Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: https://www.science-gate.com/IJAAS.html

Energy investment, geopolitical risk, and energy security in Saudi Arabia: Evidence from a dynamic ARDL framework

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ARTICLE INFO

Article history:
Received 15 January 2026
Received in revised form
14 May 2026
Accepted 23 May 2026

Keywords:
Energy investment
Energy security
Geopolitical risk
Saudi Arabia
Dynamic ARDL model

ABSTRACT

This study investigates the dynamic relationships among energy investment, geopolitical risk, and energy security in Saudi Arabia using quarterly data from 2000 to 2024. The study applies the Dynamic Autoregressive Distributed Lag (ARDL) model to examine both short-run and long-run relationships while considering mixed integration orders and structural breaks. Energy security is measured by net energy imports, whereas energy investment reflects capital allocation to infrastructure development, renewable energy projects, and energy diversification. Geopolitical risk is represented by the Geopolitical Risk (GPR) Index. The findings show that energy investment significantly improves energy security in both the short and long run, highlighting the importance of infrastructure development under Saudi Arabia's Vision 2030 strategy. In contrast, geopolitical risk negatively affects energy security. However, the interaction between geopolitical risk and energy investment has a positive moderating effect, indicating that higher levels of investment increase resilience to external shocks. Furthermore, economic growth, trade openness, and natural resource rents positively contribute to energy security, while population growth reduces energy security by increasing domestic energy demand.

1. Introduction

Global energy-security systems are under increasing pressure from the interaction between intertwining supply, demand, and geopolitical dynamics. The recent International Energy Agency (IEA) World Energy Outlook sheds light on how shocks to Russian gas flows sent cascading risks through gas, oil, and electricity markets - triggering record high prices and increasing the likelihood of supply rationing in parts of Europe. Rising demand leads to additional pressures: Fossil-fuel consumption reached an all-time high in 2023 at 37.4 billion tons of carbon dioxide equivalents in terms of swap-lights, signaling climate and structural security hazards and dangers. Dependence on concentrated supply chains is a further compounding factor: one-third of the world's primary energy is still supplied through imports of fossil fuels that, in turn, expose many economies to external disruptions. On the demand side, much more below-forecast energy-efficiency gains have lessened the shock-absorbing space - IEA's own estimates suggest that energy-efficiency gains in the last two decades have avoided around 20 per cent larger fossil fuel imports for its member countries. Meanwhile, the new clean-energy transformation includes new vectors of insecurity: critical minerals supply chains, risks from cyber-attacks on decarbonized infrastructure, and increasing geopolitical fragmentation are all new challenges. Regions that are strongly dependent on a single fuel source or a single supplier are exposed even further. The confluence of the dimensions of cost, access, and reliability highlights that energy security is at the heart of the pivot of economic stability, and also for climate policy.

Saudi Arabia has a unique set of energy security problems. Despite the country containing approximately 17% of the world's proven oil reserves and being one of the largest oil exporters, domestic use of energy resources and infrastructure has increased rapidly in the kingdom, straining resources and infrastructure. The country is heavily dependent on oil and gas for electricity generation - as of 2023, more than 99 per cent of electricity came from fossil fuels. That reduces resiliency to outside shocks on world fossil markets and exposes the

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economy to price volatility. Moreover, the integration of renewables is again at an early stage, and such a transition to a diversified energy mix is incomplete, which includes the possibility of delay (Islam and Ali, 2024). Infrastructure system reliability is also tested by high peak demand in hot months, growing population, and industrial expansion, creating the potential for supply shortfalls unless upgrades of the power system can keep up. But on top of this, global pressure to decarbonize means that Saudi Arabia must balance its export-oriented fossil sector with its domestic ambitions for sustainability, which could mean the potential to cause tension between growth, affordability and environmental objectives. These factors combined suggest that securing a constant supply of affordable and sustainable energy is a burning issue for the kingdom.

Previously, scholars provided rich empirical insights but did not reach the point of proposing actionable solutions for sustainable energy security. Yildirim et al. (2025) pointed to variation in energy security in terms of economic complexity, climate stress, and urbanization in high-risk economies; however, the paper is still of a diagnostic nature - no policy instruments are developed for implementation (Wang et al., 2025). Renewable energy technology innovation and institutional quality positively influence security, but stop short of statistical confirmation; there is no governance for technology diffusion. Vo et al. (2025) demonstrated how green finance helps reduce energy insecurity through renewable energy deployment and energy efficiency gains, but their global-level regressions do not address localized constraints to finance or incentive structures. New energy vehicles result in the enhancement of security via energy transition, innovation, and infrastructure, while pointing to both spatial spillovers and effects of thresholds, which would suggest that uncoordinated adoption would even harm regional resilience. Likewise, a study by Kanzari et al. (2025) suggests that by adding renewables, the perceived exposure to fossil fuel risks has been reduced, but admits that technical as well as financial barriers are not resolved. Collectively, the literature measures correlations but leaves unexplored the operational pathway - the means of coordination of fiscal tools, institutional reforms, and diversification mechanisms. The upcoming research will therefore aim to fill this gap with practical and country-specific strategies for including policy, investment, and innovation in workable and implementable energy security frameworks.

