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Examining the Energy-Growth Dynamics in Saudi Arabia: Insights and Policy Implications

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ABSTRACT

The empirical relationship between energy consumption and economic growth is complex and varies by country and model specification. This study focuses on Saudi Arabia, one of the largest producers and exporters of crude oil, to explore this relationship. Our analysis refutes the Energy-Kuznets Curve hypothesis for Saudi Arabia, finding neither a linear nor a curvilinear relationship between economic growth and energy consumption. Instead, we observe an asymmetric effect of economic growth on energy consumption: the rate of increase in energy consumption with rising per capita income differs from the rate of decrease when per capita income falls. Additionally, the study shows a positive impact of investment on energy consumption, indicating a dynamic interplay between economic growth, industrial activity, and improved energy access. These findings suggest that energy consumption patterns in Saudi Arabia are intricately linked to economic fluctuations but are not uniformly predictable. Policy recommendations are provided to address these complexities and promote sustainable growth.

Keywords: Energy-Kuznets Curve, Energy Consumption, Economic Growth, Saudi Arabia, Non-linear Autoregressive Distributed Lag
JEL Classifications: Q43, Q56

1. INTRODUCTION

In the Kingdom of Saudi Arabia, the oil sector is pivotal, contributing approximately 37% to the GDP and 73% to total exports in 2021, with the oil sector valued at 1,021,191 million riyals, GDP at 2,746,242 million riyals, oil exports at 762,416 million riyals, and total exports at 1,035,671 million riyals (SAMA, 2022). The country's economic growth is closely linked to substantial energy consumption (Krane, 2019), making it the sixth largest oil-consuming economy (Raggad, 2020). Factors such as hot climatic conditions and low energy prices further amplify energy consumption. Studies describe electricity consumption patterns as "non-rational," with the residential sector alone accounting for half of total electricity production, showing a pronounced increase during summers (Alshahrani and Boait 2018; Krane 2019; Brahimi 2019; Al Ghamdi 2020; Raggad 2020).

Saudi Arabia primarily relies on oil for electricity generation, with only 4% of electricity produced from non-oil sources in 2017. The country uses more crude oil for power generation than any other nation, resulting in one of the highest oil consumption rates globally, estimated at about 4% of total global consumption (Ko et al., 2019). This heavy reliance on oil is deemed unsustainable, making sustainability a critical consideration in energy consumption and associated emissions. Ideally, natural resources should be managed to ensure their availability for future generations (Sulphy, 2019).

Sustainable development and addressing climate change are significant priorities in Saudi Arabia's economic policy. Consequently, the government focuses on energy planning and resource preservation. Despite various measures to control energy consumption, the oil-based structure poses an obstacle, with energy consumption increasing faster than GDP. Between 2000 and 2009, Saudi Arabia's growth in energy consumption, energy intensity, and CO_2 intensity exceeded the world average (Saudi Arabia's Energy Efficiency Report, 2011). Structural economic changes and shifts in industrial production contribute to the rapid increase in energy consumption and carbon emissions. Global energy price fluctuations also impact energy consumption levels.

The significant decline in crude oil prices from 2014 to 2016 led to substantial changes in the business practices of oil-exporting countries. The price of Arabian Light crude dropped sharply to $38.2/barrel in 2016. In response, Saudi Arabia increased domestic energy prices in 2015, impacting utilities such as water, gas, transport fuel, and electricity tariffs (Lahn, 2016; Matar and Anwer, 2017; Al Dubyan and Gasim 2019). Additionally, Saudi Arabia implemented a value-added tax system starting January 1, 2018, and declared a major structural transformation program in 2017. Vision 2030 aims to reduce oil dependence, with plans to shift 10% of energy consumption to non-oil sources and boost electricity generation from these sources (Alghamdi, 2019).

Energy, its price and consumption are very much related with income levels (Haque, 2021). Given Saudi Arabia's reliance on energy-intensive production and high domestic energy consumption, this study estimates the relationship between energy consumption and economic growth. The significance lies in the lack of recent research, particularly up to 2021, amid oil price volatility post-2014 and the impacts of COVID-19 lockdowns. The revision of energy prices since 2015, under Vision 2030, seems to have altered energy consumption patterns. As an energy-exporting country focused on petrochemicals, Saudi Arabia is now diversifying its industries, making it crucial to re-evaluate the energy consumption-economic growth relationship.

This study hypothesizes a curvilinear relationship between economic growth and energy consumption. Initially, energy consumption may increase with economic growth due to higher industrial activity and household consumption, but beyond a certain threshold, awareness of energy conservation may lead to optimized energy use. This quadratic relationship, theoretically referred to as the Energy-Kuznets Curve, suggests an inverted U-shape. Extensively studied by Luzzati and Orsini (2009), Galeotti et al. (2016), Pablo-Romero and De Jesús (2016), Aruga (2019), Mahmood et al. (2021), and Moosa and Burns (2022), the novelty of this study lies in incorporating a cubic term to explore a potential N-shaped relationship and assess the asymmetric impact of economic growth changes on energy consumption, particularly for Saudi Arabia.

2. REVIEW OF LITERATURE

Mehrara (2007) explored the causal dynamics between GDP per capita and energy consumption per capita in 11 oil-exporting nations from 1971 to 2002. Utilizing a panel co-integration model, the results revealed a unidirectional causality from GDP to energy consumption, with no feedback effects. Economic growth and increased energy usage were attributed to extensive energy consumption subsidies, leading to recommendations for energy price reforms to encourage conservation and substitution, while cautioning about potential impacts on various population segments. Sadorsky (2011) analyzed the impact of trade on energy consumption in eight Middle East income countries from 1980 to 2007. Granger causality tests indicated that export promotion policies might affect energy demand, while energy conservation did not accelerate exports in the short run. The study found bidirectional feedback between energy consumption and imports and a positive links between income and energy consumption, suggesting that reductions in energy consumption could adversely affect income and GDP. Dehnavi and Haghnejad (2012) examined the causal links between energy consumption, pollution, and economic growth in eight OPEC countries, including Saudi Arabia, over the period 1971-2008. Their analysis indicated a long-term equilibrium and bidirectional causality among economic growth, energy consumption, and pollution. Short-term unidirectional causality was observed from economic growth to carbon dioxide emissions and from energy consumption to economic growth. The study rejected the inverted U-shaped Environmental Kuznets Curve (EKC) hypothesis but identified a cubic relationship of economic growth with carbon dioxide emissions, highlighting the importance of policies for energy management and efficient usage for sustainable development.

