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Does Education Spending Affect Energy Consumption in Saudi Arabia? A Bootstrap Causality Test

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ABSTRACT

This investigation explores the causal nexus between educational expenditure and energy utilization in Saudi Arabia spanning 1981-2023, thereby addressing a significant deficiency in the academic discourse concerning the direct influence of educational investments on energy consumption patterns. Through a bootstrap causality examination framed by an Autoregressive Distributed Lag (ARDL) approach, this investigation delves into yearly time series data to highlight educational investment's immediate and delayed effects on energy consumption. The results indicate that educational spending exerts a lagged yet positive influence on energy consumption, which materializes over time as the populace attains greater technological literacy and industrial operations proliferate. This lagged effect emphasizes the critical nature of long-term educational investments in fostering sustainable energy consumption behaviors, which aligns with Saudi Arabia's Vision 2030 objectives regarding economic diversification and ecological sustainability. Also, this investigation validates the premise that economic development and oil price volatility have substantial positive repercussions for energy consumption, emphasizing the energy-intensive traits of the Saudi economic landscape and its reliance on oil-related earnings. Additionally, population growth contributes to the escalation of energy consumption, while the ramifications of urbanization remain statistically negligible in the short run. These findings hold substantial implications for policymakers, suggesting that persistent investment in educational frameworks is imperative for attaining enduring energy efficiency and sustainability objectives. The research advocates that enhancing energy literacy and promoting technological advancement through education can facilitate the transition toward a sustainable energy paradigm.

Keywords: Education Spending; Energy Consumption; ARDL Model; Saudi Arabia; Sustainable Development
JEL Classifications: C32; Q43; I22; O13

1. INTRODUCTION

Energy consumption represents a fundamental determinant in nations' economic advancement and sustainability, particularly for states such as Saudi Arabia, which have historically depended predominantly on fossil fuel resources and energy-intensive sectors. As a preeminent global oil producer, the energy consumption trajectories of Saudi Arabia possess considerable ramifications for its economic resilience and ecological sustainability. In recent years, the Kingdom has embarked upon Vision 2030, an ambitious initiative aimed at diversifying its financial framework, diminishing reliance on petroleum, and fostering sustainable development through strategic investments in renewable energy sources and human capital development (Saudi Vision, 2030, 2016; Singh et al., 2022).

The influence of education is critical in fulfilling these targets, as it acts as a necessary component for building human capital, inspiring novel ideas, and endorsing environmentally sustainable practices. Increased educational expenditures can augment energy literacy, resulting in heightened awareness and adopting energy-efficient technologies and practices (Amirat and Zaidi, 2020; Abid et al., 2022; Benlaria et al., 2024). On the contrary, elevated educational attainment may also catalyze augmented economic activities and industrialization, leading to escalated energy consumption levels (Alkhateeb et al., 2020; Akinwale, 2018).

Consequently, comprehending the intricate relationship between educational investment and energy consumption is essential for policymakers striving to harmonize economic expansion with environmental sustainability.

Numerous scholarly investigations have scrutinized diverse dimensions of energy consumption within Saudi Arabia and the broader Gulf region. Felimban et al. (2019) assessed energy consumption patterns in residential edifices in Jeddah, elucidating the effects of rapid urbanization and demographic expansion on energy demand. Benlaria and Hamad (2022) investigated the economic ramifications of renewable energy initiatives on sustainable development in Saudi Arabia, underscoring the potential of investments in renewable energy to stimulate economic growth while mitigating environmental repercussions. Singh et al. (2022) investigated the impact of education and training on achieving sustainable development goals and stimulating economic growth within Saudi Arabia.

Despite the expanding corpus of scholarly work, a notable deficit persists regarding the direct causal link between educational expenditure and energy consumption in Saudi Arabia. Although prior investigations have recognized the vital role of education in fostering sustainability, a limited number of studies have empirically scrutinized the specific impact of educational spending on energy consumption patterns across temporal dimensions. Furthermore, the possible delayed repercussions of educational expenditure on energy consumption have yet to be comprehensively explored.

This research endeavors to bridge this knowledge gap by examining the extent to which educational expenditures influence energy consumption in Saudi Arabia. It employs a bootstrap causality test to discern both immediate and delayed effects. The study aims to provide a more nuanced understanding of how educational investments shape energy consumption patterns over time by probing into the causal relationship and possible temporal lags.

Grasping this relationship is crucial for several reasons. First, it enriches the theoretical framework surrounding the nexus of energy and economic development, providing empirical evidence to guide energy and education policies. In addition, it corresponds with the goals of Saudi Arabia's Vision 2030 by demonstrating how educational funding can aid in economic diversification and the pursuit of sustainable development targets. Finally, the results can aid policymakers in formulating effective strategies that harness educational expenditure to enhance energy efficiency and sustainability.

Consequently, the primary aims of this research are as follows:

- To ascertain whether educational expenditure significantly influences energy consumption in Saudi Arabia
- To evaluate the existence of any delayed effects of educational spending on energy consumption
- The purpose of this study is to analyze the connections between additional influences, such as economic advancement, oil price variations, population shifts, and urbanization, and how they affect educational spending and energy use.

By employing a bootstrap causality test, this study provides empirical insights into the causal dynamics between educational expenditure and energy consumption. It addresses a pivotal gap in the existing literature and offers valuable information for policymakers and stakeholders dedicated to sustainable development.