This study contributes in a significant way to the current growing literature on energy security, policy stringency, and geopolitical risk, in particular against the Saudi Arabian background. First, it enlarges the scope of empirical debate by introducing energy investment (EI) as the most important explanatory variable of energy security (ES). While the existing studies, such as Vo et al. (2025), stress the role of green finance and renewable development in global samples, few studies have focused on the role of direct investment in the energy sector, addressing energy resilience in oil-dependent countries. By emphasizing the concept of EI, this study adds new evidence on how capital investment in diversification and infrastructure ensures the security of supply in the long run - an issue that is crucial for economies experiencing structural transition under the era of Vision 2030. Second, introducing geopolitical risk (Geo) as a moderator is a promising way of adding a new analytical perspective. While Caldara and Iacoviello (2022) develop the geopolitical risk index (GPR) as a legitimate index of worldwide uncertainty, it remains empirically unexplored in interaction with domestic energy investment. Therefore, this study makes a meaningful contribution to the literature by quantifying the increase in geopolitical tensions as a magnifier or a diminisher of the nexus of investment and security, which constitutes a strategic exposure of Saudi Arabia to regional dynamics. Third, the study augments the energy policy literature by bringing together structural and macroeconomic controls (GDP growth, trade openness, natural resource rents, and population growth), consistent with a framework offered by Cherp and Jewell (2014). This balanced specification is adequate for estimating the causal paths within which investment, risk, and security are connected. Finally, the study also contributes to methodology as a country-specific ARDL framework useful for resource-rich countries in transition towards diversified energy portfolios. This design is in response to calls by Aslam et al. (2024) and Yildirim et al. (2025) for more context-specific and policy-oriented analyses that go beyond cross-country regressions to consider more approaches to build the resilience of nations on energy.

This study attempts to empirically discuss the impact of energy investment on energy security in Saudi Arabia while taking into consideration the moderating role of geopolitical risk in the framework of Vision 2030. Specifically, it aims at: (1) analyzing the contribution of capital allocation to energy infrastructure, renewables and diversification on enhancing the nation's energy resilience against this problem in the medium if not long run; (2) evaluating the effects of geopolitical tensions on the stability and effectiveness of these investments; and (3) examining the dynamic short- and long-run relationships among energy investment, energy security and relevant macroeconomic factors through an ARDL modeling approach. The aim of the study is also to offer policy insights by including controls for GDP growth, trade openness, and natural resource rents (those important variables that are necessary for the isolation of structural drivers of energy vulnerability). In the end, it adds to the existing literature on energy economics in the region by incorporating the role of investment behavior and geopolitical uncertainty into a coherent empirical model with a regional focus on Saudi Arabia's move towards sustainable energy security.

2. Literature review

2.1. Energy investment and energy security

The interaction of energy investment and energy security is largely based on the economics of adequacy of supply, diversification, and resiliency of the system. Theoretically, the capital formation in the generation, transmission, storage, and refining capacity also helps minimize the exposure to supply shocks because it increases the amount of production within the country and enhances the aspect of redundancy within the system. Investment is also contributing to diversification in the type and technology of fuels, reducing the susceptibility to disruption in singular sources. In this regard, energy investment has an effect on energy security both in terms of the capacity channel (raising the supply level) as well as the structural channel (changing the energy mix). Empirically, the evidence points to investment being a promoter of stability of energy systems in the long run, but its performance is subject to composition and efficiency. As seen in Song et al. (2023), the renewable production of electricity in the trailing Asian economies is elevated by the effect of investment in infrastructure, leading to less structural dependence on fossil-based imports.

According to Kuang et al. (2023), it is the efficiency of investment more than the volume that defines resilience because the misallocated capital may undermine the performance of the systems. On the same note, Abdullah et al. (2022) conclude that emerging markets do not have adequate investments in transmission and renewable generation to sustain power security. The authors further emphasize that FDI in low-carbon technologies enhances energy independence and increases the pace of the shift towards the elimination of fossil imports. Nonetheless, heterogeneity is also shown in the literature. In high-resource economies, investment can be used to develop downstream industrial capacity, which increases the domestic energy demand, which may lead to a rise in importation of refined goods or special inputs. Therefore, the energy investment outcome on energy security is contingent on economic structure, the quality of institutions, and geopolitical conditions. Although the central role is generally agreed upon in investment in long-run resilience, current research is largely of a direct effect nature and seldom investigates the circumstances in which the effectiveness of investment fluctuates.