Alkhathlan and Javid (2013) investigated the interplay between economic growth, energy consumption, and carbon dioxide emissions in Saudi Arabia from 1980 to 2011. Their findings confirmed a positive correlation between per capita carbon emissions and per capita income, thereby rejecting the Environmental Kuznets Curve hypothesis for Saudi Arabia. The study recommended stringent environmental regulations for sustainable development and suggested that shifting from oil to gas could mitigate environmental degradation. Farhani et al. (2013) investigated the relationship between pollution emissions, income, energy consumption, trade openness, and urbanization in MENA countries from 1980 to 2009. The analysis revealed that increases in energy consumption and trade openness elevated carbon dioxide emissions, with energy consumption having a greater impact. The study validated the EKC hypothesis and noted that higher income levels were associated with less environmental degradation. Salahuddin and Gow (2014) analyzed the empirical relationship between carbon dioxide emissions, energy consumption, and economic growth in GCC countries from 1980 to 2012. Using Pedroni cointegration tests, they found a positive but insignificant long-term association between per capita GDP and carbon dioxide emissions, while energy consumption had a significant positive impact on emissions. The study did not establish a causal link between emissions and economic growth but noted that Qatar and Saudi Arabia were leading in reducing carbon dioxide emissions among GCC countries.

Alshehry and Belloumi (2015) employed the Johansen co-integration approach to explore the dynamic causal relationship between energy prices, energy consumption, and economic activity in Saudi Arabia. Their results indicated a long-term relationship among these variables, confirming the validity of energy-led growth for Saudi Arabia. They found that low energy prices led to overuse and significant carbon dioxide emissions, suggesting that policies to reduce energy consumption and control emissions may not significantly hinder economic growth. Magazzino (2016) investigated the relationship between real GDP, energy use, and carbon dioxide emissions in the GCC countries from 1960 to 2013. Co-integration tests indicated a long-term relationship among these variables for Saudi Arabia. The study supported previous findings that real GDP has a causal relationship with energy use and suggested that a decline in energy consumption might negatively impact economic growth, underscoring the need for energy conservation policies.

Raggad (2018) analyzed the long-term relationship of economic growth with carbon dioxide emissions, urbanization, and energy use in Saudi Arabia from 1971 to 2014 using the ARDL approach. The study found a long-term cointegration among these variables and rejected the Environmental Kuznets Curve hypothesis for Saudi Arabia, noting a consistently positive relationship between economic growth and carbon dioxide emissions. The study observed that increasing domestic demand for oil deteriorated environmental quality, while urbanization contributed to reducing CO_2 emissions, though caution was advised regarding future impacts due to population growth. Altaee and Al-Jafari (2018) assessed the impact of exports, imports, energy consumption, and capital on economic growth in GCC countries from 1992 to 2014 using panel data methods. They found that exports were the leading contributor to economic growth, followed by energy utilization and gross capital formation, while imports had a negative impact. The study supported export-led growth and emphasized the need for energy usage optimization and increased capital formation

Sayed and Alayis (2019) explored the relationship of GDP with energy consumption in Saudi Arabia from 1970 to 2014 using the Granger Causality test. Their findings supported the Kuznets energy consumption theory, revealing a strong relationship between energy consumption and economic growth. The study suggested focusing on increased investment in the energy sector to meet the growing demand driven by Vision 2030. Abul et al. (2019) examined the link between energy consumption and economic growth in GCC countries from 1980 to 2014 using panel-VAR methodology. The study identified a significantly positive relationship between energy intensity and economic growth, while energy intensity had a negative association with CO_2 emissions and GDP. The study did not find evidence of a causal relationship between ener20gy consumption and economic growth but highlighted the need for actions to control CO_2 emissions. Mahmood et al. (2019) studied the impact of energy consumption and economic growth on carbon dioxide emissions in Saudi Arabia from 1968 to 2014 using the ARDL co-integration test. The results confirmed both short-term and long-term effects of energy consumption and economic growth on CO_2 emissions, indicating a positive association and suggesting that economic growth accelerates energy utilization, significantly contributing to pollution.

Almutairi (2020) in his study shifted the focus from the typical examination of oil-importing countries to explore how oil price shocks affected economic growth and unemployment in an oil-exporting country—specifically, Saudi Arabia. Using a bivariate structural VAR model, the study analyzed the dynamic effects of supply and demand disturbances on these macroeconomic variables. The results revealed that oil price shocks significantly influenced fluctuations in both economic growth and unemployment in Saudi Arabia, with supply disturbances having a lasting impact on economic growth and demand disturbances playing a more prominent role in the long term. Additionally, the analysis showed that positive oil price shocks reduced unemployment, and that most fluctuations in unemployment were attributable to these shocks. The findings highlighted the challenges posed by the inherent volatility of oil prices, which, despite benefiting the economy in the short term, posed a threat to long-term sustainable growth. This underscored the need for Saudi Arabia to implement macro-prudential policies, such as liquidity and capital buffers, and to consider diversifying its economy to reduce reliance on oil. Moreover, the study suggested that Saudi Arabia should contemplate adopting a flexible exchange rate regime to better manage external shocks. The research also pointed out the significant impact of credit shocks on economic growth, emphasizing the importance of considering other factors beyond oil in economic policymaking. Finally, the study called for further theoretical exploration of how oil price shocks affected economic activities in oil-exporting countries, a topic that had received less attention in comparison to oil-importing countries.

Algarini (2020) investigated the causal relationships between economic growth, energy consumption, CO_2 emissions, and energy production in Saudi Arabia from 1990 to 2017. Utilizing vector autoregressive (VAR) models and Granger causality tests, the research identified bidirectional causality between economic growth and energy consumption, electricity production from gas and carbon dioxide emissions, and economic growth and carbon dioxide emissions. Additionally, unidirectional causality was found where energy consumption and carbon dioxide emissions drove the growth of electricity production from gas, and where growth in electricity production from oil led to increased carbon dioxide emissions. These findings emphasized the critical role of energy consumption in Saudi Arabia's production processes, complementing labor, capital, and land in fostering economic growth. The study suggested that reducing electricity production from oil could effectively lower cardon dioxide emissions without adversely affecting economic growth. To achieve this, policymakers were encouraged to focus on enhancing the efficiency of gas-based electricity production, improve public transportation to reduce reliance on personal vehicles, and consider expanding nuclear power usage to maintain energy consumption while minimizing carbon emissions.