2. LITERATURE REVIEW

The investment in education in Saudi Arabia, often referred to as "education expense," plays a crucial role in configuring energy consumption patterns, particularly in the context of Vision 2030. Improved educational initiatives can facilitate the development of a knowledge-based economy, which is essential to promote sustainable energy practices (Amirat and Zaidi, 2020). As the quality of education improves, people become more aware of energy conservation techniques and renewable energy technologies, inspiring them to make a significant impact on consumption behaviours (Abid et al., 2022).

The research indicates a connection between education and economic growth, which suggests that the most significant investment in education correlates positively with reducing CO_2 emissions in Saudi Arabia (Alkhateeb et al., 2020). This trend is aligned with the aspirations of Vision 2030, which emphasizes the reduction of the ecological footprint while promoting economic diversification (Kahouli et al., 2022). In addition, as individuals become more intelligent technologically, the integration of renewable energy sources will likely be facilitated, contributing further to sustainable economic development (Yusuf, 2019). Ultimately, by strategically channelling educational spending, Saudi Arabia can achieve significant advances in energy efficiency, supporting the nation's long-term sustainability objectives and offering a promising vision for a more sustainable future (Sarwar, 2022; Akinwale, 2018).

2.1. Education and Energy Consumption

Education spending plays a central role in influencing energy consumption by improving economic growth and promoting energy literacy among the population. Increased investment in education contributes to the development of human capital, which is essential to stimulating sustainable economic growth (Deming, 2022). For example, educational initiatives can provide individuals with skills essential to adopt energy-efficient practices, reducing overall energy consumption (Alvarado et al., 2021).

Since education facilitates awareness of energy problems, it improves energy literacy, leading to more informed decisions concerning energy consumption (Edsand and Broich, 2020). The increase in energy literacy cultivates a desire for sustainability and encourages consumers to adopt energy-efficient technologies, such as household appliances, effectively attenuating energy demand (Bhutto et al., 2020). In addition, research has shown that improving human capital can decrease non-renewable energy consumption, especially in developed economies (Yumashev et al., 2020).

Investments in Education in Guangdong, China, significantly improve economic growth and energy efficiency, mainly through progress in Stem innovation. Researchers show that educational investments promote sustainable economic growth, suggesting a strong correlation between educational resources and economic productivity (Liao et al., 2019). In addition, inequality in terms of education influences energy consumption models, which affect urban and rural areas (Wang et al., 2020). The interaction between education and financial development also emphasizes the critical role of education in economic progress (Li and Wye, 2023). Technological progress, supported by education, improves energy efficiency, highlighted by empirical studies that connect educational initiatives to industrial progress and specific progress of energy (Huang et al., 2022; Bai et al., 2020; Zhang and Fu, 2022). Consequently, the long-term effects on energy consumption models tend to be misleading, in which more significant economic growth does not increase energy demand (Yang et al., 2020; Zhou and Shi, 2019).

2.2. Education Spending and Economic Growth

Education spending profoundly impacts Saudi Arabia's economic growth, particularly within the framework of Vision 2030. This initiative underscores the need for a diversified economy, moving away from oil dependence. Increased investment in education fosters human capital development, a fundamental element in economic diversification. According to Almutairi (2024), investment in human capital through education significantly stimulates economic growth in rich oil nations such as Saudi Arabia. Singh et al. (2022) argue that sustainable development goals related to education and training can enhance economic outcomes. In this context, education's contributions are crucial in achieving sustainable growth, aligning with Sarwar et al. (2021) and reinforcing the strategic importance of educational investments highlighted by Mohiuddin et al. (2023). Finally, Alam et al. (2022) indicate that effective reallocating government educational expenses can yield substantial economic benefits, pointing the way to realizing the 2030 vision and promoting sustainable growth.

Increased educational spending in Saudi Arabia, particularly in STEM and Energy research, can significantly boost economic diversification and promote innovation, ultimately reducing energy consumption. As Saudi Arabia transitions from an oil-dependent economy, investments in quality education, especially in STEM, can foster a new generation of innovators (Awwad and Hamdan, 2023). Research indicates that improving educational infrastructure in these fields can facilitate the development of alternative energy technologies (Derouez et al., 2024). Addressing gender inequalities in education can strengthen participation in the knowledge economy, leading to broader economic contributions (Jawhar et al., 2022). Effective policies focused on systemic innovation can also mitigate the R&D trap, promoting sustainable growth (Arman et al., 2022; El Anshasy and Khalid, 2023). Ultimately, these advances can reshape energy consumption patterns, aligning with Saudi Arabia's objectives for a more sustainable future (Kayan-Fadlelmula et al., 2022; Bastida et al., 2019).

2.3. Energy Consumption in Saudi Arabia

The energy consumption models of Saudi Arabia, mainly influenced by its oil production, undergo a significant evolution in the context of the 2030 Vision Durability objectives. This national initiative emphasizes the reduction of dependence on fossil fuels and the promotion of renewable energy sources. Research indicates that improving renewable energy production is essential to achieving these objectives (Samargandi et al., 2024; Houcine et al., 2020). The political framework is reinforced to facilitate this transition to green energy (Islam and Ali, 2024). In addition, the change to renewable energies aims to alleviate greenhouse gas emissions (Al-Ismail et al., 2023) while improving energy efficiency (Belaïd and Massié, 2023). Consequently, travelling to a sustainable energy future is evident in Saudi Arabia's commitment to these transformative changes, offering hope for a more sustainable future (Al-Gahtani, 2024).

