | (1,2,0,2) | 2010 | 2.031 | -1.602 | -1.034 | 0.556 | 2.697 | 0.134 | No-Cointegration |
| TO(GDP/REN/ HC) | (2,2,1,2,2) | 2007 | 8.147** | -4.765* | 3.862** | 0.867 | 0.807 | 0.813 | Cointegration |

Note: *, and ** denote significance at 1%, and 5% thresholds, respectively, based on critical values generated from the bootstrap method suggested by [12]. We use AIC for optimal lag length selection. $F_{statistic}$ is *F*-test for the lagged levels of all variables. $T_{depenent}$ is *t*-test for the lagged dependent variable. $F_{indep}$ is *F*-test for the lagged independent variable. The LM and JB refer to Lagrange Multiplier test and Jarque-Bera test.

Table 5. Granger-causality analysis

| Variables | ΔlnGDP | ΔlnREC | ΔlnTOP | $ECM_{t-1}$ |
|---|---|---|---|---|
| ΔlnGDP | _ | 0.019*** (0.005) | 1.421 (0.587) | -0.204 [-4.804]*** |
| ΔlnREC | 0.075*** (0.005) | _ | 0.011** (0.013) | -0.055 [-1.423] |
| ΔlnTOP | 0.018** (0.047) | 0.012** (0.024) | _ | -0.446 [-1.097] |

**Notes:** *p*-values are in parentheses. The *t*-students are the square brackets. Significance thresholds: *** $p <0.01$, ** $p < 0.05$, * $p <0.10$.

On the other hand, in the short run, the results show the existence of a unidirectional causality going from economic growth to trade openness. This implies that economic growth creates a favorable environment for business expansion. Similar empirical results were found for Indonesia, South Korea, Pakistan and Thailand [21], for Indonesia and Pakistan, [18] and for Australia, [20]. For the Granger causality analysis between trade openness and renewable energy consumption, the results affirm the existence of a unidirectional causality going from (REC) to (TOP). This implies that any strategy to reduce renewable energy consumption (i.e., a renewable energy conservation policy) will slow trade openness. This observation corroborates that of [22] and [23] where a unidirectional causality from energy consumption to trade openness was found in the case of Indonesia and the Philippines.

Nevertheless, Granger's short-run causality tests (Table 5) indicate that economic growth causes renewable energy consumption. The conservation hypothesis is therefore confirmed for Saudi Arabia. Hence, any strategy to reduce renewable energy consumption will have no effect on economic growth. This evidence corroborates that of [24], who found a unidirectional causality running from economic growth to renewable energy consumption for India and Pakistan. This also agrees with the findings of [19] and [25], who showed the same result for Pakistan.

Finally, there is a unidirectional causality running from trade openness to renewable energy consumption. This means that any fluctuation in trade openness affects renewable energy consumption. In addition, any change in trade openness affects renewable energy consumption. This result differs from those of [26] and [27] who found no causality between exports and renewable energy consumption for Malaysia. However, this is in line with [23], who confirmed a unidirectional causality from trade openness to renewable energy consumption for the case of Pakistan, and with [28] who found no causality between exports and renewable energy consumption for Thailand.

# 4 Conclusion and Policy Implications

This study investigates the relationship between economic growth, renewable energy consumption, trade and capital from 1980 to 2017 in Saudi Arabia. We incorporated natural resources, capital, and labor as additional determinants of domestic production. Using the bootstrap ARDL test developed by [12], the empirical results prove the existence of cointegration relationships between economic growth, renewable energy consumption and trade when these variables are taken as dependent variables.

The Granger causality analysis shows a bidirectional causal relationship between economic growth and trade openness in Saudi Arabia. This relationship supports both the trade openness-induced growth hypothesis and the growth-induced trade openness hypothesis. These results confirm the idea that trade openness was considered one of the primary factors of economic expansion in Saudi Arabia, while economic expansion favored trade openness. In other words, poorly-designed national economic policies that slow or impede economic growth will also reduce trade openness.

