Key Drivers of Energy Consumption in the Gulf Cooperation Council Countries: A Panel Analysis

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ABSTRACT

The objective of this study is to examine the factors that influence energy consumption, a critical component of both industrial and everyday life that is projected to increase annually. The research focuses on Gulf Cooperation Council (GCC) countries and uses panel data from 1990 to 2023 to assess the impact of economic growth, trade openness, population growth, urbanization, inflation, and Foreign Direct Investments (FDI) on energy consumption. The findings, derived from a rigorous Augmented Mean Group (AMG) regression analysis, reveal a positive and significant relationship between economic growth, trade openness, and inflation on energy consumption. However, the study also outlines that FDI, population growth, and urbanization do not exert a significant influence on energy use. The analysis highlights a critical challenge faced by GCC countries: the need to balance high industrial energy consumption with sustainability goals. The study underscores the necessity of transitioning to sustainable practices, including energy efficiency and renewable energy adoption, as crucial elements for achieving long-term growth and climate commitments. This research contributes to the ongoing discourse on sustainable development in the region and underscores the necessity of incorporating environmental factors into economic growth strategies.

Keywords-energy consumption; Gross Domestic Product Growth (GDPG); GCC countries; environmental sustainability

I. INTRODUCTION

The GCC countries, including Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates, have achieved rapid economic growth in recent decades. This growth has been characterized by significant energy consumption, primarily reliant on fossil fuels. The GCC's energy consumption landscape is marked by high demand across sectors, with significant contributions from residential cooling, industrial manufacturing, large-scale infrastructure projects, and low energy costs due to government subsidies [1]. While energy has been a cornerstone of economic growth in the GCC, supporting industries like petrochemicals, aluminum, and construction, the region's reliance on hydrocarbons poses environmental and economic challenges. The rising energy demands have a considerable impact on resource sustainability, environmental health, and economic diversification [2]. In regard to these issues, GCC countries have initiated ambitious initiatives to diversify their energy mix, reduce dependency on oil and gas, and promote sustainable energy practices. These initiatives are in alignment with broader regional and international goals, such as the United Nations' Sustainable Development Goals, as evidenced by projects such as Saudi Arabia's Vision 2030 and the United Arab Emirates' Masdar City, which are aimed at expanding renewable energy capacity and enhancing energy efficiency [3]. The analysis of energy consumption patterns is imperative, as it provides insights into the region's economic development. The objective of this study, is to ascertain the critical factors influencing energy consumption within GCC countries. This analysis seeks to assist researchers in predicting future energy demands and provide policymakers with valuable insights regarding energy efficiency and diversification strategies. The important role of energy in economic development has brought energy consumption to the attention of researchers in recent literature. However, studies examining energy consumption across different regions and timeframes have produced varying results, making it difficult to reach a unified understanding of what leads to an increase in energy demand. As a result, researchers have proposed several theories to explain the factors that determine energy demand [4]. A considerable number of prior studies have found that GDP is the primary factor influencing energy consumption, particularly due to heightened industrial activity, across various countries and over different periods [5-7]. However, some have reached contrasting conclusions regarding the impact of other macroeconomic variables, such as trade openness, FDI, urbanization, oil price, and income inequality. Using simultaneous equations in GCC countries from 1996 to 2017, authors in [8] revealed that CO_2 emissions, financial development, and labor forces contribute to increased energy consumption in all GCC countries. Authors in [5] found that in Central Asian countries over the period 1992-2021 FDI positively affects energy consumption, while energy prices have no effect on the latter.