Improving education policies in Saudi Arabia can promote energy-efficient behaviour, reducing high energy consumption in households and industries. Educational initiatives focusing on renewable energy resources can raise public awareness, as evidenced by Almulhim (2022), highlighting the importance of understanding attitudes towards sustainable practices. In addition, Singh et al. (2022) argue that integrating sustainable development objectives in education contributes to economic growth. In addition, Almulhim and Aina (2022) highlight the models for using resources during crises, indicating a coherent need for education. Energy price reforms, discussed by Aldubyan and Gasim (2021), associated with research by Zaidan et al. (2022), suggest that disseminating knowledge on energy-efficient technologies could promote positive behaviour changes in consumption models.

2.4. Empirical Studies on Causal Relationships

The relationship between educational expenditure and energy consumption in Saudi Arabia is complex and multifaceted. The increase in investments in education can lead to greater energy consumption due to the growth of technology and infrastructure (Almutairi, 2024). On the contrary, energy subsidies and government policies promoting renewable energy could mitigate environmental impacts while promoting economic growth (Berradia et al., 2023). Studies show that renewable energy consumption positively influences ecological footprints, meaning balanced approaches are needed (Abid et al., 2022). In addition, the analysis of the consumption of income and electricity reveals deeper connections that deserve further exploration (Al-Rdaydeh et al., 2021; Alam et al., 2022; Kahouli et al., 2022).

2.5. Policy Context in Saudi Arabia

The Vision 2030 initiative of Saudi Arabia means a strategic approach to carry out economic diversification thanks to integrated education reforms and renewable energy investments. Education reform is essential to equip the workforce with the necessary skills mandated by non-oil industries, thus attracting investments (Alam et al., 2023). At the same time, substantial investments in renewable energies, particularly solar energy, illustrate the country's commitment to sustainability and energy efficiency (Yamada, 2022). This double approach strengthens the economy and promotes a sustainable energy landscape (Al-Gahtani, 2024). This integration is aligned with broader trends in economic diversification and the production of renewable energies (Samargandi et al., 2024; Islam & Ali, 2024), indicating a robust political framework (Al Naimi, 2022).

Current literature indicates that educational expenditures can directly and indirectly affect energy consumption. Investments in education can enhance energy efficiency by developing human capital, energy literacy, and technological innovation. However, the precise correlation between education expenditures and energy consumption in Saudi Arabia has not been extensively investigated. This study seeks to address a substantial gap in the literature, considering the country's distinctive economic framework and its emphasis on educational reform and energy transition.

The absence of empirical studies investigating the causal relationship between educational expenditure and energy consumption in Saudi Arabia underscores the necessity for additional research. This study will utilize time-series data and apply methods such as the ARDL model and Granger causality tests to elucidate the dynamics between these variables within the Saudi context. Furthermore, comprehending this relationship will give policymakers essential insights into how educational policies can advance the nation's energy efficiency and sustainability objectives.

3. DATA AND METHODOLOGY

3.1. Variables and Data Source

This study uses macroeconomic variables from 1981 to 2023 to investigate the relationship between education spending and energy consumption in Saudi Arabia. By analysing data over these 42 years, we capture a comprehensive picture of the country's economic and social changes that have influenced energy consumption patterns. The data series used in the analysis are sourced from highly reliable institutions. Table 1 summarizes the variables and their abbreviations and provides the sources from which they were collected.

3.2. Methodology: Autoregressive Distributed Lag (ARDL) Approach

The investigation uses the Autoregressive Distributed Lag (ARDL) approach to effectively explore the short-lived and lasting connections between energy usage and macroeconomic influences. This comprehensive approach facilitates the assessment of short-term impacts alongside long-term equilibrium associations, providing a complete picture of the subject matter. The ARDL framework is particularly advantageous for managing variables that exhibit integration of disparate orders, contingent upon the absence of any variable being.

The ARDL model employed in this investigation is articulated as follows:

$$\Delta log\left(EC\right)_t = \alpha_0 + \sum_{i=1}\alpha_i \Delta log\left(EC\right)_{t-i} + \sum_{j=0}\beta_j \Delta log\left(EDU\right)_{t-j} + \sum_{j=0}\gamma_j \Delta GDP_{t-j} + \sum_{j=0}\delta_j \Delta OIL_{t-j} + \sum_{j=0}\phi_j \Delta POP_{t-j} + \sum_{j=0}\theta_j \Delta\ URBAN_{t-j} + \lambda_1 log\left(EC\right)_{t-1} + \lambda_2 log\left(EDU\right)_{t-1} + \lambda_3 GDP_{t-1} + \lambda_4 OIL_{t-1} + \lambda_5 POP_{t-1} + \lambda_6 URBAN_{t-1} + \varepsilon_t$$

Where:

- Δ represents the first difference operator.
- $log(EC)_t$ is the logarithm of energy consumption (dependent variable).
- *log (EDU)*, GDP, *OIL*, POP, and *URBAN* are the independent variables (education spending, gross domestic product, oil prices, population growth, and urbanization rate).
- α_i, β_j, γ_j, δ_j, ϕ_j, θ_j are short-run coefficients.
- λ_1, λ_2, λ_3, λ_4, λ_5, and λ_6 represent the long-run coefficients.
- ϵ_t is the error term.

The ARDL model not only examines the short-run dynamics (coefficients of the differenced variables) but also captures the long-run relationships through the lagged level variables

($log(EC)_{t-1}$, $log(EDU)_{t-1}$, GDP_{t-1}, OIL_{t-1}, POP_{t-1}, $URBAN_{t-1}$).