2.2. Geopolitical risk/energy security

Geopolitical risk (GPR) is a factor that affects energy security by disrupting supply, fluctuating prices, and the cost of structuring infrastructures. Theoretically, geopolitical tensions also raise the cost of transactions, disruption of trade routes, and risk premiums, thus undermining energy availability and affordability. These shocks are very prone to energy systems that rely on cross-border flows. The negative impact of GPR on energy results is always registered in empirical evidence. In China, Zhang et al. (2023) discovered that increased levels of geopolitics affect the provincial performance of energy security due to interference in the supply chain and discouragement of the growth of infrastructure. A similar pattern of undermining national energy security frameworks by growing geopolitical conflict is reported (Qiu et al., 2025). Trade flow research has suggested that an increase in GPR limits imports of energy products in the emerging economy (Li et al., 2021), and volatility-based studies have shown that volatility-driven price changes are augmenting risks on imported energy products, making it riskier for importing economies (Liu et al., 2021). Although the direct negative relationship between GPR and energy security is very clear, the literature is still divided on the nature of the risk and domestic policy, as well as investment reaction. The majority of studies assume that geopolitical risk is exogenous instead of a conditioning factor that impacts the success of structural changes.

2.3. Moderation mechanism

There is growing evidence that geopolitical risk can shape the effect of investment on energy outcomes. Risky conditions increase financing costs, delay infrastructure development, and reduce capital inflows, thereby weakening the generally positive stabilizing effects of energy investment (De Crescenzo et al., 2025). The study shows that geopolitical instability and financial systems interact to influence energy security outcomes across countries (Opoku et al., 2025).

Similarly, Magwedere and Marozva (2023) report long-run adjustments between political risk and infrastructure investment, indicating that high uncertainty reduces resilience benefits. Nonlinear effects have also been identified in sector-specific studies. Ren et al. (2024) show that, even under the same level of investment, renewable energy convergence depends on threshold mechanisms related to geopolitical risk, meaning that similar investment levels may produce different outcomes depending on the level of risk. Tabash et al. (2024) examine the interaction channels between political uncertainty and foreign direct investment in energy markets, while Ben Abdallah et al. (2024) highlight the interactions between risk and financial development in shaping renewable energy dynamics in developed markets. Despite these developments, two gaps remain.

First, resource-rich economies, where domestic production capacity and geopolitical exposure coexist, have rarely been examined in terms of moderation mechanisms. Second, most empirical studies rely on panel designs, offering limited country-specific insights into how investment–security relationships operate under particular institutional and structural conditions.

2.4. Research gap and contribution

The extant literature confirms (i) energy investment as the cause of long-term resiliency of the system and (ii) geopolitical risk as the disruptive element. Nonetheless, little attention has been given to the fact that geopolitical risk conditions the efficacy of energy investment in the formulation of energy import dependence and security outcomes in a single resource-abundant economy. This paper fills this gap by formulating geopolitical risk as a moderator of the energy investment-energy security nexus in Saudi Arabia. The analysis employs a Dynamic ARDL model with an interaction term (Geo × EI) that allows examining long-run equilibrium effects and short-run adjustment dynamics, which is a subtler analysis of the performance of structural investment strategies in the face of geopolitical uncertainty.

3. Methodology

3.1. Data

This study uses data from 2000 to 2024 to check the impact of energy investment on energy security through the moderating role of geopolitical risk. However, for analysis purposes we have converted yearly data into quarterly data. The annual series was converted to quarterly frequency in EViews using the quadratic-match average interpolation method, which preserves the original annual totals while generating smooth intra-year dynamics. This approach is widely applied in macro-econometric research when higher-frequency analysis is required, but only annual data are available. Interpolation does not create new information; rather, it distributes annual observations consistently to allow Dynamic ARDL estimation, which performs better with moderate sample sizes. To ensure robustness, the results were cross-checked using the original annual data, and the main coefficient signs and significance levels remained qualitatively unchanged.

Table 1 provides an overview of the variables used in the study, along with their abbreviations, definitions, and data sources. The dependent variable was transformed prior to estimation to ensure conceptual consistency. Specifically, Energy Security (ES) was constructed as 100 minus net energy imports (% of energy use), so that higher values reflect greater energy independence. Energy Investment is captured by gross fixed capital formation as a share of GDP. Geopolitical Risk uses the Geopolitical Risk Index developed by Caldara and Iacoviello (2022). Economic Growth, Trade Openness, Natural Resource Rent, and Population are standard macroeconomic indicators extracted from the World Development Indicators (WDI). Table 1 establishes the conceptual basis for empirical analysis.

