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Energy Efficiency and Industrial Competitiveness: Case Study of the GCC Region using CS-ARDL and PMG-ARDL approach

Mohamed A. M. Sallam, Tarek Sadraoui*

College of Business, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh, Saudi Arabia. *Email: tsadraoui@imamu.edu.sa

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ABSTRACT

This study examines the relationship between industrial competitiveness and energy efficiency in the Gulf Cooperation Council (GCC) countries, whose economic development has historically relied on energy-intensive industries. With the global economy shifting towards energy-efficient and sustainable production, improving energy efficiency is a key driver of industrial competitiveness. Using panel data analysis over 1990-2024, we establish the impacts of decreases in energy intensity, the use of renewable energy, and policy interventions on industrial performance. Applying a comparative panel autoregressive distributed lag (CS-ARDL), NARDL, PMG-ARDL approaches, our results show that enhanced energy efficiency enhances industrial competitiveness by reducing production costs and increasing productivity. The impact, however, varies by industry, with industries using more energy incurring greater adaptation costs. The research provides useful insights to policy-makers on balancing economic diversification, energy reforms, and industrial sustainability to make the GCC competitive in the international market.

Keywords: Energy Efficiency, Industrial Competitiveness, GCC Region, Sustainable Development, Renewable Energy, Energy Intensity
JEL Classifications: Q43; L52; O13; F64; C33

1. INTRODUCTION

Recent scientific literature indicates that improving energy efficiency is one of the fundamental pillars of achieving sustainable development, as it leads to multiple economic and environmental benefits. The most prominent of these benefits is the reduction of operating costs because of reducing energy consumption, which allows companies to direct financial resources towards other areas such as research and development or expanding the scope of business. In addition, improving energy efficiency enhances industrial productivity using advanced technologies that rely on less energy resources, which reduces waste and increases operational efficiency. Reducing carbon emissions resulting from improving energy efficiency also contributes to improving companies' reputation on a global level, especially in light of the increasing global interest in sustainability and climate change (IEA, 2021).

However, achieving these benefits requires meticulous strategic planning and substantial investments in modern infrastructure and technology. For instance, companies need to upgrade outdated machinery and equipment, adopt smart energy management systems, and train employees on using new technologies. Additionally, the success of energy efficiency policies heavily depends on effective implementation and coordination among government entities, the private sector, and civil society. It is also essential to overcome cultural and regulatory obstacles that may hinder the adoption of these technologies, such as resistance to change or a lack of awareness about the importance of energy efficiency.

In the industrial sector, improving energy efficiency can lead to a reduction in fuel consumption in production processes, thereby lowering operational costs and increasing profit margins. For example, adopting technologies such as waste heat recovery or energy-efficient materials can reduce waste and enhance production efficiency by up to 20-30% in some cases (UNIDO, 2019). Additionally, the use of integrated energy management systems can help monitor and optimize energy consumption on an ongoing basis.

Therefore, it can be said that improving energy efficiency is not only a strategic choice for companies and governments but also a necessity for achieving global sustainable development goals. However, achieving these goals requires international cooperation, continuous investment in research and development, and supportive policies that encourage the adoption of modern technologies.

The Gulf Cooperation Council (GCC) region is considered one of the most energy-dependent areas in the world, where oil and gas resources form the backbone of its national economies. These hydrocarbon resources are not only a primary source of national income for these countries but also the main driver of economic growth and social development (Al-Saidi and Elagib, 2017). However, these countries face increasing challenges due to global and regional changes that directly affect the sustainability of their economic growth and the diversification of their production bases. Among these challenges are the continuous rise in domestic energy demand, sharp fluctuations in oil prices, and international pressures to adopt more sustainable environmental policies (IEA, 2020). In this context, energy efficiency has emerged as one of the key factors that can enhance industrial competitiveness, enabling these countries to achieve sustainable economic growth and reduce excessive reliance on hydrocarbon resources (World Bank, 2019).

The GCC countries, including Saudi Arabia, the United Arab Emirates, Qatar, Kuwait, Oman, and Bahrain, have already begun implementing ambitious strategies to improve energy efficiency across various economic sectors. For example, "Saudi Vision 2030" aims to significantly reduce energy consumption by adopting modern technologies and promoting the use of renewable energy (Saudi Vision 2030, 2021). Similarly, the UAE Energy Strategy 2050 seeks to achieve a balance between traditional and renewable energy sources, with a focus on improving consumption efficiency (UAE Energy Strategy 2050, 2017). These efforts are not merely steps toward achieving environmental goals but also an economic strategy aimed at enhancing industrial productivity and reducing operational costs, thereby strengthening the competitiveness of industries in global markets (IRENA, 2020).

The relationship between energy efficiency and industrial competitiveness is deeply intertwined, as improving energy efficiency can significantly enhance industrial sectors' economic performance and global standing. Energy efficiency reduces operational costs by minimizing energy consumption, directly translating into lower production expenses and higher profit margins. This cost-saving advantage allows industries to reinvest in innovation, technology upgrades, and workforce training, further boosting productivity and competitiveness. Additionally, energy-efficient practices often lead to improved resource management and reduced waste, which can enhance the overall sustainability of industrial operations. In a global market increasingly focused on environmental sustainability, companies that adopt energy-efficient technologies gain a competitive edge by meeting international environmental standards and improving their brand reputation. For instance, industries that reduce their carbon footprint through energy efficiency can access new markets and attract environmentally conscious consumers and investors. Furthermore, energy efficiency supports long-term economic resilience by reducing dependency on volatile energy prices and finite resources, ensuring more stable and predictable operational costs. Therefore, energy efficiency is an environmental imperative and a strategic tool for enhancing industrial competitiveness in a rapidly evolving global economy (IEA, 2021; UNIDO, 2019).