The ARDL Bounds Testing Procedure is employed to ascertain the presence of cointegration amongst the variables. Evaluating a long-term relationship between the dependent and independent variables involves contrasting the F-statistic, a crucial measure, with the critical ranges. Should the F-statistic surpass the upper bound, the null hypothesis positing the absence of cointegration is consequently rejected.

Table 1: Data series overview

Series Name	Abbreviation	Source
Energy Consumption	EC	World Development Indicators
Education Spending	EDU	World Development Indicators
Gross Domestic Product (GDP) Growth	GDP	World Development Indicators
Oil Prices	OIL	World Bank Commodity Price Data
Population Growth	POP	World Development Indicators
Urbanization Rate	URBAN	World Development Indicators

Once cointegration is confirmed, the practicality of understanding immediate dynamics is achieved through an Error Correction Model (ECM), which is outlined below:

$$\Delta log\left(EC\right)_{t} = \alpha_0 + \sum_{i=1}\alpha_i \Delta log\left(EC\right)_{t-i} + \sum_{j=0}\beta_j \Delta log\left(EDU\right)_{t-j} + \sum_{j=0}\gamma_j \Delta GDP_{t-j} + \sum_{j=0}\delta_j \Delta OIL_{t-j} + \sum_{j=0}\phi_j \Delta POP_{t-j} + \sum_{j=0}\theta_j \Delta URBAN_{t-j} + \lambda ECM_{t-1} + \varepsilon_t$$

Where:

- ECM_{t-1} is the error correction term, which measures the speed of adjustment back to the long-run equilibrium after a short-run shock.
- A significant λ indicates the presence of a long-run relationship between the variables.

By utilizing the ARDL approach, the study can capture both the short-run and long-run effects of education spending and other macroeconomic factors on energy consumption in Saudi Arabia, providing a comprehensive understanding of their dynamic interactions.

4. RESULTS

We present the empirical results of our study on education spending and energy consumption in Saudi Arabia here. Our analysis uses autoregressive distributed lag (ARDL) modelling to capture short- and long-term variable dynamics. Descriptive statistics introduce the data's fundamental characteristics and set the stage for a detailed econometric analysis. We present the results of the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests after the descriptive overview. These stationarity tests show that some variables are stationary at the level, and others become stationary after the time series data differences. This mix justifies the ARDL approach, which works for variables integrated into different orders but not two. Next, we estimate the ARDL model in the short and long term. The error correction model (ECM) shows how education spending and other macroeconomic factors affect energy consumption in the short term. We examine long-run relationships to understand how these variables affect energy consumption over time. We perform serial correlation, heteroskedasticity, normality, and model stability diagnostics to ensure our findings are robust and reliable. These tests validate our model specifications and results inference.

Table 2 provides descriptive statistics for the variables used in the analysis, including energy consumption (EC), education spending (EDU), GDP growth (GDP), oil prices (OIL), population growth (POP), and urbanization (URBAN). The data show significant variability across several variables, with EC averaging 256.26 and education spending at 2.40E+10. GDP growth has fluctuated between −20.73% and 17.01%, while oil prices also show large variation, ranging from \$12.72 to \$111.97. The Jarque-Bera test indicates that GDP, oil prices, and urbanization deviate from a normal distribution ($P < 0.05$), while other variables, such as EC and education spending, appear normally distributed. The overall standard deviations highlight the dynamic nature of these variables, especially in energy consumption, education spending, and oil prices, suggesting that external factors and policy changes have played significant roles over time.

The results obtained from the Augmented Dickey-Fuller (ADF) evaluation (Table 3) and the Phillips-Perron (PP) analysis (Table 4) highlight a spectrum of integration characteristics within the studied variables. The variable denoting Gross Domestic Product (GDP) is stationary at the level, as evidenced by substantial test statistics at the 1% significance level in both assessments, implying that GDP does not necessitate differencing to achieve stationarity. Conversely, variables including LOG(EC) (log of energy consumption), LOG(EDU) (log of education spending), OIL, and POP (population) exhibit non-stationarity at the level but achieve stationarity following first differencing, as evidenced by significant test statistics at the 1% or 5% levels in both ADF and PP tests. URBAN exhibits varying behavior across tests, demonstrating non-stationarity in the ADF test (Table 3) while being stationary at the level in the PP test (Table 4), with significant values observed at both levels. The presence of both I(0) and I(1) variables, with certain variables being stationary at the level and others necessitating differencing for stationarity, supports the application of the Autoregressive Distributed Lag (ARDL) model for analysis. ARDL is effective for analyzing variables with varying orders of integration, particularly those that combine I(0) and I(1), without necessitating that all variables be stationary at the same level. This method facilitates the estimation of short-run and long-run relationships within a unified framework. The ARDL bounds testing procedure can assess cointegration among variables, irrespective of their order of integration, as long as none are I(2). The ARDL model is an appropriate and efficient method for capturing the dynamic relationship between education spending and energy consumption while accommodating the mixed data integration order.

Figure 1 presents the outcomes of the model selection process, a careful and repeated process based on the Akaike Information Criterion (AIC) for different ARDL models. The AIC values, prominently displayed on the vertical axis, are a crucial metric, with lower values indicating a better model fit. The horizontal axis lists the model numbers and their respective ARDL configurations (with lag orders). Figure 1 clearly shows that Model 1646 (ARDL(4, 2, 1, 4, 0, 4)) stands out with the lowest AIC value, making it the most optimal model for the given data.

Table 5 demonstrates a compelling finding: the calculated F-statistic (10.456) exceeds the upper bound critical value at the 1% significance level (5.256). This leads to the robust rejection of the null hypothesis, affirming the presence of a long-run relationship between the variables. The result suggests that education spending, energy consumption, and the other variables in the study are cointegrated, sharing a long-term equilibrium.

