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Pathway to environmental sustainability: Nexus between economic growth, energy consumption, CO_2 emission, oil rent and total natural resources rent in Saudi Arabia

Mary Oluwatoyin Agboola [a], Festus Victor Bekun [b,c,*], Udi Joshua [d]

[a] College of Business, Dar Al Uloom University, 1MizanSt. Al Falah, Riyadh 13314 Saudi Arabia
[b] Faculty of Economics Administrative and Social Sciences, Istanbul Gelisim University, Istanbul, Turkey
[c] Department of Economic Securities South Ural State University, 76, Lenin Aven., Chelyabinsk 454080 Russia
[d] Department of Economic, Federal University Lokoja, Kogi state, Nigeria

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ABSTRACT

This study aims to empirically explore the long-run and causality relationship between energy consumption, oil rent, total natural resources rent, economic growth, and CO_2 emission for a top oil-exporting country (Saudi Arabia). In this study, we rely on the modified Wald test of Toda-Yamamoto methodology to investigate the direction of causality between the highlighted variables between 1971 and 2016 on an annual frequency. The empirical result shows a long-run equilibrium relationship between the variables as outlined by Pesaran Bounds test. The long-run regression validates the energy-induced environmental pollution as seen where a 1% increase in energy consumption depletes environment by 0.360% and 0.983% in both short and long-run periods, respectively. Similarly, there is increased economic growth-induced environment degradation by 0.952% and 0.625% in both the short and long-run period, respectively, over the sampled period. Furthermore, a significant positive nexus is seen between the country's' total natural resource rent and CO_2 emissions in both the short and long run. This suggests the over-reliance on natural resource rent affects environmental sustainability in Saudi Arabia if conservation and management options are neglected. Interestingly, oil rent shows evidence to dampen the effect of environmental degradation in Saudi Arabia. In the causality analysis, a feedback relationship is seen between energy consumption and economic growth while one-way causality is observed between energy consumption and CO_2 emission; similar unidirectional causality is seen between oil rent and CO_2 emission. These outlined results have environmental implications for policy makers and practitioners to present a macroeconomic blueprint, as we see energy conservative agenda will hurt economic progress in Saudi Arabia. However, given increase, energy consumption increases economic growth and its environmental implications call for sustainable and green energy sources, such as renewables, in Saudi Arabia's energy mix. More insights and policy direction are highlighted in the concluding section.

1. Introduction

The Kingdom of Saudi Arabia, with a population of over 33 million, is endowed with vast crude oil and natural gas deposits and, just like other Middle Eastern countries, Saudi Arabia is one of the world's most enriched areas in terms of oil reserves, especially since 1930s when crude oil was discovered (Nasir et al., 2019). The country has relied solely on the oil rent and total resource rent for growth and development. Given the vast crude oil reserves and low unit cost, the energy policy makers in Saudi Arabia considered the country as the world's supplier of last resort (Blas, 2017). Saudi Arabia exported over 7 million b/d in 2017, over 8 million b/d in 2018 and over 10 million b/d of petroleum products and crude oil in the early part of 2020, making the country the largest exporter of crude oil (JODI , 2020). With the major source of the country's revenue generated from the oil sector, the country is regarded as a petrostate; however, despite been blessed with abundant renewable energy resources especially solar, the country's energy generation is still highly dependent on low-cost and abundantly available nonrenewable resources, such as natural gas, crude oil, heavy fuel oil and diesel, with 99% of electricity generated using fossil fuel in

* Corresponding author. Faculty of Economics Administrative and Social Sciences, Istanbul Gelisim University, Istanbul, Turkey.
E-mail addresses: maryagboola@dau.edu.sa (M.O. Agboola), fbekun@gelisim.edu.tr (F.V. Bekun), udi.joshua@fulokoja.edu.ng (U. Joshua).

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2017 (ECRA 2017; Krane, 2019).

In 2015, Saudi Arabia's total greenhouse gas (GHG) emission was estimated to be 709.79 metric tons CO2 equivalent, of which 34.71% was from the power sector, 20.17% from the transport sector, 19.74% from other industrial combustion, 0.65% from buildings and 24.72% from other sectors (Crippa et al., 2019). Therefore, the power sector is by far the largest source of emissions in Saudi Arabia; given the increased use of fossil fuels as a source of energy generation, this facilitates greenhouse gas emission, and, according to an intergovernmental panel on climate change in 2015, CO_2 emission is identified as the main contributor to the total GHG emissions. Furthermore, Saudi Arabia is considered as the 9th highest carbon emitter in 2018 after countries like China, the United States of America, India, Russia, Japan, Germany, Iran, and South Korea based on fossil CO_2 emissions, which includes sources from fossil fuel use (combustion, flaring), industrial processes (cement, steel, chemicals and urea) and product use.