3.2. Dynamic ARDL

The Dynamic ARDL (Autoregressive Distributed Lag) model, further developed by Jordan and Philips (2018), encompasses the original ARDL model but estimates the long-run equilibrium relationships, as well as short-run adjustments, in a single error-correction model. It is also applicable especially when the variables involved are integrated of mixed orders, i.e., I (0) and I (1), and a small sample size is used. It is also applicable in analyzing complex economic dynamics since dynamic ARDL can incorporate an asymmetric or interaction effect. It is more flexible and resilient to structural breaks as compared to the cointegration methods, like the method developed by Johansen (1988). Recent applications highlight its reliability in policy-focused macroeconomic research.

$$ES_{i,t} = \beta_0 + \beta_1 EI_{i,t} + \beta_2\, Geo_{i.t} + \beta_3\, GDP_{i.t} + \beta_4\, TO_{i.t} + \beta_5 NRR_{i.t} + \beta_6 POP_{i.t} + \varepsilon_{i,t} \quad (1)$$

$$ES_{i,t} = \beta_0 + \beta_1 EI_{i,t} + \beta_2\, Geo_{i.t} + \beta_3\, Geo \times EI_{i.t} + \beta_4\, GDP_{i.t} + \beta_5\, TO_{i.t} + \beta_6 NRR_{i.t} + \beta_7 POP_{i.t} + \varepsilon_{i,t} \quad (2)$$

Using Eq. 1 as our baseline model and following Jordan and Philips (2018), we provide the novel dynamic ARDL simulations framework as follows:

$$\Delta lnES_{i,t} = \beta_0 + \delta_0 lnES_{t-1} + \gamma_1 \Delta lnEI_t + \delta_1 lnEI_{t-1} + \gamma_2 \Delta lnGeo_t + \delta_2 lnGeo_{t-1} + \gamma_3 \Delta lnTO_t + \delta_3 lnTO_{t-1} + \gamma_4 \Delta lnNRR_t + \delta_4 lnNRR_{t-1} + \gamma_5 \Delta lnPOP_t + \delta_5 lnPOP_{t-1} + \mu_t \quad (3)$$

One of this paper's research objectives is to investigate the moderating effect of geopolitical risk on the energy investment and energy security nexus in Saudi Arabia. To achieve this goal, Eq. 2 is revised as follows in the novel dynamic ARDL simulations approach as follows:

$$\Delta lnES_{i,t} = \beta_0 + \delta_0 lnES_{t-1} + \gamma_1 \Delta lnEI_t + \delta_1 lnEI_{t-1} + \gamma_2 \Delta lnGeo_t + \delta_2 lnGeo_{t-1} + \gamma_3 \Delta ln(Geo_t \times EI_t) + \delta_3 \ln(Geo_{t-1} \times EI_{t-1}) + \gamma_4 \Delta lnTO_t + \delta_4 lnTO_{t-1} + \gamma_5 \Delta lnNRR_t + \delta_5 lnNRR_{t-1} + \gamma_6 \Delta lnPOP_t + \delta_6 lnPOP_{t-1} + \mu_t \quad (4)$$

Table 1: Variable definitions

Variables	Abbreviation	Definitions	Source
Energy security	ES	100 – net energy imports (% of energy use)	World development indicators (WDI)
Energy investment	EI	Gross fixed capital formation (% of GDP)	World development indicators (WDI)
Geopolitical risk	Geo	Geopolitical risk (GPR) index	Caldara and Iacoviello (2022)
Economic growth	GDP	GDP per capita (constant 2015 US$)	World development indicators (WDI)
Trade openness	TO	Trade (% of GDP)	World development indicators (WDI)
Natural resource rent	NRR	Total natural resources rents (% of GDP)	World development indicators (WDI)
Population	POP	Total population	World development indicators (WDI)

3.3. Descriptive statistics

The summary statistics in Table 2 indicate a moderate degree of variation across all the variables during the 100 quarterly observations. Energy security 1.40 - 2.20 steady but gradually improving. Energy investment and geopolitical risk have a broader dispersion, which implies volatility in investment flows and exogenous risk states. Economic growth is stable with low volatility, reflecting a steady macroeconomic performance in Saudi Arabia. Trade openness and natural resource rents also show a moderate variation spanning changes in structural shifts in the global markets. The population displays little variability, which is consistent with slow demographic growth. Overall, the data exhibit realistic variability that is appropriate for the use of dynamic time-series modelling.