The estimated Autoregressive Distributed Lag (ARDL) model, a significant tool in understanding the short-run dynamics of

Table 2: Descriptive statistics of the variables

Statistic	EC	EDU	GDP	OIL	POP	URBAN
Mean	256.2588	2.40E+10	2.311102	45.32889	3.086370	78.89347
Median	239.8096	1.37E+10	2.637412	33.41833	2.798785	80.07700
Maximum	367.1776	5.92E+10	17.01282	111.9656	4.934164	84.72900
Minimum	162.5909	4.06E+09	-20.72988	12.71654	0.129847	65.86000
Std. Dev.	56.96399	2.04E+10	7.343784	30.50962	1.178696	4.820338
Skewness	0.420002	0.574817	-0.697600	0.903241	-0.256415	-1.096380
Kurtosis	1.914798	1.634576	4.679006	2.574581	2.615215	3.468993
Jarque-Bera	3.374189	5.708320	8.538443	6.171143	0.736471	9.008771
Probability	0.185056	0.057604	0.013993	0.045704	0.691954	0.011060
Sum	11019.13	1.03E+12	99.37738	1949.142	132.7139	3392.419
Sum Sq. Dev.	136285.7	1.75E+22	2265.109	39095.15	58.35163	975.8976

Table 3: Summary of stationarity test results (ADF Test)

Variable	ADF Statistic (Level)	Result	ADF Statistic (First Difference)	Result
LOG(EC)	−1.8126	Non-Stationary	−8.3625***	Stationary
LOG(EDU)	−0.4967	Non-Stationary	−7.1224***	Stationary
GDP	−5.2833***	Stationary	−6.5956***	Stationary
OIL	−1.0751	Non-Stationary	−5.3975***	Stationary
POP	−1.1969	Non-Stationary	−5.5011***	Stationary
URBAN	−0.2784	Non-Stationary	−1.6019**	Stationary

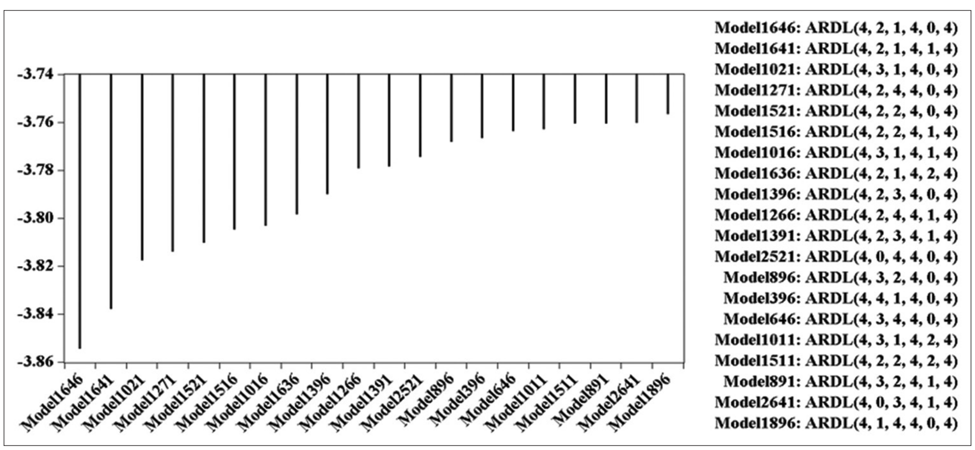
(*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant

Table 4: Summary of stationarity test results (PP Test)

Variable	PP Statistic (Level)	Result	PP Statistic (First Difference)	Result
LOG (EC)	−1.8126	Non-Stationary	−8.5466***	Stationary
LOG(EDU)	−0.4599	Non-Stationary	−7.1643***	Stationary
GDP	−5.3611***	Stationary	−19.3967***	Stationary
OIL	−1.0999	Non-Stationary	−5.2557***	Stationary
POP	−1.2957	Non-Stationary	−3.0068**	Stationary
URBAN	−8.2216***	Stationary	−3.4509**	Stationary

(*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant

Figure 1: Akaike information criteria (top 20 models)



education spending and other macroeconomic variables on energy consumption in Saudi Arabia, is examined. The model, which incorporates lagged values of both the dependent and independent variables to capture temporal effects, provides insightful results. The results in Table 6 highlight the persistence of energy consumption over time, with the second lag of energy consumption, LOG(EC(−2)), showing a positive and statistically significant coefficient (0.367193, P = 0.0210). This indicates that past energy consumption positively affects current consumption, reflecting a momentum effect. Conversely, LOG(EC(−4)) shows a negative and highly significant coefficient (-0.759380, P = 0.0001), suggesting a correction mechanism as deviations from long-term energy consumption trends are adjusted over time.

Education spending, represented by LOG(EDU), unveils a fascinating delayed effect on energy consumption. While the current value and first lag are not significant, the second lag, LOG(EDU(−2)), boasts a positive and significant coefficient (0.169120, P = 0.0396). This finding, indicating that increases in education spending affect energy consumption after two periods, sparks curiosity and invites further exploration. The positive relationship suggests that higher education investments may lead to increased energy consumption due to economic activities and higher energy demand from a more educated workforce.