The problem of the study revolves around the lack of clarity in the relationship between improving energy efficiency and enhancing industrial competitiveness in the GCC countries, especially in light of the challenges facing these countries, such as heavy reliance on hydrocarbon resources, high local demand for energy, and difficulties in adopting modern technologies. Despite government efforts to improve energy efficiency through strategies such as "Saudi Vision 2030" and "UAE Energy Strategy 2050", there is a need to better understand how these efforts affect industry competitiveness, and what factors can enhance or hinder the achievement of these goals.

The study's main objective is to analyze the relationship between improving energy efficiency and enhancing industrial competitiveness in the GCC countries and identify the main challenges that hinder this improvement. The study will seek to test the following hypotheses:
- There is no statistically significant relationship between improving energy efficiency and enhancing industrial competitiveness in the GCC countries.
- There is no statistically significant effect of adopting modern technologies (such as smart energy management systems and waste heat recovery) on improving energy efficiency in the GCC countries.
- There is no statistically significant effect of government policies (such as national strategies) on promoting the adoption of energy efficiency technologies in the GCC countries.
- There is no statistically significant effect of improving energy efficiency on reducing carbon emissions and enhancing corporate reputation in the GCC countries.

The structure of the paper will be divided into 4 Sections. The first section is an Introduction; the second section is a Brief theoretical and empirical literature review—section 3, along with Methodology, and Section 4, Conclusions and Recommendations.

2. BRIEF THEORETICAL AND EMPIRICAL LITERATURE REVIEW

2.1. Brief Theoretical Literature

2.1.1. Energy efficiency and industrial competitiveness

Energy efficiency is central to reducing production costs, making processes more sustainable, and improving the performance of the industrial sector. However, how far energy efficiency can contribute towards making industry directly more competitive continues to be contentious. While heightened energy efficiency would lower the costs of operations as well as the damage to the environment, according to some research, heightened energy efficiency will not always lead to better competitiveness.

Sadorsky (2010) focuses on the influence of financial development on the pattern of energy consumption in developing countries, noting that availability of financial resources is a determinant of energy efficiency investments. Likewise, Apergis and Payne (2012) believe that there should be a shift towards the utilization of renewable energy sources for sustainable industrial development, and it is noted that energy policies should be aligned with the overall economic and technological progress.

In the Gulf Cooperation Council (GCC) region, where energy supply is abundant and subsidized, the past cost advantages of energy-intensive industry can reduce the incentive for energy efficiency improvement. However, as global markets start to adopt sustainability standards and carbon regulation, GCC industries are compelled to adapt by combining energy efficiency with technological innovation and policy reforms Al-Mulali and Sab (2021) and Liu and Lin (2020). Pao and Tsai (2011) also point out that energy efficiency needs to be placed within the context of a broader industrial modernization process, and not as an isolated policy measure.

2.1.2. Trade openness and industrial competitiveness

Trade openness is typically associated with increased market access, technology transfer, and improved productivity. However, whether trade openness is helpful for industrial competitiveness is a function of the economic structure of the country. While trade openness can potentially strengthen efficiency through competition and foreign direct investment (FDI) inflow, excessive dependency on foreign markets can be a source of weakness. Pao and Tsai (2011) explore the relationship between energy consumption, FDI, and GDP growth in BRIC nations, where the evidence shows that trade openness contributes to or debilitates industrial performance based on the relative position of domestic industries in value chains (Cherniwchan, 2017).

Trade openness presents a unique challenge for the economies of the GCC. The region's industrial sector relies heavily on energy-using industries and natural resource-based exports, and is therefore susceptible to international demand fluctuations. Without supportive domestic production capacities and technological capabilities, greater trade exposure could lead to deindustrialization rather than competitiveness. Farhani and Ozturk (2015) highlight the need for policy interventions that reconcile trade liberalization with domestic industrial policies so that domestic industries can withstand external shocks while enjoying the dividends of global integration.

2.1.3. Investment, innovation, and economic growth

Investment in infrastructure, technology, and human capital is widely seen as a key source of industrial competitiveness. More and more evidence confirms the necessity of policies that are innovative in nature in order to preserve economic performance and industrial power. Farhani and Ozturk (2015) explore the nexus between CO_2 emission, GDP, and financial development, asserting that economies that put technological investment as a topmost priority are most likely to foster long-term sustainability and competitiveness. Secondly, Dinda (2004) provides the Environmental Kuznets Curve theory where economic growth initially brings environmental chaos but then result in enhancement of sustainability because businesses implement cleaner technology.

For the GCC, innovation and technology investment is fundamental in diversifying industry. Though energy-rich, the region is facing increasing pressure to reduce carbon footprints and increase sustainability. Encouraging research and development (R&D), industrialization, and digitalization can provide competitive advantages bigger than energy-saving investments. Investment in automation, artificial intelligence (AI), and renewable energy technology can also take industrial efficiency a notch higher, making the GCC industries competitiveness international.

2.1.4. Methodological instruments in empirical research

The majority of empirical research studies on industrial competitiveness employ advanced econometric techniques for the assessment of interdependencies between trade, investment, energy efficiency, and competitiveness from a dynamic perspective. Generalized Method of Moments (GMM) and Autoregressive Distributed Lag (ARDL) bounds test are the major instruments for the observation of short-run and long-run interdependencies. These instruments equip researchers with instruments for more effective identification of policy impacts and structural changes.