Saqib (2021) explored the causal association between energy consumption and GDP in fourteen MENA countries from 1987 to 2019, using Granger causality approach in VAR framework. The study revealed varied relationships between energy consumption and economic growth across the region. Specifically, some countries showed unidirectional causality, where either energy consumption drove GDP in Tunisia, Iran, and Egypt or GDP drove energy consumption in Saudi Arabia, along with Algeria, Kuwait, Morocco, Qatar, and Turkey). In contrast, Cyprus and Oman exhibited bidirectional causality, while Bahrain and Malta showed no causal relationship. The findings suggested that in certain MENA countries, energy consumption was a key determinant of GDP growth, leading to increased energy demand as the economy expanded. Consequently, the study recommended that the MENA region adopt more robust energy conservation policies to reduce pollution and invest in clean energy alternatives. The research emphasized that while high economic growth could lead to environmental degradation, reducing growth might increase unemployment. Therefore, policies should focus on balancing economic growth with environmental sustainability by promoting energy efficiency, investing in clean energy, and encouraging the adoption of new technologies to minimize pollution. Furthermore, the study advised MENA governments to subsidize the use of advanced technologies and renewable energy sources to promote sustainable energy consumption. It also highlighted that countries rich in natural resources and high pollution emissions might have gained more economic benefits by addressing these challenges.

Mahmood et al. (2021) explored the Energy-Kuznets Curve hypothesis in eight Middle East countries, including Saudi Arabia, from 1975 to 2019, using proxies for oil and natural gas consumption. The study found an inverted U-shaped curve for Iran and Iraq using oil consumption and for Iran, Kuwait, and the UAE using gas consumption. However, the Energy-Kuznets Curve was not valid for Saudi Arabia, Kuwait, Qatar, Oman, and Iraq, depending on the energy source used. The results showed that urbanization had a long-term positive effect on oil consumption in Iraq, Kuwait, Saudi Arabia, and Qatar, and on natural gas consumption in Iraq and Saudi Arabia. This aligned with the theory that urbanization drove up energy demand due to increased consumption of energy-intensive products. Consequently, the study suggested that Middle Eastern governments should have considered controlling urbanization to reduce energy consumption. The study also examined the impact of financial market development (FMD) on energy consumption, finding that it increased oil consumption in Saudi Arabia, likely due to the growth of small and medium enterprises and personal banking, which raised energy demand. Therefore, the study recommended monitoring FMD to ensure sustainable growth. However, FMD did not significantly affect oil consumption in the other six countries or natural gas consumption in any of the countries studied. Based on these findings, the study advised Iraq, Kuwait, Saudi Arabia, and Qatar to control urbanization to reduce oil consumption, and Iraq and Saudi Arabia to do the same for natural gas consumption. It also suggested that Saudi Arabia should regulate financial sector loans to prevent increased oil consumption. The study contributed to the existing literature on the energy-EKC hypothesis by incorporating the role of FMD, a factor not previously explored, and highlighted the need for future research to expand the scope by including more Middle Eastern countries and additional relevant variables.

Elhassan (2021) examined how renewable energy consumption, capital, and labor asymmetrically affected economic growth in Saudi Arabia from 1990 to 2019, using a nonlinear ARDL model. The findings revealed that these factors influenced economic growth in different ways, with positive shocks in renewable energy consumption boosting GDP in the long term, while the impact of labor varied based on the type and timing of the shocks. The paper suggested that Saudi Arabia should prioritize increasing renewable energy consumption by focusing on fixed capital formation and labor, rather than operating expenditures. This strategy supported broader goals of economic transformation, such as reducing fiscal deficits, improving infrastructure, and diversifying the economy. The study also underscored the need for attracting foreign investment, developing infrastructure through public-private partnerships, and maintaining socio-political stability to ensure sustainable economic growth.

Agboola et al. (2021) investigated the long-term and causal relationships between energy consumption, total natural resource rent, oil rent, economic growth, and CO_2 emissions in Saudi Arabia, a leading oil-exporting country. Using data from 1971 to 2016 and employing the Toda-Yamamoto methodology and Pesaran Bounds test, the research found a long-run equilibrium among these variables. The results revealed that increased energy consumption and economic growth contributed to environmental degradation, with a significant positive link between natural resource rent and CO_2 emissions. However, oil rent appeared to mitigate environmental harm. The study also identified a feedback loop between energy consumption and economic growth, and one-way causality from energy consumption and oil rent to CO_2 emissions. These findings suggested that while energy conservation could hinder economic growth, there was an urgent need for Saudi Arabia to diversify its energy mix by incorporating renewable sources to achieve environmental sustainability. The study highlighted the challenges and implications for policymakers, emphasizing the importance of balancing economic growth with environmental protection. Future research was encouraged to explore additional factors, such as demographic indicators, to further understand the carbon-income-oil-environment nexus.

Benlaria and Hamad (2022) investigated the asymmetric effects of renewable energy consumption, capital, and labor on economic growth in Saudi Arabia from 1990 to 2019 using a nonlinear ARDL model. The study found that these factors had an asymmetric relationship with economic growth. Specifically, positive shocks in renewable energy consumption positively impacted GDP in the long run, while labor showed mixed effects depending on the shock type and time frame. The study recommended that Saudi Arabia should focus on increasing renewable energy consumption by emphasizing fixed capital formation and labor, rather than operating expenditures. This shift aligned with broader economic transformation goals, including reducing fiscal deficits, enhancing infrastructure, and transitioning from a rentier to a more diversified economy. The paper also highlighted the importance of attracting foreign investment, improving infrastructure through public-private partnerships, and fostering a stable socio-political environment for sustained economic growth.

Al-Saidi (2022) reported that since 2016, driven by Saudi Arabia's National Vision 2030, the country's energy transition had accelerated, with significant reforms in energy subsidies and rapid developments in the renewable energy sector. This paper offered a comprehensive overview of Saudi Arabia's energy transition, focusing on its drivers, key sectors, targets, and progress. The analysis highlighted achievements in reducing carbon emissions, decreasing energy consumption, and launching ambitious solar energy projects. Energy subsidy reforms provided crucial funding for the transition and increased market participation. Other key areas of progress included low-carbon urban development and energy efficiency improvements in buildings. Additionally, energy-intensive industries, such as petrochemicals and desalination, were increasingly incorporating renewable energy. Overall, the Saudi energy transition made important strides towards sustainability, reflecting significant adjustments in the region's largest economy. The paper emphasized the need for continued environmental awareness and the promotion of sustainable lifestyles to support this transition. Transforming Saudi Arabia's carbon-intensive economy towards greater environmental responsibility could set a powerful example for other carbon-fuel exporting nations.