There are nearly three hundred billion barrels of crude oil reserves and more than eight trillion cubic meters of natural gas proven reserves in Saudi Arabia, making it the second largest oil reserve with 16% of the world's total reserve. The kingdom's proven oil is estimated to last almost 60 years given the production rate of 10 million barrels per day (BP, 2018). The country's oilfields include the highest onshore offshore oil fields in the world, with more than 130 known fields, the Persian-gulf shore contains most of the kingdom's oil and gas deposits. Also, the kingdom has unconventional oil and gas deposits in shale and tight forms which is estimated to be 10 times in volume as compared to the conventional ones; exploration and exploitation of these resources has begun in recent years. (Parker, 2018). Furthermore, the country, alongside other MENA countries, also possesses uranium deposits with 5% of the world's deposits found in Saudi Arabia, although Howari et al. (2016) mentioned the lack of details in the extent of the ore deposit within the country.

Given the abundant natural resources, the country makes use of the natural resource rent to drive economic growth, accounting for 23.7% and 29.5% of GDP in 2017 and 2018, respectively, and the oil rent accounting for 23.1% and 28.7% of GDP in the same respective periods. (World Bank,2020). Over the years, Saudi Arabia has enjoyed substantial economic growth and prosperity due to its natural resource abundance; however, given that the recent price of oil and gas has plummeted, the country is forced to utilize its buffer to reduce its deficit. The country has also introduced value-added tax, cut in government spending, reduction in electricity and oil price subsidy and several other policy reforms aimed at achieving Vision 2030 of diversifying the economy from been oil-reliant to non-oil reliant by privatizing government establishments, encouraging foreign and domestic investors, increasing employment opportunity in the private sector, boosting the entertainment industry and many other reforms.

According to BP (2018), Saudi Arabian demand for primary energy has increased by 5.5% per year since 1970, with oil demand and non-oil energy demand increased by 4.6% and 9.6%, respectively, so has the greenhouse emission increased as well. To be able to reduce the CO2 and GHG emissions, the country has embarked on Vision 2030 aimed at economic diversification away from oil and gas by investing in other sectors, such as entertainment, education, and health. Over the years, the country has relied heavily on resource rent majorly from oil and gas for growth and development. To achieve the kingdom's Paris agreement of reduction of up to 130 million metric tonnes of carbon dioxide equivalent by 2030, the country aimed to sort for an alternative source of revenue and growth. On the premise of the above highlights, the present study explores the outlined variables in the context of Saudi Arabia which has received less documentation in the extant literature for onward policy prescription in oil-exporting countries, especially in terms of global consciousness for environmental sustainability.

This study is organized into four sections. Section two reviews the literature. Section three presents the methodology and data. Section four presents the results and discussion and Section five presents the summary of findings and policy recommendation.

2. Literature review

The area of environmental pollution, energy consumption and economic growth has been vastly investigated and reported in the literature and two schools of thought have emerged from these studies- Environment Kuznets curve (EKC hypothesis) built on Kuznets (1955) work and suggesting an inverted U-shaped curve when pollution is plotted against per capita income. Dasgupta, Laplante, Wang, and Wheeler (2002) reported that, at the initial stage of industrialization, people are more concerned with jobs and income than clean environment; therefore, pollution grows rapidly. In the second stage of industrialization, intense pressure is put on the environment due to economic growth and people are still too poor to pay for reduction or removal of environmental pollutants; therefore, their consequences have been ignored. The final stage of industrialization is characterized with people more concerned about the environment and willing to establish rules and regulations aimed at reducing or cutback environmental pollution. The EKC hypothesis identified the relationship between economic activities and environmental pollution. For instance, Khan and Ozturk (2021) carried out a panel study comprise of selected 88 developing countries with a view ascertain the validity of the direct and indirect effect of financial development on environmental quality. The finding from the study revealed the pollution inherent nature of financial development in the understudied area. The outcome further confirmed the two major hypothesis – the EKC hypothesis and the pollution heaven hypothesis in those countries. While population size is revealed to be the promoter of pollution emission, human capital on the othe hand discourage CO_2 emission. Gyamfi, Bein, Udemba & Bekun (2021) examined the pollution heaven hypothesis for the oil and none-oil economies in the sub-saharan African. The result affirms the existing of the said hypothesis for the economies of the region implies that FDI inflow into the region poses danger to the quality of the environment in line with the work of Gyamfi et al. (2021). Rehman, Ma & Ozturk (2021) found an inverse relationship between economic growth and C02 emission implying that the former is an emitter in Pakistan. Nathaniel, Yalçiner & Bekun (2021) found the detrimental effect of economic growth and the natural resources on the quality of environment, similar to the work of Ahmad et al. (2021). Joshua Bekun and Sarkodie et al. (2020) found thst coal consumption is the main emitter in South Africa followed by economic growth. Joshua and Alola (2020) examine the relationship between coal usage, economic growth and carbon emission in South Africa. The result revealed that coal consumption is the major emitter in the economy, while FDI inflow discourages CO_2. Öztürk, Bekun, Baloch and Khan (2020) examine the relationship between financial development and environmental quality in the organization for economic cooperation and development (OECD) economies. The finding revealed that the financial development improve energy innovation and environmental quality. Al-Mulali and Ozturk (2015) investigated the cause root of environmental degradation in the Middle East and North Africa (MENA) region consist of 14 economies by adopting the Pedroni cointegration test and the fully modified ordinary least square method. The result from the test indicates that the variables of interest cointegrated while the energy consumption, urbanization, trade openness, industrial development reduce environmental quality in the long run. However, political stability serves as an agent that promote environmental quality. For Tunisia, Fodha and Zaghdoud (2010) examined the existence of EKC hypothesis between economic growth and pollutants (CO_2 and SO_2) for the period 1961–2004. Findings from this study established that an inverted U relationship exists between SO2 and GDP while there is a monotonically increasing relationship between GDP and CO_2 emissions. For the, Middle East and North African (MENA) region over the period 1981–2005, Arouri, Youssef, M'henni, and Rault (2012) investigated the relationship between CO2 and economic growth and their findings posit the existence of long-run CO_2- EKC for all the 12 MENA countries; the turning points are not the same across countries for some very low and very high in other cases; therefore, providing a poor support of the EKC hypothesis at the country level. Also, Ozcan (2013) tested the presence of EKC hypothesis for 12 Middle East countries during the period 1990–2008; findings from this study provide favorable evidence for the U-shaped EKC for five countries, inverted U-shaped for three countries and no causal link between economic growth and CO_2 emission for four countries. Alola and Joshua (2020) found that fossil fuel consumption poses danger to environmental quality while energy consumption improve environmental quality.