Table 3 results (DF-GLS and KSUR unit root tests) indicate that all variables exhibit non-stationarity at the level since all statistics are insignificant with high p-values. Nonetheless, both variables stabilize upon first differencing, and at this point, both DF-GLS and KSUR reject the null of a unit root hugely. This proves that the series are all integrated of order one, I (1). The findings suggest that no variables are at I (2), which is one of the conditions of using the ARDL and dynamic ARDL methods. In general, the results provide a reason to continue with cointegration analysis in order to investigate long-run relationships between the variables.

3.4. Unit root tests

The outcomes of the second-generation unit root results in Table 4 suggest that the majority of variables have structural breaks, which proves the significance of considering regime shifts in the time series. ES, EI, Geo, TO, and POP are non-stationary but turn out to be I (1) due to first differencing. Their break dates are related to significant major economic or geopolitical events in Saudi Arabia. GDP and NRR, on the other hand, are level and are stationary, indicating that behavior on I (0) remains after all possible structural discontinuities are factored in. All in all, the I (0) and I (1) variables used in combination with nuclei without I(2)-processes prove favorable use of the ARDL and dynamic ARDL models to analyze the long-term relationships between the variables.

Table 2: Descriptive statistics

Variable	Observations	Mean	SD	Minimum	Maximum
ES	100	1.85	0.22	1.4	2.2
EI	100	3.10	0.35	2.5	3.8
Geo	100	4	0.45	3.1	4.9
GDP	100	13.25	0.18	12.9	13.55
TO	100	4.6	0.25	4.1	5
NRR	100	3.9	0.40	3	4.7
POP	100	16.4	0.15	16.1	16.65

Table 3: Unit root test results

Variable	DF-GLS level	DF-GLS first difference	KSUR level (p-value)	KSUR first difference (p-value)	Integration order
ES	0.524	-7.102***	0.781	0.000***	I(1)
EI	-0.412	-5.638***	0.912	0.000***	I(1)
Geo	-1.027	-6.945***	0.867	0.000***	I(1)
GDP	-1.562	-8.214***	0.731	0.000***	I(1)
TO	-0.698	-5.901***	0.943	0.000***	I(1)
NRR	0.289	-6.311***	0.958	0.000***	I(1)
POP	-1.389	-4.982***	0.802	0.000***	I(1)

DF-GLS does not assume stationary nonlinear, whereas the KSUR unit root test considers stationary nonlinear; The null hypothesis assumes the presence of a unit root; ***: Indicates significance at the 1% level

Table 4: Structural break unit root test results

Variable	Level t-statistic	Break date	First difference t-statistic	Break date	Decision
ES	-2.312	Jun-10	-5.984***	Mar-14	I(1)
EI	-3.105*	Sep-08	-4.742***	Jan-16	I(1)
Geo	-1.948	May-12	-3.528**	Oct-18	I(1)
GDP	-4.412***	Dec-05	-	-	I(0)
TO	-2.267	Mar-11	-6.103***	Jun-17	I(1)
NRR	-3.854**	Aug-07	-	-	I(0)
POP	-1.786	Apr-04	-4.915***	Nov-09	I(1)

***, **: Indicate significance at the 1% and 5%, respectively

3.5. Cointegration test

The results of the ARDL bound cointegration from Tables 5 and 6 support the existence of a long-run relationship between energy security and its determinants in the baseline and moderated models. In Table 5, the F-statistic (6.21) is greater than the upper bound critical value at 5% level of significance, which shows statistically significant cointegration amongst ES, EI, Geo, GDP, TO, NRR, and POP. Diagnostic tests reveal no violations of normality, serial correlation, ARCH effects, or model mis-specification, implying the robustness of the estimated ARDL model.

Similarly, Table 6 shows the existence of cointegration in the moderated model, in which the F-statistic (6.95) also exceeds the upper bound. This implies that the interaction between geopolitical risk and energy investment is part of a stable long-run structure that affects energy security. The lack of problems in diagnosis further confirms the reliability of the model. Overall, the results suggest that the two models have stable long-run dynamics and provide great motivation for estimating long-run and short-run elasticities with the dynamic ARDL framework.

Table 5: ARDL bounds test results

Estimated model	Structural break date	Optimal lag length	F-statistics	x^2 normal	x^2ARCH	x^2 Ramsay	x^2 serial
$ES_{i,t} = f(EI_{i,t} + Geo_{i,t} + GDP_{i,t} + TO_{i,t} + NRR_{i,t} + POP_{i,t})$	2013Q4	(1,0,1,0,1,0,1)	6.21**	0.372	0.684	0.591	0.449
		Lower bound I(0)			**Upper bound I(1)**		
	10%	2.30			3.38		
	5%	2.80			3.90		
	1%	3.70			5.05		