Daly and Abdouli (2023) investigated the relationship between CO_2 emissions, trade openness, and economic growth in Saudi Arabia from 1990 to 2017 using a VAR model and impulse response functions. The findings revealed a bidirectional causality between CO_2 emissions and economic growth, indicating that as economic growth increased, environmental quality deteriorated, which in turn negatively impacted growth due to its effects on human health. Additionally, the study confirmed the feedback hypothesis between trade openness and CO_2 emissions, suggesting that both were interlinked and influenced each other. A retroaction hypothesis was also identified, showing that while trade openness promoted economic growth, it could simultaneously hinder international trade. The study underscored the need for Saudi Arabia to implement policies that balance economic growth with environmental protection. It recommended encouraging the use of new technologies in production, enforcing strict environmental standards, and promoting waste recycling to reduce pollution without harming economic growth. The findings highlighted that while Saudi Arabia had effective economic policies, its foreign trade policies needed improvement to better support trade liberalization. This study's results aligned with findings from similar research in the BRICTS countries but contrasted with those concerning the BRICS nations.

Derouez et al. (2024) analysed the impacts of renewable and non-renewable energy, along with various other factors like FDI, technological advancement, population, energy price, energy export, and CO_2 emissions, on the economic growth of Saudi Arabia for the period 1990-2022. Using the ARDL and Granger causality method, the research found that both non-renewable and renewable energy positively influenced economic growth. The other factors under study namely, FDI population, energy price, and energy export also positively influenced economic growth, while technological advancement and CO_2 emissions had negative effects. The study identified both ways causality involving economic growth and non-renewable energy. The study also identified both ways causality of economic growth with FDI, energy price and energy exports. The study recommended continued investment in energy diversification and technological advancements. It also highlighted the need for managing energy prices, improving education, and seeking clean energy solutions to mitigate environmental impacts and sustain economic growth.

The existing literature on the energy-growth relationship in oil-exporting countries, including Saudi Arabia, highlights several key findings. Studies have revealed both unidirectional and bidirectional causalities between GDP and energy consumption, with varying implications for energy policy and economic growth. Some research rejected the Environmental Kuznets Curve hypothesis, instead identifying cubic or linear relationships, while others confirmed long-term cointegration among economic growth, energy use, and carbon emissions. Additionally, the impact of energy price reforms, the significance of urbanization, and the need for sustainable energy policies were recurrent themes. Collectively, these studies underscore the complexity of the energy-growth nexus and the necessity for tailored policy interventions to balance economic development with environmental sustainability.

Building on this foundation, our study aims to revisit and re-evaluate the energy-growth relationship specifically for Saudi Arabia, an energy-exporting country, using the most recent data up to 2021. This is particularly important in the context of significant oil price volatility post-2014 and the economic impacts of the COVID-19 pandemic. Furthermore, the study examines the effects of energy price revisions and reforms under Saudi Arabia's Vision 2030, which have likely altered energy consumption patterns. By incorporating both quadratic and cubic terms in the analysis, our study seeks to explore the possibility of both inverted U-shaped and N-shaped relationships, as well as the asymmetric impact of economic growth changes on energy consumption. Understanding these dynamics is essential for forming effective energy policies that promote sustainable growth and reduce environmental impacts.

3. METHODOLOGY

To understand the relationship between energy consumption (EC), gross domestic product per capita (GDPC), gross fixed capital formation (GFCF), and trade openness (TO) the following function is postulated:

$\ln(EC) = f(\ln GDPC, \mathit{lnGFCF}, \mathit{lnTO})$

The data for energy consumption is sourced from BP's Statistical Review of World Energy 2022. In this study, energy consumption is represented by primary energy consumption per capita, measured in gigajoules per capita. The data for GDP per capita (GDPC), gross fixed capital formation (GFCF), and trade openness (TO) is obtained from the World Development Indicators (WDI) database of the World Bank. All data are transformed into logarithmic form prior to analysis. The period of study is 1970-2019. The study emphasizes that time series data often exhibit non-stationarity at their levels, necessitating methodologies beyond Ordinary Least Squares (OLS) for estimating long-run relationships. When time series data consist of a mix of stationary and non-stationary variables, requiring differencing only once to achieve stationarity, the Autoregressive Distributed Lag (ARDL) approach to cointegration, as pioneered by Pesaran et al. (1999a; 2001b), is employed.

The ARDL model is estimated using the following equation:

$$\begin{aligned}\Delta \ln EC_t &= \beta_0 + \beta_1 \ln EC_{t-1} + \beta_2 \ln GDPC_{t-1} + \beta_3 \ln\left(GDPC\right)^2_{t-1} + \\ &\beta_4 \ln\left(GDPC\right)^3_{t-1} + \beta_5 \ln GFCF_{t-1} + \beta_6 \ln TO_{t-1} + \\ &\sum_{i=1}^{p}\varphi_i \Delta \ln EC_{t-i} + \sum_{j=0}^{q}\varphi_j \Delta \ln GDPC_{t-j} + \\ &\sum_{j=0}^{q}\varphi_j \Delta \ln\left(GDPC\right)^2_{t-j} + \sum_{j=0}^{q}\varphi_j \Delta \ln\left(GDPC\right)^3_{t-j} + \\ &\sum_{j=0}^{q}\varphi_j \Delta \ln GFCF_{t-j} + \sum_{j=0}^{q}\varphi_j \Delta \ln TO_{t-j} + \varepsilon_t\end{aligned}$$

The above equation estimates the presence of cointegration applying the joint significance F-test using the given below hypothesis:

H_0: $\beta_1 = \beta_2 = \cdots \beta_n = 0$

H_0: $\beta_1 \neq \beta_2 \neq \cdots \beta_n \neq 0$

Furthermore, the study introduces the concept that relationship may exhibit a asymmetric pattern. Shin et al. (2014) furthered the ARDL framework to allow for asymmetric relationship between variables. This extension enables the capture of short-term volatilities and asymmetries in the analysis. The non-linear ARDL (NARDL) method has gained popularity in recent research studies, as indicated by references to various studies (Kisswani, 2017; Ridzuan et al. 2018; Alkhateeb and Mahmood, 2019; Raggad, 2020). The method is particularly useful for understanding the complexities and dynamics of the association between economic growth and energy consumption.