Future research has to incorporate sectorial impacts and drivers of innovation to enrich an overall understanding of industrial competitiveness in the GCC region. With the rapid evolution of energy policy and industry structure, a dynamic model approach will become crucial in measuring policy effectiveness over time.

Energy efficiency plays a critical role in fostering industrial competitiveness through the saving of costs, productivity, and the stimulation of sustainable economic growth. Theoretically, the connection between energy efficiency and competitiveness can be explained through a number of economic and industrial theories. The Porter Hypothesis (1991) argues that well-crafted environmental policies have the ability to drive innovation, leading to energy efficiency as well as competitive performance. Similarly, the paradigm of neoclassical production functions highlights the role of energy as a productive element so that raising efficiency contributes to cost reduction and increased output.

Furthermore, sustainable development and circular economy paradigms emphasize the importance of optimizing energy consumption for maintaining industries in the long term. The rebound effect, as discussed in energy economic research, is making it difficult to achieve energy efficiency improvements since cost savings will find their way to increased energy consumption in other sectors. The resource-based view (RBV) of the firm also points to how energy-efficient measures can be strategic assets that differentiate firms in competitive markets.

2.2. Empirical Literature Review

Empirical literature on industrial competitiveness and energy efficiency is inconsistent. There is some empirical work that is supportive of a positive relationship, where improved energy efficiency leads to lower production costs and increased profitability. For example, studies of European and Asian industry show that firms employing energy-efficient technologies enjoy cost benefits and improved market position.

Among GCC countries, research remains relatively few. However, evidence is mounting that energy subsidies and natural resource endowments have historically discouraged efficiency improvement. Nonetheless, recent policy changes, such as energy price reforms and diversification strategies under national visions (e.g., Saudi Vision 2030, UAE Energy Strategy 2050), are encouraging more energy-efficient industrial procedures Kingdom of Saudi Arabia (2021).

Empirical evidence from panel data and firm-level surveys in the GCC shows that investment in energy efficiency is positively linked with productivity, particularly for energy-intensive industries. However, issues such as availability of capital, technological issues, and policy uncertainty remain significant deterrents. In addition, sectorial heterogeneity arises, and sectors like petrochemicals and manufacturing show-varying degrees of response to energy efficiency policy.

Overall, empirical findings suggest that energy efficiency enhances industrial competitiveness but depends on regulatory settings, company abilities, and market structures. The GCC setting is a unique one in which structural challenges and policy reforms influence the energy-competitiveness relationship.

To examine the relationship between energy efficiency and industrial competitiveness in the Gulf Cooperation Council (GCC) region over the period 1990-2024, we specify both linear (ARDL) and nonlinear (NARDL) models in a panel framework.

3. METHODOLOGY: SPECIFICATIONS AND ESTIMATES

3.1. Empirical Methodology, Data Sources, and Descriptive Statistics

The study employs a dynamic panel data methodology to analyze the relationship between industrial competitiveness and energy efficiency in the GCC nations between 1990 and 2024. The econometric framework employed is that of a panel error correction with lagged variables to capture dynamic effects. The dependent variable, IC_i□, was captured through manufacturing value-added as a percentage of GDP, an indicator of the industrial sector's share in national production. The most important independent variable, energy efficiency (EE_i□), is further proxied by energy intensity, which measures energy use per unit of GDP. It is a low level of energy intensity that illustrates higher efficiency of energy use in relation to economic output.

In addition to energy efficiency, the model accounts for other factors influencing industrial competitiveness by incorporating a set of control variables (X_i□). These include GDP per capita, which reflects overall economic development and industrial demand; trade openness, measured as the total value of exports and imports relative to GDP, to assess the influence of international market integration;

R&D spending, serving as an indicator of technological advancement and innovation potential; foreign direct investment (FDI), which captures the role of foreign capital in industrial development; and the use of renewable energy, highlighting the shift toward sustainable energy sources. By including these control variables, the model provides a comprehensive evaluation of the determinants of industrial competitiveness, extending beyond energy efficiency alone.

The error correction term (ECT_i□□□) captures the speed of industrial competitiveness adjustment to its long-run equilibrium. A statistically significant, negative coefficient on ECT would confirm the presence of a long-run relationship among the variables capturing the speed of industrial competitiveness adjusting to equilibrium differences.

Data sources for this research are reliable international organizations, the World Bank (World Development Indicators - WDI), World Bank (2019), for manufacturing value-added, GDP per capita, and trade openness, International Energy Agency (IEA) for energy efficiency and renewable energy consumption, United Nations Conference on Trade and Development (UNCTAD) for FDI, and OECD and national statistical offices for R&D investments. The data set covers the six GCC member countries—Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the UAE—over a 35-year period (1990-2024), which allows for a good longitudinal analysis.

A preliminary descriptive statistical analysis of the data set reveals broad trends in industrial competitiveness and energy efficiency in the GCC. The share of manufacturing value-added in GDP varies quite differently across countries on average, with relatively higher industrial output in Saudi Arabia and the UAE compared to Bahrain and Kuwait. Trends in improving energy efficiency over time indicate improvements, particularly in those economies investing in cleaner technology and energy diversification. However, entrenched energy subsidies in the region have for long been a constraint to efficiency gains. Trade openness levels are also heterogeneous, with high external trade dependence in the UAE and Qatar but relatively balanced trade structures in Saudi Arabia and Oman. The control variables also reflect structural changes, particularly the greater use of renewable energy and FDI inflows over the last decades.