Gross Domestic Product (GDP) demonstrates a lagged effect, with the first lag, GDP(−1), being positive and significant (0.003425, P = 0.0143). This implies that economic growth influences energy consumption with a one-period delay, reflecting the energy-growth relationship observed in developing economies. As for oil prices, the current oil price (OIL) is positive and significant (0.002079, P = 0.0034), indicating that higher oil prices may lead to more lavish public spending and increased energy use. The first lag of oil prices, OIL(−1), however, has a negative and significant coefficient (−0.002070, P = 0.0286), suggesting that higher oil prices in the previous period may lead to energy-saving efforts or shifts in consumption patterns. The third and fourth lags of oil prices, OIL(−3) and OIL(−4), are positive and significant, revealing the complex and delayed impact of oil prices on energy consumption over time, a phenomenon that piques interest and invites further investigation.

The long-run estimation outcomes derived from the ARDL model, as exhibited in Table 7, elucidate the interrelationship among diverse macroeconomic variables and energy consumption. The connection between energy expenditure and GDP is distinctly positive and highly important, highlighted by a coefficient of 0.0033 (P = 0.0215). This reveals that economic advancement results in greater energy consumption in Saudi Arabia, thus underscoring the energy-saturated qualities of its economic activities. Concurrently, economic advancement engenders a heightened demand for energy to satisfy industrial, commercial, and residential requirements. The influence of oil pricing on energy demand is a significant and enduring one, marked by a coefficient of 0.0025 (P = 0.0017). This indicates that higher oil prices are associated with increased energy consumption, a fact that the audience should be aware of due to its economic implications, likely due to the increased national income generated from oil exports, which boosts domestic energy demand and public spending. The coefficient for education spending, LOG(EDU), is positive (0.0801) but not statistically significant (P = 0.1591). While the positive sign suggests that higher education spending may contribute to increased energy consumption in the long run, this effect is not strong enough to be confirmed statistically. Thus, there is no conclusive evidence of a direct link between education spending and long-run energy consumption based on this model. Population growth, represented by POP, has a positive coefficient of 0.0133 and is marginally significant (P = 0.0996), indicating that population growth contributes to higher energy consumption over the long term. As the population increases, there is greater demand for energy to support residential, commercial, and industrial activities. Urbanization, denoted by URBAN, also shows a positive coefficient (0.0232) but is not statistically significant (P = 0.1822). While this suggests that urbanization may contribute to increased energy consumption, the effect is not strong enough to be validated in this model. Therefore, although urbanization is generally expected to drive energy consumption due to urban infrastructure and services development, its long-term impact on energy consumption still needs to be conclusive in this analysis.

The diagnostic assessments delineated in Table 8 substantiate the robustness and dependability of the estimated Autoregressive Distributed Lag (ARDL) model. The remarkable R-squared value of 0.9889 and the adjusted R-squared at 0.9766 highlights that

Table 5: ARDL bound test results

F-Bounds Test		Null Hypothesis: No levels of relationship		
Test Statistic	**Value**	**Signification**	**I(0)**	**I(1)**
F-statistic	10.456	10%	2.306	3.353
k	5	5%	2.734	3.92
		1%	3.657	5.256

Table 6: Short-run estimation results of the ARDL model

Variable	Coefficient	Standard Error	t-statistic	P-value
LOG(EC(−1))	0.131749	0.130789	1.007339	0.3271
LOG(EC(−2))	0.367193	0.145140	2.529920	0.0210**
LOG(EC(−3))	−0.005032	0.127755	−0.039386	0.9690
LOG(EC(−4))	−0.759380	0.146106	−5.197454	0.0001***
LOG(EDU)	0.067065	0.060639	1.105988	0.2833
LOG(EDU(−1))	−0.134794	0.089274	−1.509891	0.1484
LOG(EDU(−2))	0.169120	0.076229	2.218569	0.0396**
GDP	0.000688	0.001260	0.546594	0.5914
GDP(−1)	0.003425	0.001263	2.710778	0.0143**
OIL	0.002079	0.000617	3.367465	0.0034***
OIL(−1)	−0.002070	0.000870	−2.380409	0.0286**
OIL(−2)	−0.000708	0.000997	−0.710577	0.4865
OIL(−3)	0.002449	0.000874	2.803433	0.0117**
OIL(−4)	0.001407	0.000546	2.575247	0.0191**
POP	0.016825	0.009533	1.764949	0.0945*
URBAN	0.432769	0.137214	3.153962	0.0055***
URBAN(−1)	−0.738503	0.226781	−3.256454	0.0044***
URBAN(−2)	0.527465	0.190527	2.768456	0.0127**
URBAN(−3)	−0.350690	0.145027	−2.418110	0.0264**
URBAN(−4)	0.158322	0.071999	2.198953	0.0412**
C	2.049434	0.615159	3.331553	0.0037***

(*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant

Table 7: Long-run estimation results of the ARDL model

Variable	Coefficient	Standard Error	t-Statistic	P-value
LOG(EDU)	0.080121	0.054538	1.469092	0.1591
GDP	0.003250	0.001291	2.517163	0.0215**
OIL	0.002494	0.000675	3.696507	0.0017***
POP	0.013295	0.007658	1.736105	0.0996*
URBAN	0.023203	0.016722	1.387538	0.1822
C	1.619504	0.571447	2.834043	0.0110**

(*) Significant at the 10%; (**) Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant

Table 8: Diagnostic tests

Test name	Value (P-value)
R-squared	0.9889
Adjusted R-squared	0.9766
Durbin-Watson statistic	2.6974
Jarque-Bera test	0.4807 (0.7863)
Breusch-Godfrey Serial Correlation LM test	2.324 (0.1170)
Breusch-Pagan-Godfrey test	0.7567 (0.7282)

the model successfully explains a substantial range of variation in energy use, pointing to a firm fit overall. The Durbin-Watson statistic, recorded at 2.6974, is near the ideal value of 2, suggesting a lack of substantial autocorrelation within the residuals. This proposition is further supported by the Breusch-Godfrey Serial Correlation LM test (P = 0.1170), where the null hypothesis, which asserts the nonexistence of serial correlation, remains unchallenged at the 5% significance level. These results underscore the robustness of the ARDL model, providing reassurance about its strength in energy use analysis.