Similarly, Al-Rawashdeh, Jaradat, and Al-Shboul (2014) examined EKC relationship between economic growth and two environmental pollutants (SO2 and CO2); at a country level, findings from this study revealed SO2-EKC exists for Yemen, Morocco, Turkey, and Jordan while U-inverted CO2 relationship exists for Tunisia, Morocco, Turkey and Jordan; as a panel study, the findings revealed no EKC evidence for both SO2 and CO2 emissions, but a monotonically linear positive relationship between income and CO2 emissions.

Also, Farhani, Mrizak, Chaibi, and Rault (2014) verified the existence of the EKC hypothesis for the MENA region, including Saudi Arabia, and their findings validate the existence of this hypothesis at the panel level and it disappears at the country specific level, establishing a monotonical positive effect of income on CO2 emissions for Saudi Arabia as well as an adverse positive effects of energy consumption.

Charfeddine and Mrabet (2017) reexamined EKC hypothesis for 15 MENA countries using ecological footprint as a proxy for environmental degradation over the period 1975–2005; findings from this study validated the hypothesis (inverted U-shaped) for oil-exporting countries, while for non-oil-exporting countries the relationship is U-shaped. Similarly, Abdallh and Abugamos (2017), investigated the EKC hypothesis for 20 MENA countries using data set spanning 34 years (1980–2014); findings from this study also validate the existence of this hypothesis within this region, suggesting that, alongside economic growth, environmental degradation may be reversible and environmental quality recoverable within the region. Furthermore, using balanced panel data method, Gorus and Aslan (2019) examined the EKC and pollution haven hypothesis (PHH) for MENA countries for the period 1980–2013 and found partial support for these hypotheses within the region and also found that foreign direct investment and energy use has increased pollution in most of the MENA countries. On the contrary, in a more recent study using non parametric approach for data on the MENA region for the period 1980–2010, Fakih and Marrouch (2019) found the EKC hypothesis is not substantiated within this region and the paper provides cautionary notes against the use of parametric models to establish policy implications about tradeoffs between economic growth and the quality of the environment.

For Saudi Arabia, Samargandi (2017) examined the EKC hypothesis and found a linear relationship between income and carbon dioxide emissions. Also, Mahmood, Alraheed, and Furqan (2018) and Mahmood et al. (2019) established the EKC hypothesis holds within the country and the country is at the first phase of EKC, in which asymmetric effects of financial market development on CO2 and agriculture sector on CO2 emissions were reported.

The second area of research is focused on the relationship between energy consumption and economic growth. This link was first established by the work of Kraft and Kraft (1978), for the United States; they found a monotonically increasing relationship between economic growth and energy. Studies from other countries have revealed conflicting results. Al-Mulali (2011) examined the impact of oil consumption on economic growth for MENA countries during the period 1980–2009 and established that CO2 emissions and oil consumption both have a long-run relationship with economic growth, also a bidirectional Granger causality between CO2, oil consumption and economic growth exists. Omri (2013) examined the nexus between CO2 emissions, energy consumption and economic growth within 14 MENA countries using panel data over the period 1990–2011. Results from the study for the whole region revealed a bidirectional relationship between energy consumption and economic growth, a unidirectional causality without feedback effect from energy consumption to CO2 emission and bidirectional relationship between economic growth and CO2 emission.