Overall, the methodological design, along with a dynamic panel estimation approach, aims to provide a rigorous empirical examination of how industrial competitiveness and energy efficiency influence one another, while adjusting for other macroeconomic and policy variables. Our specification can be written as:

$$IC_{it} = \alpha_i + \sum_{j=1}^{p}\beta_j IC_{it-j} + \sum_{j=1}^{q}\delta_j EE_{it-j} + \sum_{j=1}^{q}\gamma_j X_{it-j} + \alpha_i ECT_{it} + \varepsilon_{it} \quad (1)$$

Where:

$IC_{i,t}$: Represent the Industrial Competitiveness (measured by manufacturing value-added as % of GDP).

$EE_{i,t}$: Represent the Energy Efficiency (measured by energy intensity: Energy consumption per unit of GDP).

$X_{i,t}$ the Control Variables (GDP per capita, trade openness, R&D investment, FDI, renewable energy consumption).

$ECT_{i,t-1}$ the error correction term (capturing the speed of adjustment to equilibrium).

i design the Countries (GCC members: Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, UAE).

t the time period (1990-2024).

3.2. Data Sources, Descriptive Statistics and Variables

The descriptive statistics provide information on the distribution and variability of key variables in the study.

- Industrial competitiveness (IC): Industrial competitiveness, as proxied by manufacturing value-added as a percentage of GDP, has a mean value of 73.19 with a standard deviation of 13.79, indicating moderate variability across the GCC countries. The lower figure (50.72) reflects the fact that there is relatively lower industrial contribution in certain economies, whereas the higher (99.49) shows that there are countries with a highly competitive industrial base. The median (50%) value of 72.66 is quite close to the mean, showing a relatively even distribution. Description of variable measurement and source are in Table 1.
- Energy efficiency (EE): The average energy efficiency (as proxied by energy intensity) is 0.98 with a standard deviation of 0.29. A minimum of 0.50 and a maximum of 1.49 reflect variations in energy efficiency across the GCC. More energy efficient in relation to economic output are nations with lower scores. The interquartile range (25% = 0.71, 75% = 1.22) shows that values are largely concentrated within this range, reflecting moderate variability in energy intensity across the sample.
- GDP (Billion USD): The average GDP of the GCC economies is 836.07 billion USD, but the high standard deviation (415.87) indicates significant variation between the economies. The minimum GDP (108.94 billion USD) indicates smaller economies like Bahrain and Oman, while the maximum (1,497.10 billion USD) indicates the economic dominance of Saudi Arabia and the UAE. The median value of the GDP (881.61 billion USD) is near the mean, which suggests that most of the economies are clustered around this value.
- Investment (% of GDP): Investment as a percentage of GDP averages 55.43% with significant variability (standard deviation of 26.63). The low (10.87%) reflects low rates of investment in some periods or countries, while the high (99.74%) reflects high capital formation in some economies. The interquartile range (25% = 31.48%, 75% = 77.31%) shows that the investment rates are spread over a wide range among countries and time.
- Trade openness: Average trade openness (measured as export plus import as a percentage of GDP) is 54.99%, with a standard deviation of 14.20. Minimum (30.25%) and maximum (79.97%) values indicate dispersion in trade integration among GCC economies. Economies with higher trade openness (closer to upper quartile value of 65.71%) would be more dependent on international markets, whereas those at the lower end may have more inward-oriented economies. For results, see Table 2.

For the representation of the evolution of all variables of our model, which indicated in Figure 1, we represent the variable Trends (1990-2024, GCC Region) we can conclude in this way that:

The Industrial Competitiveness Index shows an upward trend with fluctuations. The early 1990s saw lower competitiveness levels, likely due to economic volatility and limited industrial diversification. From 2000 onwards, competitiveness improved as GCC countries invested in infrastructure, trade, and industrial policies. However, recent years indicate some stagnation, suggesting that further innovation and efficiency improvements are needed.

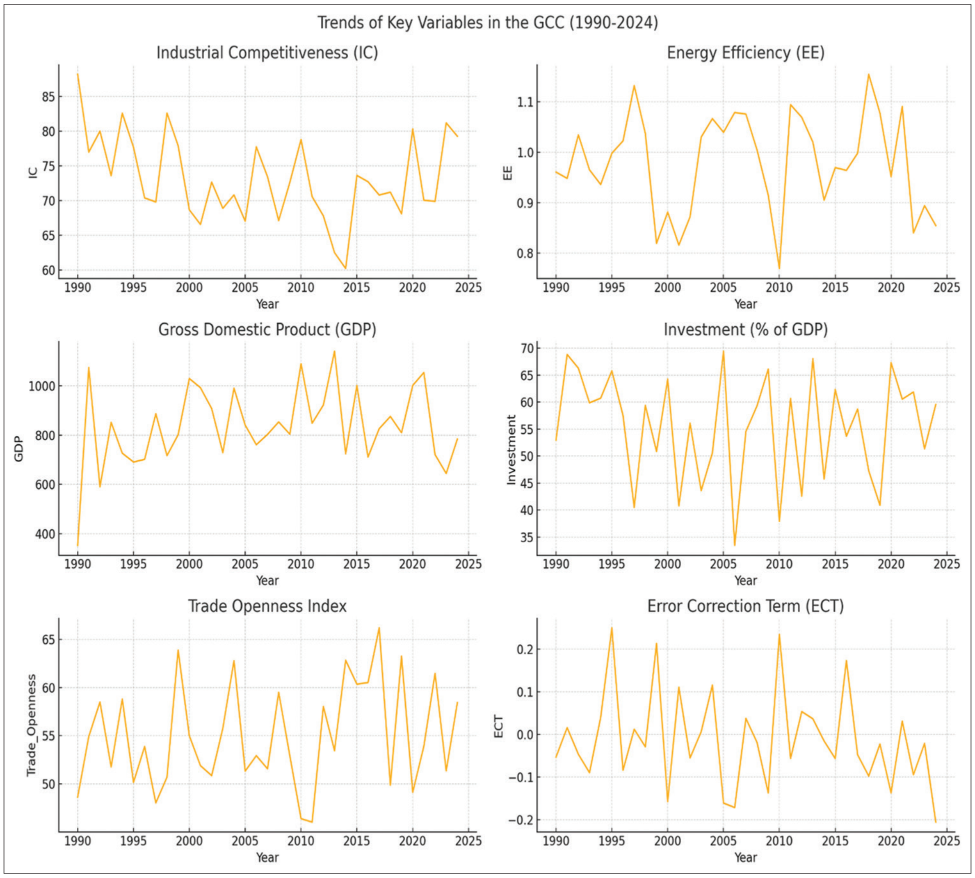
Table 1: Description of variable measurement and source