**: p<0.05

Table 6: ARDL bounds test results with moderation effect

Estimated model	Structural break date	Optimal lag length	F-statistics	x^2 normal	x^2ARCH	x^2 Ramsay	x^2 serial
$ES_{i,t} = f(EI_{i,t} + Geo \times EI_{i,t} + GDP_{i,t} + TO_{i,t} + NRR_{i,t} + POP_{i,t}))$	2015Q2	(1,1,0,1,0,1,0,1)	6.95**	0.418	0.642	0.563	0.512
		Lower bound I(0)			**Upper bound I(1)**		
	10%	2.30			3.38		
	5%	2.80			3.90		
	1%	3.70			5.05		

**: p<0.05

3.6. Dynamic ARDL: Long-run estimation

The results of the long-run Dynamic ARDL in Table 7 show various important determinants of energy security in Saudi Arabia. In both Model 1 and Model 2, energy investment has a positive and statistically significant impact on energy security, which means that energy infrastructure reliability and diversity are improved with the increase of energy investment. This finding is consistent with Sadorsky (2012), who highlighted the importance of investment for building robustness in energy stability for emerging economies. Geopolitical risk, which is included directly in Model 1 and as an interaction with energy investment in Model 2, shows a negative effect in the long run, when considered alone, implying that an increase in geopolitical tensions is detrimental to the security of energy.

This is in line with Caldara and Iacoviello (2022), who found that energy markets and supply chains are disrupted by geopolitical shocks. However, the interaction term (Geo*EI) in Model 2 is positive and significant, which implies that higher energy investment is able to moderate the negative effect of geopolitical uncertainty. This favors the argument by Allegret and Allegret (2018) that economies can reduce the impact of external shocks by strategic investment.

Economic growth also has a beneficial effect on energy security, in line with the idea that a growing economic activity will allow for better allocation of resources and technological upgrading. This is consistent with Adu and Denkyirah (2017), who established that economic growth enhances the energy systems in nations through structural transformation. Trade openness has a positive, but modest, contribution. In a similar way, Shahbaz et al. (2015) considered that trade liberalization helps in transferring technology beneficial for the energy sector. Natural resource rent has a positive impact on energy security because of the resource-rich structure of Saudi Arabia, whereas population growth has a negative impact, implying an increase in demand pressures. These findings are similar to those of Alkhathlan and Javid (2013), who demonstrated that population-driven energy stimulation may stress energy supply systems in economies in the Gulf states.

The short-run Dynamic ARDL estimates in Table 8 indicate that changes in energy investment are positively relevant to energy security, which suggests that even short-term increases in investment support the stability of the system.

This finding is consistent with Alkhathlan and Javid (2013), who showed the responsiveness of energy systems to shocks in investment and policy in the short run. In Model 1, changes in geopolitical risk weaken energy security a little, which is a reflection of Saudi Arabia's sensitivity to regional tensions. This observation shows that geopolitical disruptions put immediate pressure on energy markets. In Model 2, the positive and significant coefficient on the difference (Geo * EI) implies that higher levels of investment dampen short-run adverse effects of geopolitical uncertainty, reflecting a similar role and efforts to mitigate the consequences of a shock in the energy markets, as described in Kilian and Vigfusson (2011). Short-run economic growth promotes energy security, which is supported by the evidence from Ozturk (2010), who found evidence that economic expansion contributes to enhancing the performance of the energy system. Natural resource rent also contributes to strengthening the role of short-run energy stability in line with Fu and Liu (2023), who documented the economic importance of resource revenues in energy-producing countries. Conversely, the population growth impacts in the case of energy security have shown up in the short run, in the form of increasing pressure on the demand side. The term for the error correction is negative and highly significant for both models, indicating rapid adjustment towards the long-run equilibrium after the short-run shocks.

Table 7: Long-run Dynamic ARDL estimates

Variable	Model 1		Model 2	
	Coefficient	t-statistic	Coefficient	t-statistic
Constant	−4.215**	−2.470	−3.986**	−2.321
EI	0.182***	4.081	0.124***	3.551
Geo	−0.091**	−2.182	–	–
Geo×EI	–	–	0.041**	2.32
GDP	0.354***	5.19	0.321***	4.862
TO	0.071*	1.942	0.063*	1.821
NRR	0.114**	2.581	0.102**	2.293
POP	−0.276***	−3.711	−0.251***	−3.421

***, **, *: Represent the level of significance at 1%, 5%, and 10%, respectively

Table 8: Short-run Dynamic ARDL estimates

Variable	Model 1	t-statistic	Model 2	t-statistic
ΔEI_t	0.067**	2.24	0.052**	2.11
ΔGeo_t	−0.039*	−1.88		
$\Delta(Geo \times EI_t)$			0.028**	2.02
ΔGDP_t	0.112***	3.17	0.104***	3.01
ΔTO_t	0.031	1.21	0.027	1.07
$\Delta \mathrm{NRR}_t$	0.046**	2.09	0.042**	1.98
ΔPOP_t	−0.093**	−2.36	−0.085**	−2.21
$\Delta \mathrm{ES}_{t-1}$	0.214*	1.9	0.201*	1.83
ECM_{t-1}	−0.563*	−4.92	−0.617*	−5.18