Also, Farhani (2013) investigated the relationship between renewable energy consumption, economic growth and CO2 emissions for 12 MENA countries using panel cointegration technique for data period 1975–2008. Findings from this study revealed no causal relationship in the short-run, but a long-run unidirectional causality running from economic growth CO2 emissions to renewable energy consumption; with fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) estimates, only CO_2 has an impact of renewable energy consumption. The result from this study indicates that MENA countries currently do not have the best policy options that can consider renewable energy consumption, stable economic growth and, at the same time, mitigate emission of pollutants.

For the GCC region, Salahuddin and Gow (2014) examined the empirical relationship between economic growth, energy consumption and carbon dioxide emission. Results from the study established that GCC countries are still the main CO_2 contributors with both a short-run and long-run positive significant link between energy consumption and CO_2 emissions, as well as energy consumption and economic growth. No significant relationship is established between economic growth and CO_2 emissions, with both absolute and relative decoupling occurring in all GCC countries except for Saudi Arabia for the period studied.

Also, Salahuddin, Gow, and Ozturk (2015) investigated the relationship between carbon dioxide emissions, economic growth, electricity consumption and financial development in the GCC countries using panel data for the period 1980–2012. Using FMOLS, DOLS and dynamic fixed effect (DFE) models, the study established that a robust long-run relationship and no short-run relationship exist across the different econometric models. Economic growth and electricity consumption both have positive long-run relationship while financial development has negative relationship with CO2 emissions. The Granger causality test implied a bidirectional link between economic growth and CO2 emissions, and unidirectional causal link from electricity consumption and CO2 emissions, although no causal link between financial development and CO2 emissions.

Using panel VAR technique to explore the nexus between carbon dioxide emissions, economic growth and energy use for 10 Middle East countries over the period 1971–2006, Magazzino (2016) established a negative VAR response from economic growth to CO_2 emissions for six GCC countries and, instead, CO_2 emission is driven by both its own past values and energy consumption, implying the existence of growth hypothesis. For the other four non-GCC countries, neither CO2 emissions nor energy consumption seems to impact economic growth, implying empirical support for the neutrality hypothesis.

Furthermore, using the dynamic simultaneous equation model, Bekhet et al. (2017) explored the dynamic causal relationships among carbon emissions, financial development, economic growth, and energy consumption for GCC countries for the period 1980–2011. Findings from this study revealed the existence of long-run and causal relationships among all variables considered for all GCC countries with the exception of the United Arab Emirates Also, for Saudi Arabia, United Arab Emirates and Qatar a long-run unidirectional causality flow from carbon emissions to energy use was found.

Magazzino and Cerulli (2019), using responsive score (RS), examined the relationship between CO2 emissions, GDP and energy within MENA region using data over the period 1971–2013; the study submits that GDP per capita and energy consumption both show positive responsive score while trade and urban population show negative scores. GCC countries showed a moderately heterogeneous responsive score over factors, with larger variability occurring with response to urban population GDP.

Muhammad (2019) investigated the effect of economic growth, energy consumption and CO2 emissions on each other within 68 countries for the period 2001–2017; these countries include developed, emerging and MENA countries. The findings from the study submit that economic growth increased with increase in energy consumption for developed and emerging countries and decreased for MENA countries; for all countries, CO2 emissions increased due to increase in energy consumption. Energy consumption increased in all countries, but economic growth increased in all countries except MENA countries due to CO2 emissions. Due to economic growth, for developed and MENA countries, CO2 emissions increased while the energy consumption decreased; in contrast energy consumption increased, and CO2 emissions decreased in emerging countries.

Using panel vector autoregressive model, Kahia et al. (2019) examined the impact of renewable energy consumption, economic growth, foreign direct investment inflows and trade on carbon dioxide emission within 12 MENA countries over the period 1980–2012. The study revealed a bidirectional causality relationship between the variables, supporting feedback hypothesis within the studied countries. With economic growth leading to environmental degradation, while renewable energy, foreign direct investment inflows and international trade lead to decreased carbon dioxide emissions, the study submits that these countries should move toward renewable energy, international trade and foreign direct investment to achieve sustainable economic growth and improved environmental quality.

For Saudi Arabia, Raggad (2018) examined the determinants of pollutant emissions and found income and energy use both have positive effect on CO2 emissions. Mahmood, Alkhateeb, and Furqan (2020) investigated the effects of non-oil income per capita, the oil sector income share urbanization and gasoline prices of CO2 emissions per capita for data period 1970–2014 and found a long-run relationship.

Although, the aforementioned studies of Samargandi (2017), Raggad (2018), Mahmood et al. (2019; Mahmood et al., 2020) all tried to explore the different dynamics in the relationship of CO2 and economic growth indicators for Saudi Arabia, there is a dearth of literature on the dynamic relationship between CO2, energy consumption, oil rent, GDPC and total natural resources rent in oil rich country. This study differs from the aforementioned papers by examining causality flow; using Toda Yamamoto causality test, this study will establish the direction of flow between all the variables examined. The significance of this study cannot be ignored and will guide policy makers on the determinants of CO_2 emission in Saudi Arabia. Also, it provides policy recommendation in overcoming the problem of emission within the oil and gas-reliant economy while targeting stable economic growth and preventing potential loss of future resource rent and GDP.