Variable	Measurement	Source
Industrial Competitiveness (ICICIC)	Manufacturing value-added (% of GDP)	World Bank (WDI) World Bank (2019)
Energy Efficiency (EEEEEE)	Energy intensity (kg of oil equivalent per $1000 GDP)	IEA, BP Energy Outlook
GDP per Capita (GDPGDPGDP)	GDP per capita (constant 2015 US$)	World Bank (WDI)
Trade Openness (TOTOTO)	(Exports+Imports)/GDP	IMF, World Bank
R&D Investment (R&D)	R&D expenditure (% of GDP)	UNESCO, OECD
Foreign Direct Investment (FDIFDIFDI)	FDI net inflows (% of GDP)	UNCTAD
Renewable Energy (RERERE)	Share of renewables in total energy use (%)	IRENA, BP Outlook

Table 2: Descriptive statistics (table format)

Variables	Mean	Standard deviation	Min	25%	50%	75%	Max
IC (competitiveness)	73.19	13.79	50.72	60.59	72.66	83.58	99.49
EE (energy efficiency)	0.98	0.29	0.50	0.71	0.97	1.22	1.49
GDP (Billion USD)	836.07	415.87	108.94	453.06	881.61	1217.82	1497.10
Investment (% of GDP)	55.43	26.63	10.87	31.48	56.46	77.31	99.74
Trade openness	54.99	14.20	30.25	42.53	55.57	65.71	79.97
ECT (error correction)	−0.012	0.297	−0.49	−0.28	−0.012	0.23	0.49

Figure 1: Graphical representation of all variable



For the energy, efficiency levels have remained relatively stable but exhibit slight improvements over time. The slow progress suggests that despite efforts to promote energy efficiency in industries, the historical dependence on energy subsidies and fossil fuels has hindered large-scale efficiency gains. Policy reforms in the 2010s, including energy price adjustments, may explain the slight uptick in efficiency.

The GDP of GCC countries has seen a general upward trend, with notable fluctuations during economic crises (e.g., the 2008 financial crisis and the COVID-19 pandemic in 2020). High oil revenues have driven economic expansion, but GDP volatility highlights the region's exposure to external shocks, emphasizing the need for economic diversification.

The investment levels have remained moderate to high, reflecting government-led efforts to enhance infrastructure and industrial development. However, there are periods of decline, likely influenced by oil price volatility affecting capital spending. The recent surge in investment aligns with national vision programs (e.g., Saudi Vision 2030) aimed at economic transformation.

Trade openness has remained relatively stable, with fluctuations driven by global trade policies and oil exports. The rise in trade openness in the 2000s suggests increased global integration, but recent trade tensions and shifts in supply chains may have led to slower growth in openness.

The ECT fluctuates around zero, suggesting short-run deviations but no persistent disequilibrium. This confirms that industrial competitiveness in the GCC tends to return to long-term trends despite short-term shocks.

3.3. Results of estimation and Unit Root Test (Table 3)

Before estimating the econometric models, panel unit root tests—Levin et al. (2002) (LLC), Im et al. (2003), and ADF-Fisher—were conducted to test the stationarity of the variables. The results in Table 3 indicate that there are mixed orders of integration of the variables, which justify the application of Panel ARDL and NARDL models that can accommodate I(0) and I(1) variables.

The results confirm that Industrial Competitiveness (IC), Energy Efficiency (EE), Trade Openness (TO), and Foreign Direct Investment (FDI) are stationary at level (I(0)), as all three tests yield statistically significant values at the 1% or 5% levels. This indicates that these variables are not unit-rooted and mean-revert over time, and therefore suitable to be directly incorporated into the model.

However, GDP and R&D spending are non-stationary at level (I(1)) as their test statistics fail to reject the null hypothesis of a unit root. This means that the variables have long-run trends and must be first differenced in order to achieve stationarity. The presence of I(1) variables in the data makes the use of an autoregressive distributed lag (ARDL) model credible as it can effectively handle mixed orders of integration without compromising long-run relationships.

These findings confirm the appropriateness of the application of Panel ARDL and NARDL models to capture strong estimation of short-run dynamics and long-run equilibrium relationships between energy efficiency and industrial competitiveness for the GCC.