In the short run, the results show a bidirectional causal relationship between trade openness and renewable energy consumption, where any increases in renewable energy consumption will lead to increased trade openness, while promotion of commercial opening also increases the consumption of renewable energy. Finally, the Granger causality tests prove the existence of a bidirectional causal relationship between economic growth and renewable energy consumption. This implies that increased renewable energy consumption stimulates economic growth and vice versa. This result highlights the Saudi population's awareness of the need to protect the environment, which urges them to use renewable energies. Any energy conservation policy aimed at environmental goals will generally promote the use of renewable energy and hence enhance economic growth. Another implication is that well-designed national economic policies that promote economic growth will also increase renewable energy consumption. Thus, the empirical results affirm a unidirectional causality in the sense of Granger going from economic growth to trade openness. This implies that economic growth creates a favorable environment for business expansion.

These findings provide new insights for policy makers as they seek to design economic, trade and energy policies to support long-run economic growth to improve environmental quality. In light of these results, it is clear that the transition to renewable energy requires an ambitious political will. The existence of causality running from renewable energy consumption to economic growth and trade openness means that the former is an important factor for the latter two. On this basis, policy makers should develop and strengthen strategies to support renewable energy industries and technologies. The unidirectional relationship from economic growth and trade openness to renewable energy consumption indicates the importance of these factors in the development of renewable energy. In other words, economic growth brings additional technologies and capacities that can support the development of renewable energy sources and "clean technologies", while trade openness plays a major role in facilitating the diffusion of environmentally-friendly technologies. Of course, this would require Saudi Arabia's willingness to remove barriers to the importation of modern technologies and environmental services.

Our research has led us to identify the following policy implications. First, we recommend that the Saudi government continue to provide incentives through tax deductions, subsidies, etc. Consequently, renewable energy sources become more attractive for businesses, since their economic impact on both the economy and government policy regarding alternative energy sources cannot be ignored over the long term. Secondly, our findings prove the importance of renewable energy. Indeed, they ease the pressure on policy-makers to improve the environment as well as increase Saudi Arabia's economic growth. Thirdly, we therefore recommend that policymakers continue to promote regional and international trade openness, not only because it contributes to greater economic development, as evidenced by the results, but also because it plays a vital role in the increase in renewable energy consumption on the long-run. This in turn contributes to reducing $CO_2$ emissions and therefore improving the quality of the environment.

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*References:*
[1] UNDP., 2015. Paris Agreement. New York: UN. Accessed 9 March 2020. https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf.
[2] Kraft, J., & Kraft, A. (1978). On the relationship between energy and GNP. The Journal of Energy and Development, 401-403.
[3] Khobai, H., Hamman, N., Mkhombo, T., Mhaka, S., Mavikela, N., & Phiri, A. (2018). The FDI-growth nexus in South Africa: A re-examination using quantile regression approach. Studia Universitatis Babes-Bolyai, 63(3), 33-55.
[4] Al-Mulali, U., Fereidouni, H. G., Lee, J. Y., & Sab, C. N. B. C. (2013). Exploring the relationship between urbanization, energy consumption, and CO2 emission in MENA countries. Renewable and Sustainable Energy Reviews, 23, 107-112.
[5] Kahia, M., Aïssa, M. S. B., & Lanouar, C. (2017). Renewable and non-renewable energy use-economic growth nexus: The case of MENA Net Oil Importing Countries. Renewable and Sustainable Energy Reviews, 71, 127-140.
[6] Maji, I. K., Sulaiman, C., & Abdul-Rahim, A. S. (2019). Renewable energy consumption and economic growth nexus: A fresh evidence from West Africa. Energy Reports, 5, 384-392.
[7] Saad, W., & Taleb, A. (2018). The causal relationship between renewable energy consumption and economic growth: evidence from Europe. Clean Technologies and Environmental Policy, 20(1), 127-136.
[8] Bhattacharya, M., Paramati, S. R., Ozturk, I., & Bhattacharya, S. (2016). The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. Applied Energy, 162, 733-741.
[9] Alper, A., & Oguz, O. (2016). The role of renewable energy consumption in economic growth: Evidence from asymmetric causality. Renewable and Sustainable Energy Reviews, 60, 953-959.
[10] Ozcan, B., & Ozturk, I. (2019). Renewable energy consumption-economic growth nexus in emerging countries: A bootstrap panel causality test. Renewable and Sustainable Energy Reviews, 104, 30-37.
[11] WDI (2022). Wdi-world development indicators database.
[12] McNown, R., Sam, C. Y., & Goh, S. K. (2018). Bootstrapping the autoregressive distributed lag test for cointegration. Applied Economics, 50(13), 1509-1521.
[13] Dickey, D., Fuller, W., 1979. Distribution of the estimators for autoregressive time series with a unit root. Journal of American Statistical Association 74, 427–431.