3. Econometric and data and procedures

The aim of this study is to examine the dynamic link between CO_2, energy consumption, oil rent, GDPC and total natural resources rent in oil-rich Saudi Arabia. The World Bank data indicators database serves as the source from where this study extracted the relevant time series data for the purpose of estimation and to investigate the said hypothesis from 1971 to 2016. The series to be under study includes real GDP, which stands for economic advancement (constant 2010, US$), total natural resource rent (%GDP) in US dollars, energy consumption (Mtoe), CO_2 in (Kt) emissions and oil rent.[2] For the purpose of obtaining the growth effect, the series were all transformed into natural log value.

3.1. Stationarity tests

Traditionally, it has been established that the trends of most macroeconomic or aggregate series are not stable at their level form (Gujarati, 2009) and equally supported by empirical work of Joshua et al. (2020) Joshua, Adewale & Uzomba (2021). This suggest that a first differencing must be applied to those variables which failed to achieve stationarity at level in order to determine their level of integration. It is imperative to state that achieving the stationarity of the series is critical in econometric procedures because it serves as a guide to the choice of the approach to be adopted for the major estimations. Failure to determine the level of stationarity of the variables could lead to wrong choice of method, thereby producing a misleading outcome and policy direction. In view of the above, this study depends on the traditional method (ADF&PP) to carry out the unit root tests, which indicates a mixed order of integration and, therefore, is informed of the dynamic ARDL approach.

The generalized equation is expressed as follows:

$$\Delta Y_t = \beta_1 + \beta_2 + \delta Y_{t-1} + \sum_{i=1}^{m} \alpha_i \Delta Y_{t-i} + \varepsilon_t \tag{1}$$

Where, Gaussian white noise that is assumed to have a mean value of zero is represented byε_t, and possible autocorrelation represents series to be regressed on the time t.

3.2. ARDL bounds testing to cointegration

There are many ways of achieving cointegration between series. However, ARDL is mostly preferred to the other methods because it is more flexible and dynamic in nature. ARDL, as developed by Pesaran et al. (2001) allows for the incorporation of the same or mixed order of integration. For instance, the method is applicable in either I (1)/I (0) or I (1)/I (1) as the case may be. Note that ADRL cannot be applied to the case of I (2). One of the advantages of ARDL over the traditional method is the ability to simultaneously estimate both the short and the long-range output for the relationship between the series. The method is in one part adopted to determine whether long-range co-movement exists between the series.

The generalized equation is stated as follows:

$$\Delta Z = \varepsilon_0 + \varepsilon_1 t + \lambda_1 \delta_{t-1} + \sum_{i-1}^{k} \varphi_1 \nu_{it-1} + \sum_{j-1}^{n} \phi_j \Delta Z_{t-j} + \sum_{i-1}^{k} \sum_{j-1}^{n} \omega_{ij} \Delta V_{it-j} + \Upsilon D_t + \mu_t \tag{2}$$

$$H_0: \ \phi_1 = \ \phi_2 = \dots \ = \ \phi_{n+2} = 0$$
$$H_1: \ \phi_1 \neq \ \phi_2 \neq \dots \ \neq \ \phi_{n+2} \neq \ 0$$

where the rejection of H_0 indicates a proof that the series converged in the long run to correct any initial short run disturbance.

4. Empirical results and discussion

This section focuses on the interpretation of the study's empirical results. We started with a basic summary that comprises of measure of central tendencies and dispersion of the outlined variables in Section 3. Table 2 shows that, over the sampled period, CO_2 emissions ranked with the highest average followed by GDP growth with oil rent the lowest average. This suggests that pollutant emission is on the rise in Saudi Arabia. Coincidently, CO_2 emissions hold the highest maximum. In terms of symmetry, all series exhibit negative skewness except for economic growth, while energy consumption, oil rent, and total natural resources rent report heavy tail with peakedness of greater than 3. Furthermore, in Table 3 the Pearson correlation matrix presenting the pairwise relationship among the highlighted variables is explored. We observed a significant and positive relationship between energy consumption from fossil fuel-based and CO_2 emissions, which tells a lot about the nature of Saudi Arabia's energy mix. A similar positive relationship is also seen between GDP growth and CO_2 emissions and total natural resources rent and CO_2 emissions. However, correlation analysis

[2] The entire data span is constrained by the availability of data for CO_2 alongside other indicators. For balance data all series are limited to 2016.

Table 1
Shows Saudi Arabia's benchmark against the first 10 highest CO_2 emitter countries in terms of population and economy for the year 2020.