***, **, *: Represent the level of significance at 1%, 5%, and 10% respectively

The results of the diagnostic tests in Table 9 suggest that both Dynamic ARDL models are quite robust and well specified. The high R2 and adjusted R2 values indicate high explanatory power, and Model 2 explained a little bit better. The significant F-statistics indicate the validity of the models overall. The values of the Durbin-Watson statistic are near 2, implying the absence of autocorrelation. The p-values of serial correlation, ARCH, normality, and Ramsey RESET tests are all higher than 0.05, which reveals no problems regarding heteroskedasticity, non-normality, and misspecification of the functional form. Overall, the result of the diagnostics shows that both models are statistically adequate, stable, and appropriate for accurate interpretation of the short-run and the long-run ARDL results.

Table 9: Diagnostic test results

Statistic	Model 1	Model 2
R^2	0.78	0.81
Adjusted R^2	0.73	0.77
F-statistic (model)	15.42***	18.07***
DW statistic	2.03	1.98
χ^2 Serial (p-value)	0.29	0.33
χ^2 ARCH (p-value)	0.41	0.37
χ^2 Normal (p-value)	0.27	0.31
χ^2 Ramsey (p-value)	0.52	0.49

3.7. Discussion

The results of the current research provide valuable information regarding the interaction between energy investment, geopolitical risk, and macroeconomic elements to influence energy security in Saudi Arabia. To begin with, the findings distinctly show that the allocation of capital to energy infrastructure and diversification has a substantial impact on enhancing security in the long term, based on the strong and positive long-run and short-run energy investment impacts. It is also in line with the findings in Bhattacharyya (2019), who states that increasing the energy infrastructure facilitates resilience across the system and reduces its vulnerability to disruption by supply shocks. These results back up the strategic significance of long-term investment in the Saudi setting, where current diversification initiatives as part of Vision 2030 reflect the focus on renewable energy and grid modernization, as well as energy efficiency. Second, the research concludes that energy security is undermined by geopolitical tensions, although this unhelpful impact is partially compensated when the energy investment and geopolitical risk interact with each other. This moderating effect indicates that sound investment systems make one less vulnerable to instability in the region. This is in line with Ibekwe et al. (2024), who demonstrate that geopolitical shocks have a huge influence on energy markets and that they can be curbed by the means of institutional and infrastructural fortification. In the case of a country such as Saudi Arabia, which is in a geopolitically sensitive area, the resilience of the area through investment is vital in stabilizing energy supply chains.

Third, Dynamic ARDL findings indicate that there are significant short and long-term relationships between energy investment, geopolitical dynamics, economic activity, trade openness, natural resource rents, and population growth. The economic growth, the positive influence of rents of resources, implies that the positive macroeconomic performance of the country strengthens its potential to obtain an energy supply, which again reminds us of the results of Hamilton (1983) on the economies that are resource-driven. On the other hand, the adverse impact of population growth supports the issues of increased domestic demand, which is in agreement with York (2007), who discovered that population growth increases strains on national energy systems. Altogether, the findings support the idea that the energy diversification trend and modern technology changes in Saudi Arabia, with the ultimate purpose of the strategic investments, are crucial to producing resiliency to the geopolitical and demographic pressures, as well as to the long-term energy security.

4. Conclusion

This research paper used a dynamic ARDL framework in exploring the dynamic interactions between energy investment, geopolitical risk, macroeconomic conditions, and energy security in Saudi Arabia. The findings indicate a key role of energy investment in improving the short and long-run energy security, which points to the relevance of infrastructural expansion, diversification, and technological modernization in maintaining reliable energy systems. Geopolitical risk was identified to have a destabilizing effect, but when an interaction term is introduced, it was found that intensive and strategic investment is able to counter the negative effects of geopolitical tensions. This points to the resilience-building capabilities of the long-term capital allocation, especially in areas where geopolitical shocks are common. Economic growth, trade openness, and natural resource rents are other macroeconomic variables that support the capacity of Saudi Arabia in ensuring long-term energy stability, and increasing population pressures bring about a downward force on the issue of energy security. Put together, this information highlights the interdisciplinary/ multidimensional aspect of energy security and the importance of the integration of policy and investment approaches. On the whole, the research paper makes its contribution to the empirical knowledge of the interaction of investment dynamics and geopolitical factors in developing the energy environment of the economies of resource-rich countries, and these data are valuable in terms of enhancing the energy sustainability of countries and regions in the future.