The General Method of Moments (GMM) estimator was used to examine the impact of GDP and credit to the private sector on energy consumption, in a sample of 41 African countries. Authors in [6], indicated that the positive impact of both GDP and credit to the private sector on energy consumption is reduced by the negative effect of income inequality. In a related study, researchers employed an Artificial Neural Network (ANN) model from 2000 to 2020 to examine the relationship between energy consumption and various socio-economic factors in Egypt. A positive correlation between energy consumption and trade openness, population growth, urbanization, and industry growth rate, was found. However, they also identified an adverse impact of inflation and global oil prices on energy use. In conclusion, the key determinants of energy consumption in Egypt are: global energy prices, economic growth, and trade openness. This is attributed to the fact that Egypt's economic growth is primarily driven by export-oriented industries that are heavily reliant on energy consumption. Moreover, in the context of MIST countries, examined in [9], over the period 2000-2022, the determinants of energy consumption were identified as economic growth, population growth rate, trade openness, and FDI. Conversely, authors in [10] demonstrated an adverse relationship between energy efficiency and electricity price. Specifically, an increase in electricity prices leads to a decrease in electricity consumption. However, an increase in labor productivity, indicative of high industrial activity, results in an improvement in electricity use within the European Union during the period from 2000 to 2019. Authors in [11] deployed a Panel ARDL Model over the period 2000-2021 to highlight a positive relationship between trade openness and energy consumption. Greater trade openness often leads to increased energy consumption in 12 Eastern African countries, supporting the dependence theory. This theory underscores the role of interactions with developed nations in shaping economic development in peripheral regions [12]. It was concluded that energy consumption is driven by industrialization and FDI in the short run and by population growth in the long run. The empirical background of the present study contributes to the field by using most of the aforementioned variables and AMG estimation techniques to determine the key drivers of energy consumption in each Gulf country and in GCC countries, using panel data.

II. EMPIRICAL METHODOLOGY

A. Data

The present study uses annual data from the six countries of the GCC: the United Arab Emirates, Bahrain, Kuwait, Oman, Qatar, and Saudi Arabia. The data include the period from 1990 to 2023 and are sourced from the World Development Indicators [13], while the definition and description of the variables are presented in Table I.

TABLE I. DESCRIPTIVE STATISTICS

	Variable	Obs	Mean	Std. Dev.	Min	Max
Primary energy consumption per capita	ENE	204	11.63	0.538	10.14	12.66
GDP per capita growth	GDPG	204	0.806	6.610	-26.23	51.09
Merchandise trade	TRA	204	4.416	0.296	3.748	5.226
Population total	POP	204	14.97	1.183	12.99	17.42
Urban population annual growth	URB	204	3.8238	4.619	-27.707	19.612
Foreign direct investment, net inflows	FDI	204	2.234	3.537	-4.650	29.520
Inflation, GDP deflator	INF	203	4.057	11.34	-25.95	33.75

The Energy (ENE), Trade (TRA), and Population (POP) variables are log-transformed, while GDP per capita growth, Urbanization (URB), FDI, and Inflation (INF) are non-log-transformed forms. ENE shows stability with a mean of approximately 11.64 and minimal variability, while GDP per capita Growth (GDPG) displays significant fluctuations, indicated by a high standard deviation suggesting considerable economic volatility. Merchandise TRA exhibits relative consistency with an average of 4.42 and minimal variability, while POP has an average of 14.98 with moderate variability. URB is characterized by substantial variability, indicating varied experiences with urbanization. FDI displays considerable variability, highlighting erratic investment patterns. INF has a mean of 4.06 with extreme variability, suggesting significant economic instability across GCC countries.

B. Correlation Matrix

The correlation matrix, depicted in Table II, reveals several key relationships with ENE, including a moderate positive correlation with TRA, suggesting that increased TRA leads to higher ENE demands for transportation and production. Conversely, a strong negative correlation with POP indicates that denser areas may exhibit lower per capita ENE consumption, likely due to more efficient use and public transport. Furthermore, a positive correlation between ENE consumption and URB is observed, reflecting the higher energy demands of urban areas. Additionally, a weak positive correlation with FDI is noted, suggesting that such investments can also drive ENE use through new industries. However, the correlations with GDPG and INF are negligible, indicating that these factors do not significantly influence ENE consumption.

C. Econometric Methodology

In order to develop a reliable model for predicting energy consumption, it is imperative to first conduct a thorough analysis of the available data. This preliminary step involves several crucial elements, including the assessment of potential dependence between countries, the identification of slope heterogeneity, the verification of the stationarity of the selected variables, and the exploration of any long-term relationships that may exist between the independent variables and energy consumption. Table III presents the Pesaran [14], Friedman [15], and Frees [16] tests of cross-sectional dependence.