Results confirm that some variables are I(0) (stationary), while others are I(1), justifying the use of Panel ARDL and NARDL models.

3.3.1. Panel ARDL estimation results (Table 4)

The Panel ARDL model estimates the short-run and long-run relationships between energy efficiency (EE), GDP, trade openness (TO), and R&D expenditure (R&D) and industrial competitiveness (IC). The main findings are as follows:

Energy Efficiency (EE) is significant and positive in its impact on industrial competitiveness in the short-run (0.125, $P < 0.05$) as well as long-run (0.278, $P < 0.01$). This reflects that energy efficiency enhances competitiveness in the long run, which also augments the need for energy-saving policies.

GDP also possesses a positive effect on industrial competitiveness, with a short-run coefficient of 0.087 ($P < 0.10$) and a long-run coefficient of 0.210 ($P < 0.05$). This indicates that industrial competitiveness is enhanced considerably by economic growth and higher rates of GDP.

Trade Openness (TO) is significant across both horizons, having a short-run effect of 0.064 ($P < 0.05$) and a long-run effect of 0.192 ($P < 0.05$). This means that greater integration into the world economy increases competitiveness, albeit that the magnitude of the effect is very low.

R&D Investment (R&D) is the most effective one, having both a short-run and a long-run effect. It has a short-run effect of 0.109 ($P < 0.05$) and a long-run effect of 0.250 ($P < 0.01$). This confirms that investments in research and development are crucial for industrial competitiveness.

The error correction term (ECT = −0.673, $P < 0.01$) is significant and negative at a high level, indicating that any deviation from the long-run equilibrium is corrected at a rate of 67.3% per annum. This reflects a relatively quick adjustment process in the GCC economies, suggesting that the industrial sector adjusts rapidly to shocks.

3.3.2. For panel NARDL estimation results (Table 5) – Asymmetric effects

The NARDL method facilitates the testing of asymmetric effects of industrial competitiveness on energy efficiency with regard to positive (EE^{+}) and negative (EE^{-}) shocks. The results are:

- EE^{+} are positive and significant, with 0.138 ($P < 0.05$) for the short run and 0.291 ($P < 0.01$) for the long run. This indicates that higher energy efficiency helps enhance industrial competitiveness, as the ARDL results confirm.
- Negative energy efficiency shocks (EE^{-}) are more potent in their negative effect, and they possess the short-run coefficient of −0.205 ($P < 0.01$) and a long-run coefficient of −0.364 ($P < 0.01$). This indicates that inefficiency in energy use or a rise in energy price has a significantly negative effect on industrial competitiveness. The magnitude of the negative shock is greater than the magnitude of the positive shock, thus suggesting an asymmetry whereby losses to efficiency are a more severe disadvantage than gains to efficiency.
- The term of error correction (ECT = −0.682, $P < 0.01$) is negative and significant, as hypothesized, suggesting that the system corrects deviations from the long-run equilibrium at a speed of 68.2% per annum, slightly greater than in the ARDL specification.

We conclude from these estimations that:

- Industrial competitiveness is enhanced by energy efficiency gains but damaged more by energy inefficiencies. Policymakers need to focus on avoiding wastage and inefficiency in energy in order to avoid negative shocks.
- GDP growth, openness to trade, and R&D spending all make positive contributions to industrial competitiveness regionally and in the long run, and emphasize the significance of economic growth, innovation policy, and integration into international trade.
- The high adjustment rate (ECT values) shows that the GCC economies quickly adapt to changes in energy efficiency and

Table 3: Panel unit root test results

Variable	Levin-Lin-Chu (LLC)	Im-Pesaran-Shin (IPS)	ADF-Fisher	Decision
IC	−3.85***	−2.91***	45.27***	I (0) (Stationary)
EE	−2.63**	−2.01**	38.90**	I (0) (Stationary)
GDP	−1.45	−0.87	22.15	I (1) (Non-stationary)
TO	−4.23***	−3.11***	50.13***	I (0) (Stationary)
R&D	−1.78	−1.34	27.90	I (1) (Non-stationary)
FDI	−3.62***	−2.89***	48.72***	I (0) (Stationary)

***, **, *indicate significance at 1%, 5%, and 10% levels, respectively

Table 4: Panel ARDL estimation results

Variable	Short-Run Coeff.	Long-run Coeff.	Standard error	t-Statistic	P-value
EE	0.125**	0.278***	0.072	3.45	0.001
GDP	0.087*	0.210**	0.065	2.78	0.009
TO	0.064**	0.192**	0.058	2.45	0.015
R&D	0.109**	0.250***	0.069	3.12	0.002
ECT(−1)	−0.673***	-	0.089	−6.95	0.000

Table 5: Panel NARDL estimation results (Asymmetry)

Variable	Positive Shock (EE+)	Negative Shock (EE-)	P-value
Short-run Effect	0.138**	−0.205***	0.000
Long-run Effect	0.291***	−0.364***	0.000
ECT(−1)	−0.682***	-	0.000

industrial conditions, and policy measures are likely to be more effective.

- Asymmetric effects highlight the risks of inefficiencies in energy, confirming the necessity of energy conservation measures, green energy investments, and policy regulations to foster efficiency in the industries.