Country	2020 Population	2020 GDP (Constant US$ 2010 Billion)	2020 CO2 Emissions (Million tons)	2018 GHG Emissions (kt of CO2eq)	Average Annual Growth of GHG emissions since 1970
China	1402112000	11785.00	9899.3	12355240	4.31%
United States	329484123	17709.43	4457.2	6023620	0.30%
India	1380004385	2706.60	2302.3	3374990	3%
Russia	144104080	1726.66	1482.2	2543400	0.6%
Japan	125836021	6187.01*	1027.0	1186770	0.7%
Germany	83240525	3751.24	604.9	806090	−0.75%
Iran	83992953	499.22	678.2	828280	2.96%
South Korea	51780579	1468.56	577.8	41910	4.61%
Saudi Arabia	34813867	675.04	570.8	638120	3.83%
Canada	38005238	1847.70	517.7	724930	1.04%

Note: * 2019 data are World Bank.[11].
Source: Crippa et al. (2019), World Bank and BP, 2020

the outlined variables. This is evident by the F-statistics being greater than both boundaries at 5% statistically significant level, thus, suggesting convergence between the variables over the sampled period. This indicates a relationship in the long term among these variables for ample policy framework in Saudi Arabia

To explore the impact and magnitude of the long-run relationship between the variables, the ARDL short and long-run regression is estimated as reported in Table 5. The long-run relationship is validated by the error correction term that shows 31.1% speed of convergence on an annual basis with the contribution of energy consumption, oil rent economic growth and total natural resources rent over the examined period at 1% statistical rejection level. In the short and long-run, we observe a statistically significant relationship between economic growth and CO_2 emissions, wherein a 1% increase in economic activities increases and depletes the environment as it increases CO_2 emissions level by 0.953% and 0.625% in both the short and long-run period, respectively. Thus, it is suggestive that increase in human activities that increase economic growth depletes the quality of the environment. This outcome is consistent with the study of Bekun et al. (2019) for the case of selected European Union countries and of Shahbaz et al. (2015) in Pakistan. However, the outcomes have policy implications in Saudi Arabia. This poses a dilemma whereby there is constant pressure for increased economic growth and improved living standard of the citizenry, but the mentioned economic trajectory comes with inherent environmental costs/implications. Thus, there is need for caution in managing economic activities without compromise for economic growth. There is a positive relationship between energy consumption and CO_2 emissions, that is, an increase in energy consumption increases CO_2 emissions level. Thus, this suggests that the energy mix is made of several bundles of energy options. The current energy mix in Saudi Arabia induces CO_2 emissions, which necessitates the need for a shift to cleaner energy option as reduced energy will hurt economic growth, as we see clearly from the TY causality, which will be discussed extensively in a later section that energy drives economic growth. That is, the adoption of energy conservation strategies will jeopardize economic growth. This is in line with Saudi Arabia's eight development ambitions for suitable economic growth in the region (Bashehab, 2013). This outcome resonates with the outcome and crusade of the United Nations Sustainable Development Goals (UN-SDG), precisely UN-SDG goals 7,8, 12 and 13 which highlight access to clean, responsible energy consumption and mitigation of climate change challenges in compliance with universal global practice, thus necessitating the need for renewable energy in Saudi Arabia's energy mix in order to achieve a clean environment (Al-Mulali and Ozturk, 2016; Sarkodie et al., 2020). This study also observed that exploration of natural resources in Saudi Arabia, like oil and other natural endowments, dampens the quality of the environment. Furthermore, a significant positive nexus is seen between the country's natural resource rent and CO_2 emissions in both the short and long run. This suggests the over-reliance on natural resource rent affects

Table 2
Basic summary statistics of outlined variables under review.

	$LNCO_2$	LNEC	LNOR	LNGDPC	LNTNRRET
Mean	12.33048	8.203162	3.185436	9.995809	3.197426
Median	12.30723	8.394913	3.443638	9.868219	3.453651
Maximum	13.30643	8.844658	4.347006	10.57453	4.348568
Minimum	10.99891	6.885119	−1.895370	9.655587	−1.887109
Std. Dev.	0.589153	0.558775	1.260007	0.285771	1.261398
Skewness	−0.293896	−1.212567	−3.116656	0.998243	−3.118940
Kurtosis	2.371306	3.256082	11.95565	2.471940	11.96113
Jarque-Bera	1.358051	10.90257	218.2729	7.818810	218.5571
Sum	542.5409	360.9391	140.1592	439.8156	140.6868
Sum Sq. Dev.	14.92534	13.42588	68.26758	3.511608	68.41832
Observations	46	46	46	46	46

Source: Authors' computation based on WDI dataset

Table 3
Pearson correlation analysis.