The Jarque-Bera test (P = 0.7863) provides evidence that the residuals adhere to a normal distribution, satisfying a fundamental requirement for robust regression analysis. Moreover, the Breusch-Pagan-Godfrey assessment regarding heteroskedasticity (P = 0.7282) implies that the residuals show homoskedasticity, reflecting that the error variance stays uniform across different data points. This consistency reinforces the reliability of standard errors, ensuring the precision of the model's estimates and the integrity of hypothesis testing. These diagnostic outcomes collectively illustrate that the ARDL model is aptly specified, and the estimated coefficients are unbiased and efficient, thereby offering robust support for the validity of the conclusions derived from the analysis.

The CUSUM test graph (Figure 2) and CUSUM of Squares test graph (Figure 3) provide compelling evidence of the stability of the estimated model. In Figure 2, the CUSUM line remains within the 5% significance bounds throughout the sample period, indicating that the model's coefficients are stable over time with no structural breaks. Similarly, in Figure 3, the CUSUM of Squares test also shows that the plot stays within the critical boundaries, although there is some upward movement around the 16th period. This suggests that while minor variance changes might occur, the overall model remains stable. Importantly, these tests confirm the model's reliability and the absence of significant structural instability over the observed period, providing a sense of security and ease about the model's stability.

Figure 2: CUSUM test graph

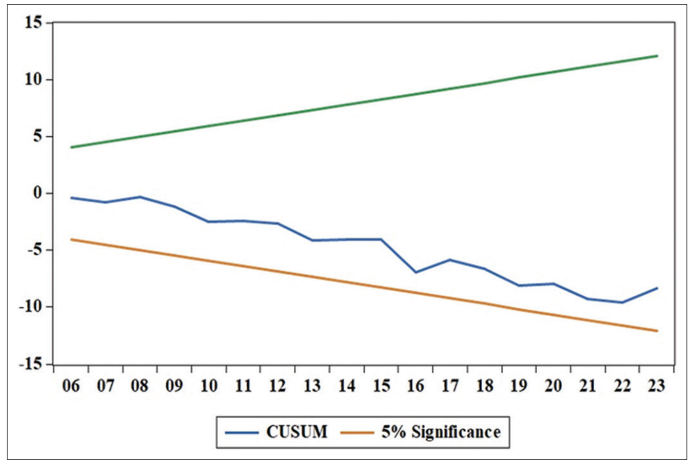
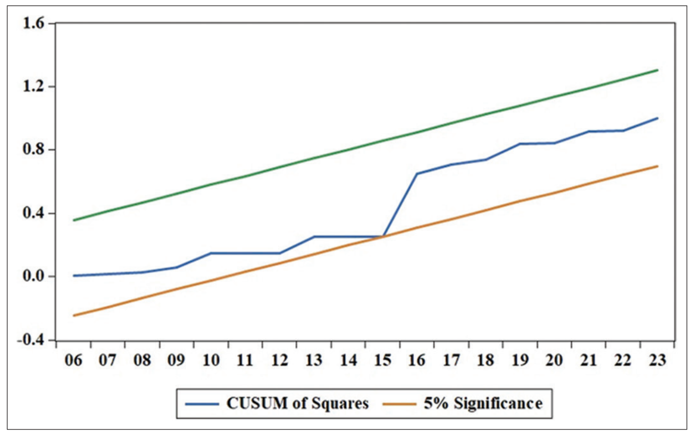


Figure 3: CUSUMSQ test graph



5. DISCUSSION

This study provides significant insights into the causal relationship between education spending and energy consumption in Saudi Arabia, enriching the existing literature on how educational investments influence energy consumption patterns. The findings confirm that education spending has a delayed positive impact on energy consumption, suggesting a nuanced and gradual relationship that unfolds over time.

Building upon the scholarly contributions of Amirat and Zaidi (2020) and Abid et al. (2022), our investigation substantiates the premise that educational programs cultivate a knowledge-driven economy, augment energy literacy, and endorse sustainable energy methodologies. As individuals pursue advanced educational qualifications, their understanding of energy conservation methodologies and renewable energy innovations is significantly augmented, consequently influencing their energy consumption behaviors favorably. This corresponds with the goals outlined in Saudi Arabia's Vision 2030, underscoring the necessity for sustainability and decreasing reliance on fossil fuel sources. The analysis by Singh et al. 2022, a significant contribution to the field, underscores how crucial education and training are for fulfilling sustainable development goals and improving the economy in Saudi Arabia. Their empirical findings indicate that investments in education not only enhance economic performance but also facilitate the integration of sustainable practices, thereby reinforcing the enduring advantages elucidated in our research.

A key finding is the delayed effect of education spending on energy consumption. While the current and immediate past values of education spending were not statistically significant, the second lag showed a positive and significant coefficient. This suggests that the benefits of educational investments on energy consumption manifest over time. Alkhateeb et al. (2020) explain that education contributes to human capital development, which is vital for economic diversification. As technological literacy improves due to education, it can lead to greater energy consumption through enhanced industrial activities and infrastructure development. This observation resonates with the arguments of Sarwar (2022) and Akinwale (2018), who suggest that targeted educational investments can have a long-term impact on energy consumption patterns by promoting energy-efficient technologies and practices.