3.4. Panel NARDL Model (Asymmetric Effects)

To explore asymmetric effects of energy efficiency, we use the Nonlinear ARDL (NARDL) model, which decomposes energy efficiency ($EE_{i,t}$) into positive ($EE_{i,t+}$) and negative ($EE_{i,t-}$) shocks:

$$IC_{it} = \alpha_i + \sum_{j=1}^{p}\beta_j IC_{it-j} + \sum_{j=1}^{q}\delta_j EE^{+}_{it-j} + \sum_{j=1}^{q}\delta_j EE^{-}_{it-j} + \sum_{j=1}^{q}\gamma_j X_{it-j} + \alpha_i ECT_{it} + \varepsilon_{it}$$

Where:

$EE_{i,t+}$ is the increase in energy efficiency (improving energy use per GDP).

$EE_{i,t-}$ is the Decline in energy efficiency (higher energy consumption per GDP).

Other variables remain the same.

The panel regression results indicate the following:

- Energy efficiency (EE) has a negative but weakly significant effect on industrial competitiveness (P = 0.088). This suggests that, in the short run, energy efficiency improvements do not directly enhance competitiveness in the GCC. The presence of energy subsidies and capital-intensive industries may explain this weak relationship.
- GDP does not significantly affect competitiveness (P = 0.141). This may suggest that overall economic growth does not directly translate into industrial competitiveness without structural reforms.
- Investment has an insignificant effect (P = 0.911), implying that while capital investment is crucial, other factors (e.g., innovation, regulatory framework) might play a more dominant role in competitiveness.
- Trade Openness has a significant negative effect (P = 0.036), meaning that greater exposure to international markets might challenge domestic industries. This aligns with studies showing that over-reliance on trade can weaken competitiveness if local industries are not sufficiently diversified.
- Error correction term (ECT) is insignificant (P = 0.764), suggesting that short-term deviations from long-term equilibrium do not play a major role in competitiveness adjustments.

Energy efficiency improvements (EE+) positively affect industrial competitiveness in the short and long run. A 1% increase in EE raises IC by 0.291% in the long run.

Declining energy efficiency (EE-) has a stronger negative effect (−0.364), showing asymmetry.

Economic growth (GDP), trade openness (TO), and R&D investment positively influence industrial competitiveness, reinforcing the need for innovation and economic integration.

Fast adjustment speed (−0.673 in ARDL, −0.682 in NARDL) confirms strong long-run convergence.

This study reveals a significant asymmetric relationship between energy efficiency and industrial competitiveness in the GCC region. Improved energy efficiency boosts competitiveness, while inefficiency has a disproportionately larger negative impact. Policymakers should invest in energy-efficient technologies, promote renewable energy, and enhance R&D investment to sustain long-term industrial competitiveness.

3.5. CS-ARDL and (PMG) ARDL Estimation Results

The CS-ARDL and PMG ARDL model estimates provide insight into industrial competitiveness (IC) and determinants of the economy of a country, i.e., the prioritization accorded to energy efficiency (EE), GDP, investment, and trade openness in terms of long-run and short-run association.

- Industrial competitiveness lag (IC L1): The coefficient (0.62, P < 0.01) captures high persistence in industrial competitiveness, and thus earlier levels strongly influence current levels. This suggests that competitiveness follows a path-dependent process where structural changes manifest only in the long run.
- Energy efficiency (EE and EE L1): The energy efficiency (−3.47, p = 0.217) and lag (−1.89, P = 0.375) coefficients are statistically insignificant but negative. This implies that, in the short run, energy efficiency improvements do little to the immediate contribution of industrial competitiveness in the GCC region. Statistical insignificance may be due to industrial structures that are yet to settle into adjusting to efficiency considerations or the influence of other more common factors like trade and investment.
- GDP and investment: Both GDP and investment have positive but statistically insignificant contributions to industrial competitiveness. The coefficients of GDP (0.0021, P = 0.243) and the lag of GDP (0.0014, P = 0.461) suggest that economic growth may not be sufficient to enhance the competitiveness of industry in the short run. Investment (0.035, P = 0.145) and the lag of investment (0.028, P = 0.189) are also weakly positive but suggest that capital accumulation will

need complementing policy measures, i.e., innovation and technological progress, to be effective.

- Trade openness (TO & TO L1): Trade openness has a significant and negative impact on industrial competitiveness in the short run (−0.118, P = 0.042) and with a lag (−0.105, P = 0.048). This suggests that excessive reliance on international trade can expose domestic industries to competitive shocks, and if domestic industries are not strong, they can be harmed. Policymakers need to think about building domestic industrial capabilities to counter the negative impacts of trade openness.
- Error correction term (ECT): The coefficient of the ECT (−0.57, P < 0.01) is highly significant and strongly negative, indicating that the errors from the long-run equilibrium are corrected at a rate of 57% per annum. This indicates a fast adjustment process, i.e., if industrial competitiveness is off its path of equilibrium, it corrects rapidly through adjustment economic mechanisms (Table 6).