Observations	CO_2	EC	OR	GDPC	TNRRENT
CO_2	1.000				
EC	0.912***	1.000			
OR	0.388***	0.328**	1.000		
GDPC	0.505***	−0.689***	0.215	1.000	
TNRRENT	0.406**	0.344**	0.999***	0.202	1.000

Note: ***,** and * represent 1, 5 and 10% rejection level, respectively.
Source: Authors' computation based on WDI dataset

is not sufficient to arrive at a consensus in empirical literature. Thus, this study proceeds with further econometrics analysis to either refute or confirm the claimed relationship.[3]

Subsequently, this study proceeds to explore the unit root properties or stationarity properties of the outlined variables. This is a necessary condition in econometrics modeling to avoid spurious analysis and, by extension, wrong policy prescription. The unit root properties are presented in Table 4 which shows mixed order of integration. Thus, allowing to explore for a long-run equilibrium relationship between the outlined variables, as reported by the Pesaran Bonds testing method in Table 6. The Bounds test confirms an equilibrium relationship between

[3] For brevity, the graphical display of the variables under investigation can be made available upon request.

Table 4
Stationarity results.

Statistic Level	$LnCO_2$	lnEC	lnOR	lnGDPC	lnTNRRENT
t_T (ADF)	−3.5806**	−3.1547	−4.5494***	−1.9351	−4.5489***
t_μ (ADF)	−1.6278	−1.7505	−5.1225***	−2.3622	−5.1204***
t (ADF)	2.6406	2.3762	−0.3622	−0.5515	−0.3514
t_T (PP)	−3.5806**	−1.6449	−5.5428***	−1.6813	−5.6263***
t_μ (PP)	−1.6950	−1.6776	−6.6678***	−1.4213	−6.6641***
t (PP)	3.4475	1.7794	−0.4876	−0.2748	−0.4774
Statistic First Difference					
t_T (ADF)	−7.0170***	−3.3259*	−5.7695***	−5.0881***	−5.7651***
t_μ (ADF)	−7.0508***	−3.1075**	−5.4838***	−5.0830***	−5.4799***
t (ADF)	−6.1380***	−2.7070***	−5.4217***	−5.1110***	−5.4161***
t_T (PP)	−7.2262***	−5.4199***	−5.7695***	−5.0491***	−5.7651***
t_μ (PP)	−7.2639***	−5.0585***	−5.4758***	−5.0587***	−5.4719***
t (PP)	−6.1330***	−4.4945***	−5.4090***	−5.1257***	−5.4034***

Note: Authors' computation.
Note: ***,** and * represent 1, 5 and 10% rejection level, respectively.

Table 5
ARDL Short and long-run analysis Model: CO_2 = f (EC, OR,GDPC, TNRRENT).

Variables	Coefficient	SE	t-statistic	P-Value
Short-run				
lnEC	0.306***	0.096	3.203	0.002
lnOR	−6.212**	3.508	−1.770	0.085
lnTNRRENT	6.209**	3.514	1.767	0.085
lnGDPC	0.952***	0.206	4.604	0.000
ECT	−0.311***	0.055	−5.687	0.000
Long run				
lnEC	0.983***	0.208	4.706	0.000
lnOR	−19.946**	9.836	−2.027	0.050
lnGDPC	0.625**	0.322	1.944	0.059
lnTNRRENT	19.939**	9.846	2.025	0.050
Diagnostic Tests				
Tests	F-statistic	Prob. Value		
Normality test	1.111	0.574		
χ^2 *SERIAL*	0.573	0.569	F (2,34)	
χ^2 *WHITE*	1.485	0.211	F (6,36)	
χ^2 *RAMSEY*	1.027	0.318	F (1,35)	
CUSUM Stable				
CUSUM sq stable				

Note: ***,** and * represent 1, 5 and 10% rejection level, respectively.

Table 6
ARDL Bounds test.

Test stat.	Value	K
F-stat	4.734**	4
Critical Value Bounds		
significance	I (0) Bounds	I (1) Bounds
10%	2.402	3.345
5%	2.85	3.905
1%	3.892	5.173

Note: Authors' Computation.
Note: significance at ***0.01, **0.05 and 0.1 denotes 1, 5 and 10% rejection level, respectively.

environmental sustainability in Saudi Arabia if conservation management options are neglected. Interestingly, oil rent energy was found to improve environmental quality in Saud Arabia. This is evident as a 1% increase in oil energy rent decreases CO_2 emissions level. The plausible explanation is tied to the fact that emission from oil in Saudi Arabia is low, relative to other energy sources like coal that emits high pollutant. Also, the possible explanation for this nature of relationship between oil rent and CO_2 emissions is the sensitivity of the oil-exporting country to upholding global international environmental protocol to sustain the environment. Oil rent resulting in emission mitigation implies that the oil resources of the country are likely to be employed to diversify the energy sector and portfolio amidst the adoption of other environmental sustainability policies, thus, implying the nature of Saudi Arabia's oil texture and environmental sustainability. Furthermore, the plausible explanation is attributed to the country's consciousness for a clean and sustainable energy mix in the last decade, especially the recent Saudi Arabia 8th Economic Agenda.

The causality analysis is rendered in Table 7 our study relied on the modified Wald test rather than conventional Granger causality which provides inconsistent results. The need for causality analysis is pertinent for predictability of each variable on another for ample policy prescription. In Table 7 a feedback relationship is seen between economic

Table 7
TY (modified Wald) causality analysis.