In the context of NARDL, the objective is to decompose GDPC into positive and negative changes. This decomposition helps to understand the effects of positive changes in GDPC on energy consumption and how these effects differ from negative changes in GDPC. Here, b_1 and b_2 are the parameters reflecting the asymmetric impact of GDPC in terms of a positive and negative shock of GDPC on energy consumption by positive GDPC and negative GDPC, in the long run.

The nonlinear ARDL is assumes the following form:

$$\begin{aligned}\Delta EC_t &= b_0 + b_1 EC_{t-1} + b_2 GDPC^{+}_{t-1} + \\ &b_3 GDPC^{-}_{t-1} + b_4 \ln GFCF_{t-1} + b_5 \ln TO_{t-1} \\ &+ \sum_{i=1}^{c}\theta_{1i}\Delta EC_{t-i} + \sum_{i=0}^{d}\theta_{2i}\Delta GDPC^{+}_{t-i} + \sum_{i=0}^{e}\theta_{3i}\Delta GDPC^{-}_{t-i} + \\ &\sum_{i=0}^{f}\theta_{4i}\Delta \ln GFCF_{t-m} + \sum_{i=0}^{g}\theta_{5i}\Delta \ln TO_{t-n} + \int_t\end{aligned}$$

In the final stage, diagnostic tests on residuals will be conducted to validate the appropriateness of the estimated model. This includes checking for the absence of serial correlation, conformity to a normal distribution, and homoscedasticity of the error terms. The Breusch-Godfrey LM Test, Breusch-Pagan-Godfrey test and Jarque-Bera test will be used to check for serial correlation, heteroscedasticity and normality, respectively. For all the three tests the null hypothesis indicates that there is no problem All hypotheses will be tested at a 95% confidence level. A $P > 0.05$ suggests that the null hypothesis is not rejected, implying the absence of serial correlation, heteroscedasticity, and non-normality for the respective residual diagnostic tests. Finally, the CUSUM and CUSUM square graphs will be employed to examine whether the model is stable or not. If the plots remain within the critical limits, it signifies that the parameter stability.

4. RESULTS

A graphical representation of the data used is provided in Figure 1. Each variable has been plotted separately to identify the possible trend in the data. EG and GFCF show an overall increasing trend, while GDPC and TO are stochastic in nature. From the graphical representation it can be guessed that the data would be not be stationary at level. Hence, the data is formally tested for stationarity. The ADF test suggests that EC, GDPC and TO are stationary after first order differencing while GFCF is stationary at level (Table 1). This calls for using the ARDL method for estimating the cointegrating relationship between variables.

The results of the estimated models are presented in Table 2. Model 1 assumes a linear relationship between the variables, while Model 2 incorporates a quadratic relationship. If the coefficient for GDPC is positive and significant and the coefficient for the squared term of GDPC is negative and significant, it would indicate an inverted U-shaped relationship, supporting the Energy-Kuznets Curve hypothesis. Model 3 introduces a cubic term to test for an N-shaped curve. If the coefficients for GDPC are positive and significant, the squared term is negative and significant, and the cubic term is positive and significant, it would suggest an N-shaped relationship. Model 1 shows that GDPC is not significant at the 5% level, and the CUSUM graphs indicate model instability. In Models 2 and 3, where GDPC is included in quadratic and cubic forms respectively, GDPC remains insignificant. These results suggest that neither the linear, quadratic, nor cubic models effectively capture the relationship between energy consumption and economic growth.

The only model yielding significant results is obtained from the NARDL method (Model 4). In this model, both positive (GDPC+) and negative (GDPC-) changes in GDP per capita are significant. Specifically, an increase in GDPC leads to a 1.89 increase in energy consumption, while a decrease in GDPC results in a 0.32 decrease in energy consumption. In the NARDL model, gross fixed capital formation (GFCF) is significant with a positive coefficient, whereas trade openness (TO) is not significant. The error correction term (ECT) is negative and significant, with a coefficient of 0.39, indicating that 39% of any disequilibrium is corrected within a year. The diagnostic tests support the model's robustness. The Jarque-Bera test confirms that the residuals are normally distributed. The Breusch-Godfrey LM Test indicates no serial correlation, and the Breusch-Pagan-Godfrey test shows no heteroscedasticity. The CUSUM and CUSUMSQ graphs confirm the stability of the model.

Figure 1: Graphical representation of data

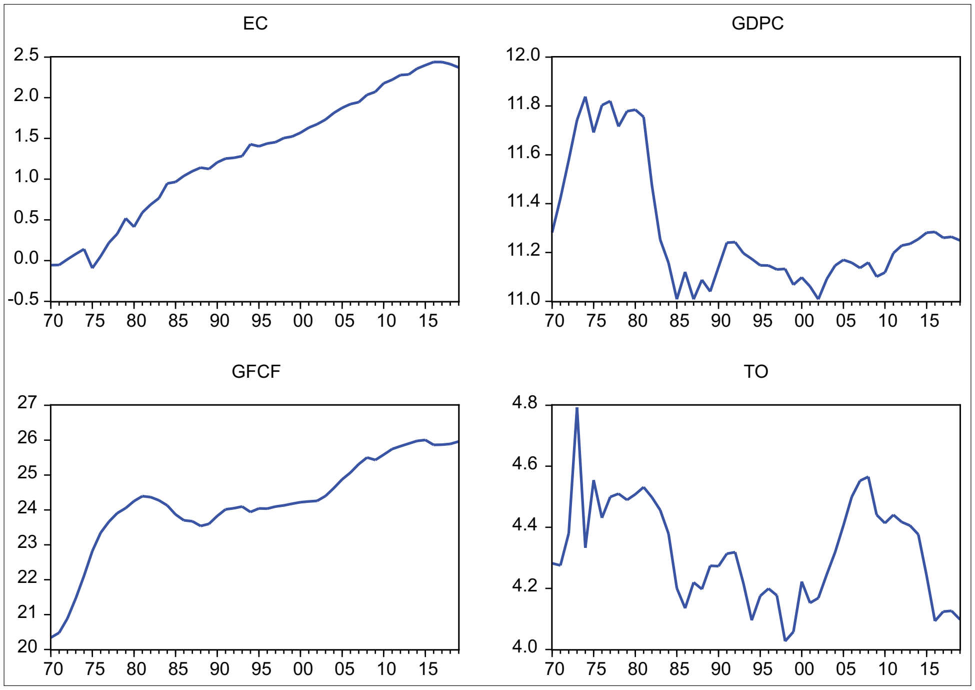

Table 1: Unit root tests

Variables	EC		GDPC		GFCF		TO	
	t-Stat	P-value	t-Stat	P-value	t-Stat	P-value	t-Stat	P-value
C	−1.275923	0.6335	−2.174824	0.2179	−3.442626	0.0141	−1.744645	0.4029
C, L	−1.585558	0.7844	−2.160716	0.4996	−5.369964	0.0003	−2.112836	0.5257
N	1.087258	0.9256	−0.078835	0.6515	0.832594	0.8878	−0.306386	0.5702
	DEC		DGDPC		DGFCF		DTO	
C	−7.971500	0.0000	−5.349431	0.0000	−2.158689	0.2236	9.418749	0.0000
C, L	8.167919	0.0000	−5.291299	0.0004	−2.351860	0.3991	−9.406639	0.0000
N	−2.096704	0.0359	5.401381	0.0000	−1.915884	0.0536	−9.508361	0.0000