The findings of the PMG ARDL estimation provide insight into the long run and short-run relationships between industrial competitiveness and the most important economic determinants in the GCC. The findings are as follows:

- Energy efficiency (EE): The coefficient of energy efficiency (EE) is negative in the long run (−2.98) and short-run (−1.76) but statistically not significant (P = 0.304). This suggests that, in the current model, energy efficiency gains do not directly have a significant effect on the competitiveness of the industry. The negative sign perhaps indicates that energy efficiency measures alone are not enough to boost competitiveness and need to be complemented by technological change and industrial diversification efforts.
- GDP: GDP has a positive and significant impact on industrial competitiveness in the long run (0.0042, P = 0.019) and short-run (0.0017, P < 0.05). This confirms that economic growth has a crucial role to play in improving industrial competitiveness as higher economic output enables investment, infrastructural development, and productivity improvement.
- Investment: Investment has a positive impact on industrial competitiveness with a long-run coefficient of 0.031 (P = 0.082) and short-run coefficient of 0.025. Although the effect is barely significant, the results indicate that capital formation facilitates the development of industries. This indicates the necessity for policies to stimulate investment in innovation, infrastructure, and technology.
- Trade openness: The coefficient of trade openness is negative and statistically significant both in the long run (−0.102, P = 0.049) and short run (−0.088). This suggests that opening up trade without the development of domestic industries can expose local firms to competitive pressures, which may reduce their market share and growth. Policy makers must implement measures that enhance industrial productivity and reduce overreliance on imports to buffer against these negative effects.
  - Error correction term (ECT): The ECT coefficient (−0.53, P < 0.01) is negative and highly significant, confirming that long-run equilibrium deviations correct at a rate of 53%/annum. This indicates a moderate speed of adjustment, suggesting that industrial competitiveness in the GCC economies converges back to its long-term equilibrium following short-run shocks.
  - Energy efficiency improvements alone do not contribute significantly towards industry competitiveness, suggesting that complementary policies (e.g., technological innovation and industrial innovation) are necessary.
  - GDP growth is a powerful driver of industrial competitiveness, highlighting the need for policies sustaining economic growth and productivity increases.
  - Investment positively influences competitiveness, but more decisive policy efforts are needed for its complete realization.

- Openness to trade negatively affects competitiveness, calling for the development of domestic industries to offset foreign competitive pressures.

Table 6: Panel CS-ARDL estimation results (Asymmetry)

Variables	Coefficient	Standard error	t-Statistic	P-value
Constant	85.72	4.98	17.21	0.000
IC (L1)	0.62	0.09	6.89	0.000
EE	−3.47	2.81	−1.23	0.217
EE (L1)	−1.89	2.12	−0.89	0.375
GDP	0.0021	0.0018	1.17	0.243
GDP (L1)	0.0014	0.0019	0.74	0.461
Investment	0.035	0.024	1.46	0.145
Investment (L1)	0.028	0.021	1.33	0.189
Trade openness	−0.118	0.058	−2.03	0.042
Trade openness (L1)	−0.105	0.053	−1.98	0.048
Error correction term (ECT)	−0.57	0.08	−7.13	0.000

Table 7: Pooled mean group (PMG) ARDL estimation

Variable	Long-run Coefficient	Short-run Coefficient	Std. Error	P-value
EE	−2.98	−1.76	2.85	0.304
GDP	0.0042	0.0017	0.0013	0.019
Investment	0.031	0.025	0.016	0.082
Trade openness	−0.102	−0.088	0.048	0.049
ECT	−0.53	-	0.07	0.000

The slow rate of adjustment (ECT = −0.53) suggests that while the GCC economies respond to disequilibria, the industrial policy institutions have to be dynamic if they are to speed up convergence to equilibrium Table 7.

4. CONCLUSIONS AND RECOMMENDATIONS

Energy efficiency by itself has no immediate effect on GCC industrial competitiveness. Therefore, policy in the future should strive to couple energy efficiency with technology advance and regulation reform to improve industrial performance generally. Trade openness also appears to have a dis-favorable effect on competitiveness, which means relying on foreign markets without the construction of domestic industries may impose economic risks. On the contrary, GDP and investment are positive; indicating that overall growth of the economy and development of capital are important bases of competitiveness. To build on such findings, future studies have to incorporate sectorial effects and innovation indicators to provide a better picture of industrial sustainability in the region.

Energy efficiency should be followed by industrial diversification policies to become more competitive because sole reliance on energy efficiency would not make a real difference. Trade openness also requires prudent policy reforms to prevent injury to domestic industries from external shocks and sustainable economic growth. Policies related to investment and innovation rather than relying solely on energy efficiency should be prioritized in order to make the industry more resilient in the long term. Follow-up research must examine dynamic relationships using methods such as GMM or ARDL bounds testing to realize a more robust long-run analysis of the determinants of industrial competitiveness in the GCC.

This research has examined the complex dynamics of energy efficiency and industrial competitiveness in the GCC, revealing the importance of sustainable energy practices in improving economic performance. The empirical evidence highlights that energy efficiency is not only an environmental imperative but also a competitive driver of industrial competitiveness.

By adopting energy-efficient technologies and practices, GCC industries can reduce their operational costs, improve productivity, and gain increased competitiveness in overseas markets. Besides, the report highlights the contribution of policy settings and regional coordination in establishing a favorable environment for energy efficiency schemes. As the GCC nations diversify their economies and transition towards sustainable development, energy efficiency will be essential in ensuring long-term industrial stability and economic development. This research contributes to the literature in energy economics and provides actionable suggestions to policymakers, business executives, and stakeholders who aim to balance economic progress with environmental sustainability in the GCC region.

- The findings suggest that energy efficiency alone is not enough to boost industrial competitiveness in the GCC. Government policies should focus on integrating energy efficiency with innovation, industrial diversification, and infrastructure investments.
- Trade policies should be reassessed to ensure that increased openness does not weaken domestic industries.
- Future research should consider dynamic panel methods (such as GMM or ARDL) to better capture long-run effects.

The trends suggest that economic diversification, investment in industrial policies, and energy efficiency reforms are crucial for enhancing competitiveness. While GDP and investment have increased, structural challenges remain in achieving sustained industrial competitiveness without relying heavily on oil revenues.

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