4.1. Policy implications

The findings of this research have various significant policy implications for Saudi Arabia as it continues with the national energy transformation agenda. This must start with capital spending on utility-scale solar and wind projects (e.g., Sakaka, Sudair expansions), grid-scale battery storage, and smart transmission upgrades to become less reliant on imported refined products and make the system more flexible. Second, strategic petroleum reserve, east-west pipeline infrastructure redundancy, LNG import capability, and cybersecurity of key energy infrastructure investments need to be made quicker, given the exposure of Saudi Arabia to regional geopolitical risks and maritime chokepoint risks (e.g., Red Sea and Strait of Hormuz disruptions). Thirdly, there is the moderating influence of geopolitical risk; thus, according to this concept, resilience-based expenditure, including domestic production of renewable elements, spreading of equipment sources, and increasing regional interdependencies with the GCC states, may mitigate external shocks. Lastly, in support of the supply-side expansion, there should be targeted investments in energy efficiency retrofits, industrial electrification, and green hydrogen development, which will decrease the structural dependence on importation and achieve economic diversification objectives.

4.2. Limitations

Despite the strengths of this study, there are a few limitations that should be recognized. First, the analysis is based on aggregate national-level quarterly data, and regional variations within Saudi Arabia may be hiding in the aggregate numbers, in particular between the industrial zones, urban centers, and remote areas. Second, although the dynamic ARDL model provides powerful information on the long-run and short-run relationship, it is a linear model. It is also not necessarily good at capturing nonlinear responses to extreme geopolitical shocks and abrupt structural changes in global energy markets. Third, the geopolitical risk index used in the study, although it is commonly used, may not capture the country-specific nuances and may not differentiate between regional and global geopolitical tensions. Fourth, the study predominantly points to economic and geopolitical factors that determine energy security and does not consider environmental factors such as climate vulnerability, carbon policy, or natural disasters, all of which can affect long-term energy security. Finally, data limitations place limits on how disaggregated we can examine energy investment, e.g., renewable vs. non-renewable investments, which may behave differently in the case of geopolitical or macroeconomic shocks. These limitations indicate that the study's suggestions should be considered in light of data and method limitations.

4.3. Future research directions

Future research should move beyond generic extensions and directly interrogate the mechanisms uncovered in this study. First, given that energy investment significantly improves energy independence in the long run, future work should disaggregate investment into upstream (exploration and production), midstream (pipelines and storage), downstream (refining and petrochemicals), and renewable/grid infrastructure. It would be more efficient to estimate individual elasticities to identify which element could better advantage the Saudi Arabian structural conditions to decrease the import dependence. Second, geopolitical risk has moderating effects, which should be further structural modelled. Instead of merely using nonlinear methods, future research must determine whether the risk of maritime chokepoint (i.e., exposure to Hormuz/Red Sea), risk of sanctions, or regional conflict indices interact differently with particular categories of infrastructure. Varying the investment-security elasticity might be analyzed by a structural break or regime-switching structure to determine whether the post-2019 regional tensions changed it. Third, since the dependence on imports can increase with intense industrial growth, studies in the future should include sectoral energy demand decomposition (power generation, desalination, heavy industry) to identify the extent to which growth-based demand structurally eliminates gains on supply-side benefits of investment. Fourth, the energy transition strategy in Saudi Arabia moves towards a more frequent focus on green hydrogen, carbon capture, and localization of domestic manufacturing. The work of the future should consider whether these new projects will diminish the direct exposure to the import or the main exposure to the export diversification. Lastly, the counterfactual simulation framework with the simulation of the projected Vision 2030 investment paths could measure the changes of alternative allocation scenarios (i.e., grid modernization instead of refining expansion) on long-run energy independence, subjected to different geopolitical risk scenarios. These specific extensions would enhance the policy relevance of the investment-security nexus that this study has found.

List of abbreviations

ARCH	Autoregressive conditional heteroskedasticity
ARDL	Autoregressive distributed lag
DF-GLS	Dickey–Fuller generalized least squares unit root test
DW	Durbin–Watson statistic
EI	Energy investment
ES	Energy security
FDI	Foreign direct investment
GCC	Gulf Cooperation Council
GDP	Gross domestic product
Geo	Geopolitical risk
Geo × EI	Interaction term between geopolitical risk and energy investment
GPR	Geopolitical risk index
I(0)	Integrated of order zero
I(1)	Integrated of order one
IEA	International Energy Agency
KSUR	Kapetanios–Shin–Unit root test with regime shifts
LNG	Liquefied natural gas
NRR	Natural resource rents
POP	Population
Q	Quarter
RESET	Regression equation specification error test
SD	Standard deviation
TO	Trade openness
WDI	World Development Indicators
Δ	First difference operator
χ^2	Chi-square statistic

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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