C: Constant, C, L: Constant linear trend, N: None

Table 2: Estimation results of ARDL and NARDL models

Restricted Constant and No Trend (Automatic lag selection)								
Variable	ARDL (2, 0, 2, 4)		ARDL (2, 0, 0, 2, 4)		ARDL (3, 1, 2, 1, 1, 2)		ARDL (3, 3, 4, 1, 3)	
	Coefficient	Prob.						
LNGDPC	−1.655013	0.0553	50.04980	0.4915	4195.472	0.5264		
LNGDPC2			−2.253584	0.4775	−366.6713	0.5288		
LNGDPC3					10.67400	0.5314		
LNGDPC_POS							1.795586	0.0000
LNGDPC_NEG							−0.325769	0.0358
LNGFCF	4.450167	0.0040	3.733411	0.0209	2.635633	0.0222	0.856702	0.0023
LNTO	0.924736	0.6358	0.793339	0.6441	2.689496	0.1023	0.145567	0.5036
C	3.944434	0.6378	−289.8351	0.4840	−16006.93	0.5238	−4.078944	0.0001
ECT	−0.047619	0.0000	−0.054637	0.0000	−0.068707	0.0000	−0.39	0.00
Bounds F-test	9.284510	2.79;3.67	7.670240	2.56; 3.49	8.079591	2.39; 3.38	13.02500	2.56; 3.49
Jarque-Bera	0.237878	0.887862	0.489413	0.782934	4.090373	0.129356	1.493361	0.473937
Breusch-Godfrey	2.277357	0.3202	2.567851	0.2769	1.423754	0.4907	1.707869	0.4257
Breusch-Pagan-Godfrey	18.51799	0.0703	18.87678	0.0915	19.46521	0.1094	22.67920	0.2032
CUSUM and CUSUMSQ	Outside the range		Within the range		Outside the range		Within the range	

The findings from Model 1 suggest that a simple linear relationship does not adequately describe the energy consumption-economic growth nexus in Saudi Arabia, which is consistent with previous studies that found complex dynamics rather than straightforward linear associations (Mehrara, 2007). Models 2 and 3's results, which incorporate quadratic and cubic terms, also fail to capture the expected non-linear relationships. This contrasts with some literature that supports the Energy-Kuznets Curve hypothesis, suggesting an inverted U-shaped relationship (Dehnavi and Haghnejad, 2012; Alkhathlan and Javid, 2013). However, our findings align with studies such as those by Salahuddin and Gow (2014) and Magazzino (2016), which also did not confirm the EKC hypothesis for energy consumption in similar contexts.

The significant results from the NARDL model highlight the asymmetric effects of economic growth on energy consumption. This finding is critical as it underscores the complexity of energy consumption patterns in response to economic changes. The positive coefficient for GDPC+ and the negative coefficient for GDPC- indicate that energy consumption increases more with economic growth than it decreases with economic decline. This asymmetric impact is supported by the work of Raggad (2018) and Alkhateeb and Mahmood (2019), who also found varying effects of economic variables on energy consumption and emissions.

Furthermore, the positive and significant coefficient for gross fixed capital formation (GFCF) in the NARDL model suggests that investments play a crucial role in driving energy consumption, which is consistent with the findings of Sayed and Alayis (2019). The insignificance of trade openness (TO) indicates that, within the context of Saudi Arabia, external trade does not have a substantial direct impact on energy consumption, a finding that contrasts with some global studies but may reflect the unique economic structure of Saudi Arabia. The error correction term (ECT) being significant and negative indicates a strong adjustment mechanism, where deviations from the long-term equilibrium are corrected at a rate of 39%/year. This is in line with the adaptive responses highlighted in the ARDL framework by Pesaran et al. (1999a; 2001b), demonstrating the robustness of the long-term relationship despite short-term fluctuations.

In summary, our study contributes to the understanding of the energy-growth relationship in Saudi Arabia by highlighting the inadequacy of simple linear and even quadratic models to capture this relationship fully. The use of the NARDL model reveals the complex, asymmetric nature of this relationship and emphasizes the importance of considering both positive and negative changes in economic growth. These insights are crucial for policymakers aiming to balance economic development with sustainable energy consumption.

5. DISCUSSION

As a major oil-producing nation, Saudi Arabia relies heavily on oil for its economic foundation and has a history of substantial energy consumption. The research identifies a cointegrating relationship between GDP per capita, trade openness, gross fixed capital formation, and primary energy consumption in the country. This cointegration implies that energy conservation policies will significantly impact Saudi Arabia's economic growth. In line with its economic transformation plan, Saudi Arabia is currently re-evaluating its energy pricing strategies. The study's findings reveal an asymmetric relationship, indicating that changes in per capita income do not uniformly affect energy usage. Specifically, an increase in GDP per capita leads to a proportionally larger increase in energy consumption, whereas a decrease in per capita income results in a decrease in energy consumption.

Investments significantly impact energy consumption in Saudi Arabia, likely due to the nature of these investments, which are predominantly oil-based. When investments in an oil-exporting country positively impact energy consumption, it typically indicates economic growth and increased industrial activity, leading to higher energy usage. Such investments often enhance infrastructure and improve access to energy, fuelling greater demand. Economic development and rising incomes boost domestic consumption of energy-intensive goods and services. Additionally, investments in oil export sector itself can raise energy needs due to more intensive extraction and production processes. Overall, higher energy consumption reflects the country's expanding economy and development efforts driven by strategic investments.