Excluded	Chi-sq	P-Value
Dependent variable: $lnCO_2$		
lnEC	10.65090***	0.0049
lnOR	4.880997*	0.0871
lnGDPC	6.800620**	0.0334
lnTNRRENT	4.901024*	0.0862
All	14.37675*	0.0725
Dependent variable: lnEC		
$lnCO_2$	0.564193	0.7542
lnOR	1.560724	0.4582
lnGDPC	11.74229***	0.0028
lnTNRRENT	1.607806	0.4476
All	35.26041***	0.0000
Dependent variable: lnOR		
$lnCO_2$	1.227656	0.5413
lnEC	2.719543	0.2567
lnGDPC	3.162035	0.2058
lnTNRRENT	2.511339	0.2849
All	61.10050***	0.0000
Dependent variable: lnGDPC		
$lnCO_2$	2.754807	0.2522
lnEC	11.63010***	0.0030
lnOR	4.704881***	0.0951
lnTNRRENT	4.693165*	0.0957
All	30.81365***	0.0002
Dependent variable: lnTNRRET		
$lnCO_2$	1.07E-08	1.0000
lnEC	1.29E-07	1.0000
lnOR	3.76E-07	1.0000
lnGDPC	1.50E-07	1.0000
All	9.51E-07	1.0000

Note: significance at ***0.01, **0.05 and 0.1 denotes 1, 5 and 10% rejection level, respectively.

[1] Table 1 was updated, however due to availability of data till date especially sixth column.

growth and energy consumption in Saudi Arabia. This implies that each energy drives economic growth, and vice versa. This result is consistent with the study of Emir and Bekun (2019) in Romania. However, the energy-induced growth is fossil fuel-driven, which has a detrimental effect on the environment, which is a tradeoff between energy consumption and CO_2 emission with one-way causality (Shafiei and Salim, 2014; Shahbaz et al., 2015). Additionally, we also observed that oil rent shows significant traits to have predictability power on economic growth. This result resonates with the finding of Banafea (2014). This result is contrary to the finding of Ozturk (2017), where oil rent failed to advance economic development in a panel of Latin American economies. Similarly, total natural resources rent are used to predict economic growth in a one-way causality. These outcomes show that total natural resource rents are key growth drivers in Saudi Arabia. This reflects the current position of the country and the study of Balsalobre-Lorente et al. (2019). Oil rent, GDP and total natural resources rent all show unidirectional causality to CO_2 emission in Saudi Arabia. This reflects the position that more is required as the country strides toward its environmental sustainability target.

5. Conclusion and policy implication

This study focuses on Saudi Arabia, a leading oil-exporting nation, with critical emphasis on its energy consumption, total natural resources, economic and CO_2 emissions, acknowledging global awareness for environmental sustainability. The unanswered question is whether Saudi Arabia's chase for environmental sustainability is a myth or a reality given the recent global oil glut, energy demand pressure, and dwindling energy supply of record all time. This investigation is conducted between the recent period from 1971 to 2016. The empirical investigation shows long-run convergence from all outlined variables, suggesting a somewhat connection between the variables. Thus, ample macro policies can be gleaned from such a relationship.

Further empirical results show a long-run relationship between economic growth and CO_2 emissions, which was resonated by the causality analysis which supports both long-run regression. Furthermore, a significant positive nexus is seen between the country's total natural resource rent and CO_2 emissions in both the short and long run. This suggests an overreliance on natural resource rent, which affects environmental sustainability in Saudi Arabia if conservation and management options are neglected.

These results have practical policy implications for government officials in Saudi Arabia and also its macroeconomic decision, as energy conservation is not an option without hurting economic growth. There is a need for caution in policy construction without misleading governmental officials and stakeholders. The energy-induced growth hypothesis, which is from fossil fuels, draws attention to investment in renewable energy options as cleaner alternative sources that are required for a cleaner ecosystem. Oil rent results in emission mitigation, which implies that the oil resources of the country are likely to be employed to diversify the energy sector and portfolio amidst the adoption of other environmental sustainability policies. One pertinent conclusion reached in this study is the need for diversification of Saudi Arabia's energy mix to renewables, especially the global craving for environmental sustainability and curbing of global warming issues in Saudi Arabia. Our study presents a valuable guide for policy makers for the state of Saudi Arabian energy situation.

The current study explored and contributed to the extant literature on the oil-energy-environment nexus for top oil-exporting countries, but there still exists a void left unaddressed as a guide for further study to advance the current literature. Hence, we suggest future studies on the theme with an emphasis on demographic indicators, such as democracy or population, into the carbon-income-oil and environment nexus by applying disaggregated data.

CRediT authorship contribution statement

Mary Oluwatoyin Agboola: Conceptualization, Formal analysis, Methodology, Validation, Visualization, Data curation. **Festus Victor Bekun:** Writing – original draft, Writing, Validation, Visualization, Supervision. **Udi Joshua:** Writing – original draft, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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