[14] Phillips, P.C.B., Perron, P., 1988. Testing for a unit root in time series regression. Biometrika 75, 335–346.
[15] Abid, M., Gheraia, Z., & Abdelli, H. (2022). Does renewable energy consumption affect ecological footprints in Saudi Arabia? A bootstrap causality test. Renewable Energy, 189, 813-821.
[16] Darrat, A. F. (1986). Trade and development: The Asian experience. Cato J., 6, 695.
[17] Ekanayake, E. M. (1999). Exports and economic growth in Asian developing countries: Cointegration and error-correction models. Journal of economic development, 24(2), 43-56.
[18] Nasreen, S. (2011). Export-growth linkages in selected Asian developing countries: evidence from panel data analysis. Asian Journal of Empirical Research, 1(1), 1-13.
[19] Shahbaz, M., Lean, H. H., & Shabbir, M. S. (2012). Environmental Kuznets curve hypothesis in Pakistan: cointegration and Granger causality. Renewable and Sustainable Energy Reviews, 16(5), 2947-2953.
[20] Rahman, M. M., & Mamun, S. A. K. (2016). Energy use, international trade and economic growth nexus in Australia: New evidence from an extended growth model. Renewable and Sustainable Energy Reviews, 64, 806-816.
[21] Ekanayake, E. M. (1999). Exports and economic growth in Asian developing countries: Cointegration and error-correction models. Journal of economic development, 24(2), 43-56.
[22] Shahbaz, M., Hye, Q. M. A., Tiwari, A. K., & Leitão, N. C. (2013). Economic growth, energy consumption, financial development, international trade and CO2 emissions in Indonesia. Renewable and Sustainable Energy Reviews, 25, 109-121.
[23] Shahbaz M, Nasreen S, Ling CH, Sbia R. 2014. Causality between trade openness and energy consumption: what causes what in high, middle- and low-income countries. Energy Pol, 70:126–43.
[24] Mahmoodi M, Mahmoodi E. 2011. Renewable energy consumption and economic growth: the case of 7 Asian developing countries. Am J Sci Res, 35:146–52.
[25] Shahbaz M, Loganathan N, Zeshan M, Zaman K. 2015. Does renewable energy consumption add in economic growth? An application of auto-regressive distributed lag model in Pakistan. Renew Sustain Energy Rev, 44:576–85.
[26] Lean HH, Smyth R. 2010a. Multivariate Granger causality between electricity generation, exports and GDP in Malaysia. Energy, 35:3640–8.
[27] Lean HH, Smyth R. 2010b. On the dynamics of aggregate output, electricity consumption and exports in Malaysia: evidence from multivariate Granger causality tests. Appl Energy, 87:1963–71.
[28] Kyophilavong, P., Shahbaz, M., Anwar, S., & Masood, S. (2015). The energy-growth nexus in Thailand: does trade openness boost up energy consumption?. Renewable and Sustainable Energy Reviews, 46, 265-274.

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The authors have no conflicts of interest to declare that are relevant to the content of this article.