Increased investments can lead to economic growth, which typically results in higher energy consumption. As the economy expands, industries, transportation, and households tend to use more energy. Investments may be directed towards industrialization and infrastructure development. Building factories, expanding transportation networks, and developing urban infrastructure require significant energy, thus boosting energy consumption. Investments could be improving access to energy for the population. This might involve expanding the electricity grid, increasing energy production capacity, or subsidizing energy costs, leading to higher overall energy usage as more people and businesses gain access to reliable energy sources. As investments lead to higher incomes and improved standards of living, domestic demand for energy-consuming goods and services (such as cars, air conditioning, and electronic devices) may rise, thereby increasing energy consumption. If investments enhance the oil export sector, this might indirectly increase domestic energy consumption. For instance, developing new oil fields or improving extraction and transportation infrastructure requires substantial energy inputs. Government policies and subsidies resulting from increased revenues from investments can also influence energy consumption. For example, subsidized energy prices can lead to higher consumption by making energy more affordable.

6. CONCLUSION

The relationship between energy consumption and economic growth is inherently complex. This study aimed to identify the appropriate model to establish this relationship for an energy-exporting economy, specifically Saudi Arabia. The findings indicate that there is no simple linear relationship between energy consumption and economic growth, nor is there evidence supporting the Energy-Kuznets Curve for Saudi Arabia. Despite the lack of a clear linear, quadratic, or cubic relationship, it is premature to conclude that energy consumption and economic growth are entirely decoupled. Further investigation reveals an asymmetric relationship: Energy consumption increases with positive shocks in per capita income and decreases with negative shocks. This suggests that while the relationship is not straightforward, it is indeed significant and complex. These findings align with previous studies, such as those by Raggad (2018) and Alkhateeb and Mahmood (2019), which also noted the nuanced effects of economic variables on energy consumption and emissions.

The policy implications of this study are critical for Saudi Arabia as it continues to navigate its economic transformation under Vision 2030. Encouraging consumer behavior towards adopting energy-saving technologies is paramount. This could involve public awareness campaigns and incentives for using energy-efficient appliances. Reducing reliance on energy-intensive industries by diversifying the economy is another crucial step. Investments in energy-efficient infrastructure, such as green buildings and sustainable public transportation systems, can significantly reduce overall energy consumption. Policy interventions should also include financial incentives and tax breaks for businesses and individuals who invest in renewable energy sources and energy-efficient technologies. Additionally, implementing stricter regulations on emissions and energy use in industrial sectors can drive the transition towards a more sustainable energy consumption model.

Future research should focus on exploring the long-term impacts of these policy measures on the energy-growth relationship. Longitudinal studies that incorporate more recent data and account for global economic fluctuations, such as those caused by the COVID-19 pandemic, would provide deeper insights. Additionally, examining the role of technological innovation and its adoption rate in influencing energy consumption patterns could offer valuable perspectives. In conclusion, while the relationship between energy consumption and economic growth in Saudi Arabia is complex and non-linear, it is evident that economic activities significantly impact energy use. The findings underscore the importance of targeted policy interventions to promote energy efficiency and sustainability, which are crucial for the country's economic resilience and environmental sustainability.

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REFERENCES

Abul, S., Satrovic, J., Muslija, A. (2019), The link between energy consumption and economic growth in gulf cooperation council countries. International Journal of Energy Economics and Policy, 9(5), 38-45.

Agboola, M.O., Bekun, F.V., Joshua, U. (2021), Pathway to environmental sustainability: Nexus between economic growth, energy consumption, CO_2 emission, oil rent and total natural resources rent in Saudi Arabia. Resources Policy, 74, 102380.

Al Dubyan, M., Gasim, A. (2019), Gasoline Price Reform in Saudi Arabia, Instant Insight. Saudi Arabia: Kapsarc, KS--2019-II08.

Algarini, A. (2020), The relationship among GDP, carbon dioxide emissions, energy consumption, and energy production from oil and gas in Saudi Arabia. International Journal of Energy Economics and Policy, 10(1), 280-285.

AlGhamdi, A. (2020), Saudi Arabia energy report. King Abdullah Petroleum Studies and Research Center, 19, 1-28.

AlGhamdi, A.S. (2019), Potential for rooftop-mounted pv power generation to meet domestic electrical demand in Saudi Arabia: Case Study of a villa in Jeddah. Energies, 12(23), 4411.

Alkhateeb, T.T.Y., Mahmood, H. (2019), Energy consumption and trade openness nexus in Egypt: Asymmetry analysis. Energies, 12(10), 2018.

Alkhathlan, K., Javid, M. (2013), Energy consumption, carbon emissions and economic growth in Saudi Arabia: An aggregate and disaggregate analysis. Energy Policy, 62, 1525-1532.

Almutairi, N. (2020), The effects of oil price shocks on the macroeconomy: Economic growth and unemployment in Saudi Arabia. OPEC Energy Review, 44(2), 181-204.

Al-Saidi, M. (2022), Energy transition in Saudi Arabia: Giant leap or necessary adjustment for a large carbon economy? Energy Reports, 8, 312-318.

Alshahrani, J., & Boait, P. (2018). Reducing high energy demand associated with air-conditioning needs in Saudi Arabia. Energies, 12(1), 87.

Alshahrani, J., Boait, P. (2018), Reducing high energy demand associated with air-conditioning needs in Saudi Arabia. Energies, 12(1), 87.

Alshehry, A.S., Belloumi, M. (2015), Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia. Renewable and Sustainable Energy Reviews, 41, 237-247.

Altaee, H.H.A., Al-Jafari, M.K. (2018), Trade openness and economic growth in the GCC Countries: A panel data analysis approach. International Journal of Business and Economic Sciences Applied Research, 11(3), 57-64.

Aruga, K. (2019), Investigating the energy-environmental Kuznets Curve hypothesis for the Asia-Pacific region. Sustainability, 11(8), 2395.

Benlaria, H., Hamad, A.A.J.H. (2022), Economic impact of renewable energy on sustainable development in Saudi Arabia. International Journal of Energy Economics and Policy, 12(5), 311-318.

Brahimi, T. (2019). Using artificial intelligence to predict wind speed for energy application in Saudi Arabia. Energies, 12(24), 4669.

Daly, S., Abdouli, M. (2023), The nexus between environmental quality, economic growth, and trade openness in Saudi Arabia (1990-2017). International Journal of Energy Economics and Policy, 13(4), 579-598.

Dehnavi, J., Haghnejad, A. (2012), Energy consumption, economic growth, and pollution in selected OPEC Countries: Testing the environmental Kuznets curve hypothesis. Journal of Academic Research in Economics, 2, 149-166.