The results align with the study conducted by Benlaria and Hamad (2022), which investigated the economic effects of renewable energy on sustainable development in Saudi Arabia. Investments in renewable energy, bolstered by educational initiatives, can facilitate sustainable economic growth. Education is essential for providing the workforce with the skills required to develop and implement renewable energy technologies, thus shaping energy consumption patterns toward more sustainable sources.

Contrary to the immediate effects proposed by Edsand and Broich (2020), our study indicates that the influence of education spending on energy consumption is more complex and gradual. The lack of significant short-term effects implies that policies aimed at improving energy efficiency through education may take time to yield measurable results. This delayed impact underscores the importance of adopting a long-term perspective in education policies focused on sustainability goals.

The affirmative and substantial impact of economic progression on energy utilization corroborates the extensive academic discourse surrounding the energy-growth relationship. In alignment with the conclusions drawn by Kahouli et al. (2022) and Yumashev et al. (2020), our findings substantiate that in the context of Saudi Arabia, economic development continues to serve as a pivotal catalyst for energy consumption, attributable to the energy-intensive characteristics of its economic operations and dependence on petroleum-derived revenues. Benlaria and Almawishir (2024) further explore this relationship in the context of the Gulf Cooperation Council (GCC) countries, highlighting how electricity consumption, oil prices, and GDP are interconnected. Their study suggests that fluctuations in oil prices and economic growth significantly impact energy consumption patterns, aligning with our findings on the significant role of oil prices.

The study also highlights the significant role of oil prices in shaping energy consumption patterns. The immediate positive effect of current oil prices on energy consumption, coupled with the negative effect of previous period oil prices, suggests a nuanced relationship. Higher oil prices increase national income from oil exports, leading to increased public spending and energy use, as noted by Islam and Ali (2024). However, higher oil prices in the previous period may incentivize energy-saving efforts or shifts in consumption patterns, as suggested by Al-Gahtani (2024). This reflects the dynamic nature of Saudi Arabia's energy landscape and the feedback mechanisms at play.

Regarding demographic factors, population growth has a positive and marginally significant effect on energy consumption, aligning with the findings of Wang et al. (2020) and Almutairi (2024). As the demographic population expands, the requirement for energy to sustain residential, commercial, and industrial operations concomitantly escalates. Felimban et al. (2019) conduct a comprehensive evaluation of energy utilization within residential edifices in Jeddah, Saudi Arabia, highlighting the way population proliferation and urban development augment the demand for residential energy. Their research accentuates the imperative for energy-conserving architectural practices and policies to alleviate the repercussions of escalating energy consumption attributable to demographic transformations.

The effect of urbanization, however, was positive but not statistically significant. This suggests that while urbanization may contribute to increased energy consumption due to infrastructure and services development, its impact may be offset by efficiencies gained through urban planning and technology adoption. This finding mirrors Li and Wye (2023), who argue that urbanization can lead to both increases and decreases in energy demand depending on the stage of urban development and policy interventions.

The application of the Autoregressive Distributed Lag (ARDL) model and bounds testing approach has effectively captured both the long-run and short-run dynamics between education spending and energy consumption. The substantial F-statistic derived from the bounds test substantiates the presence of a long-term relationship among the variables under investigation. Nevertheless, the lack of a significant short-term impact from education expenditure highlights the necessity for patience and ongoing investment in educational programs to attain long-term sustainability objectives. This assertion aligns with the perspectives of Alvarado et al. (2021) and Liao et al. (2019), who elucidate the enduring advantages of educational investments in fostering sustainable energy practices. In brief, this analysis supplements the existing scholarship by revealing empirical correlations between educational expenditure and energy consumption in Saudi Arabia, all within the scope of Vision 2030. The evidence suggests that although educational investment does not provide a quick impact on energy consumption, it is key in directing the future pathways of energy usage patterns. As Saudi Arabia progresses in diversifying its economy and minimizing its reliance on oil, investments in education that enhance energy literacy, stimulate technological innovation, and promote sustainable practices will be imperative for realizing long-term energy efficiency and environmental objectives. Subsequent inquiries should investigate the specific mechanisms by which education expenditure affects energy consumption, potentially by analyzing the contributions of curriculum development, vocational training, and public awareness initiatives in advocating for energy-efficient technologies and the adoption of renewable energy sources.

6. CONCLUSION

This research analyzed the connection between educational expenditure and energy demand in Saudi Arabia, implementing the Autoregressive Distributed Lag (ARDL) technique. The results elucidate that educational expenditure exerts a lagged yet affirmative influence on energy consumption, underscoring the criticality of long-term investments in education for the cultivation of sustainable energy consumption paradigms. Moreover, how economic growth interacts with oil price movements greatly influences energy consumption patterns, underscoring the energy-demanding aspects of the Saudi economy and its dependence on oil-derived profits. The lagged impact of educational expenditure implies that strategies designed to enhance energy literacy and encourage sustainable practices may necessitate an extended timeframe to manifest tangible outcomes.

Consequently, policymakers should embrace a long-term outlook, emphasizing educational initiatives that promote technological innovation and energy efficiency, aligning with the objectives of Vision 2030. Subsequent inquiries should investigate how education affects energy consumption, including curriculum development and public awareness initiatives, to facilitate the transition toward a sustainable energy future in Saudi Arabia.

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