Derouez, F., Ifa, A., Aljughaiman, A.A., Haya, M.B., Lutfi, A., Alrawad, M., Bayomei, S. (2024), Energy, technology, and economic growth in Saudi Arabia: An ARDL and VECM analysis approach. Heliyon, 10(4), e26033.

Elhassan, T. (2021), Impact of oil price fluctuations on economic growth in Saudi Arabia: Evidence from a nonlinear ARDL approach. International Journal of Energy Economics and Policy, 11(5), 579-585.

Farhani, S., Shahbaz, M., Arouri, M. (2013), Panel Analysis of CO_2 Emissions, GDP, Energy Consumption, Trade Openness and Urbanization for MENA Countries. Munich Personal RePEc Archive, MPRA Paper No. 49258.

Galeotti, M., Howarth, N., Lanza, A. (2016), Energy Productivity in the GCC: Evidence from an International Kuznets Curve Analysis (No. ks--1648-mp043a). Saudi Arabia: King Abdullah Petroleum Studies and Research Center.

Haque, M.I. (2021), Oil price shocks and energy consumption in GCC countries: A system-GMM approach. Environment, Development and Sustainability, 23(6), 9336-9351.

Kisswani, K.M. (2017), Evaluating the GDP-energy consumption nexus for the ASEAN-5 countries using nonlinear ARDL model. OPEC Energy Review, 41(4), 318-343.

Ko, W., Al-Ammar, E., Almahmeed, M. (2019), Development of feed-in tariff for PV in the Kingdom of Saudi Arabia. Energies, 12(15), 2898.

Krane, J. (2019), Energy Governance in Saudi Arabia: An Assessment of the Kingdom's Resources, Policies, and Climate Approach. Texas: James A. Baker III Institute for Public Policy of Rice University. p36.

Lahn, G. (2016), Fuel, Food and Utilities Price Reforms in the GCC A Wake-up Call for Business. Energy, Environment and Resources Department. England: The Royal Institute of International Affairs Chatham House.

Luzzati, T., Orsini, M. (2009), Investigating the energy-environmental Kuznets curve. Energy, 34(3), 291-300.

Magazzino, C. (2016), The relationship between real GDP, CO_2 emissions, and energy use in the GCC countries: A time series approach. Cogent Economics and Finance, 4(1), 1152729.

Mahmood, H., Alkhateeb, T.T.Y., Al-Qahtani, M.M.Z., Allam, Z.A., Ahmad, N., Furqan, M. (2019), Energy Consumption, Economic Growth and Pollution in Saudi Arabia. MPRA Paper No. 109143.

Mahmood, H., Maalel, N., Hassan, M.S. (2021), Probing the energy-environmental Kuznets curve hypothesis in oil and natural gas consumption models considering urbanization and financial development in Middle East countries. Energies, 14(11), 3178.

Matar, W., Anwer, M. (2017), Jointly reforming the prices of industrial fuels and residential electricity in Saudi Arabia. Energy Policy, 109, 747-756.

Mehrara, M. (2007), Energy consumption and economic growth: The case of oil exporting countries. Energy Policy, 35, 2939-2945.

Moosa, I.A., Burns, K. (2022), The energy Kuznets curve: Evidence from developed and developing economies. The Energy Journal, 43(6), 47-70.

Pablo-Romero, M.D.P., De Jesús, J. (2016), Economic growth and energy consumption: The energy-environmental Kuznets curve for Latin America and the Caribbean. Renewable and Sustainable Energy Reviews, 60, 1343-1350.

Pesaran, M.H., Shin, Y., Smith, R.J. (2001b), Bounds testing approaches to the analysis of level relationships. Journal of Allied Econometrics, 16(3), 289-326.

Pesaran, M.H., Shin, Y., Smith, R.P. (1999a), Pooled mean group estimation of dynamic heterogeneous panels. Journal of the American Statistical Association, 94(446), 621-634.

Raggad, B. (2018), Carbon dioxide emissions, economic growth, energy use, and urbanization in Saudi Arabia: Evidence from The ARDL approach and impulse saturation break tests. Environmental Science and Pollution Research, 25, 14882-14898.

Raggad, B. (2020), Economic development, energy consumption, financial development, and carbon dioxide emissions in Saudi Arabia: New evidence from a nonlinear and asymmetric analysis. Environmental Science and Pollution Research, 27(17), 21872-21891.

Ridzuan, A.R., Razak, M.I.M., Mohammad, N., Fatima, N., Latiff, A.R.A. (2018), Nexus among carbon emissions, real output and energy consumption in Malaysia and South Korea: New evidence using non-linear autoregressive distributed lag (NARDL) analysis. Jurnal Ekonomi Malaysia, 52(2), 39-54.

Sadorsky, P. (2011), Trade and energy consumption in the Middle East. Energy Economics, 33(5), 739-749.

Salahuddin, M., & Gow, J. (2014). Economic growth, energy consumption and CO2 emissions in Gulf Cooperation Council countries. Energy, 73, 44-58.

SAMA (2022). 58th Annual Report. Saudi Arabian Monetary Agency. Available at: https://www.sama.gov.sa/en-US/EconomicReports/pages/annualreport.aspx

Saudi Arabia's Energy Efficiency Report (2011). http://www05.abb.com/global/scot/ scot316.nsf/veritydisplay/f90e53733342b472c125786400519e97/$file/saudi% 20arabia.pdf) as cited by Alkhathlan, K., & Javid, M. (2013). Energy consumption, carbon emissions and economic growth in Saudi Arabia: An aggregate and disaggregate analysis. Energy Policy, 62, 1525-1532.

Salahuddin, M., Gow, J. (2014), Economic growth, energy consumption and CO_2 emissions in Gulf Cooperation Council countries. Energy, 73, 44-58.

Saqib, N. (2021), Energy consumption and economic growth: Empirical evidence from MENA region. International Journal of Energy Economics and Policy, 11(6), 191-197.

Sayed, M.N., Alayis, M.M.H. (2019), The nature of the relationship between GDP and energy consumption in Saudi Arabia. International Journal of Business and Management, 14(7), 28-35.

Shin, Y., Yu, B., Greenwood-Nimmo, M. (2014), Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework. In: Festschrift in Honor of Peter Schmidt. New York: Springer. p281-314.

Sulphy, M.M. (2019), The Islamic perspective of environmental sustainability and management. Middle East Journal of Management, 6(5), 536-550.