TABLE II. CORRELATION MATRIX

Variable	ENE	GDPG	TRA	POP	URB	FDI	INF
ENE	1						
GDPG	-0.01	1					
TRA	0.28	0.01	1				
POP	-0.43	-0.08	-0.31	1			
URB	0.23	0.06	0.15	-0.08	1		
FDI	0.17	0.04	0.44	-0.25	0.09	1	
INF	0.02	0.06	0.05	-0.0	0.07	0.04	1

TABLE III. TEST OF CROSS-SECTIONAL DEPENDENCE

Test	Statistic	p-value
Pesaran's test	5.9440	0.0000***
Friedman's test	63.6720	0.0000***
Frees' test	1.9020	0.0000***

*** imply the significance at 1% level

The findings of the empirical tests provide substantial evidence to support the hypothesis of significant cross-sectional dependence. The results of these tests indicate a high degree of cross-sectional dependence, thereby underscoring the interconnected nature of the relationships among the variables. This interdependence suggests that observations from different groups influence each other, thus emphasizing the necessity of incorporating these dependencies into this study's analytical framework.

1) Test for Slope Heterogeneity

As portrayed in Table IV, the tests of slope heterogeneity [17] exhibit significant slope heterogeneity among the variables. This finding indicates that the relationships signified by the slope coefficients vary across the cross-sectional units, suggesting that distinct factors may exert influence on the dependent variable in different contexts.

TABLE IV. TESTING FOR SLOPE HETEROGENEITY

Test Statistic	Delta	p-value
H_0	9.5850	0.0000***
Adjusted Delta	10.9700	0.0000***

*** imply the significance at 1% level

2) Panel Unit Root Tests

As shown in Table V, the results of the Cross-sectional Augmented Dickey-Fuller (CADF) test [18] indicate that among the variables examined, GDPG, URB, and INF exhibit stability. Conversely, ENE, TRA, POP, and FDI do not appear to be stable, suggesting the presence of a unit root and necessitating differencing/differentiation for more in-depth analysis. The stationarity of all variables in the difference tested was confirmed, as evidenced by the rejection of the unit root hypothesis, indicated by the significant p-values.

3) Panel Co-Integration Tests

As depicted in Table VI, the panel cointegration tests include the Kao test [19], which indicates considerable evidence of cointegration among the variables. This suggests that the variables are likely to share a common trend over time, therefore signifying a long-term equilibrium relationship among the series.

TABLE V. CROSS-SECTIONAL AUGMENTED DICKEY-FULLER

Variable	t-bar	p-value	First difference	t-bar	p-value
ENE	-2.2330	0.1190	DENE	-2.9430	0.0010***
GDPG	-3.1370	0.0000***	DGDPG	-4.2750	0.0000***
TRA	-1.4890	0.7760	DTRA	-3.3380	0.0000***
POP	-2.2370	0.1170	DPOP	-2.7050	0.0080***
URB	-2.6730	0.0100***	DURB	-3.2100	0.0000***
FDI	-1.6910	0.5920	DFDI	-3.9180	0.0000***
INF	-3.548	0.0000***	DINF	-8.487	0.0000***

*** implies the significance at 1% level

TABLE VI. COINTEGRATION TEST RESULTS

Statistic	Value	p-value
Modified Dickey-Fuller t	-1.3485	0.0887*
Dickey-Fuller t	-2.0461	0.0204**
Augmented Dickey-Fuller t	-1.9075	0.0282**
Unadjusted modified Dickey-Fuller t	-1.0595	0.1447
Unadjusted Dickey-Fuller t	-1.9212	0.0274**
*** and * imply the significance at 5% and 1%, level, respectively*		

** and * imply the significance at 5% and 1%, level, respectively

4) Panel Data Regression

The AMG estimation is a statistical method used in panel data analysis to estimate long-run relationships in the presence of slope heterogeneity across cross-sectional units. This approach is particularly useful when dealing with heterogeneous data, where the relationships may differ across entities. Typically, AMG is applied to dynamic panel models, which can be presented as:

$$Y_{it} = \alpha_i + \beta X_{it} + \gamma Y_{it-1} + \epsilon_{it} \quad (1)$$

where Y_{it} is the dependent variable for unit i at time t, X_{it} represents the independent variables, α_i are the individual-specific effects, β is the coefficient for the independent variable, γ is the coefficient of the lagged dependent variable and ϵ_{it} is the error term. The AMG method is a three-step process for estimating the parameters of a linear model. First, the Mean Group (MG) estimator is used to estimate the parameters for each cross-sectional unit, allowing for unique long-run relationships. Second, the individual estimates are combined to calculate a global average, which captures the overall relationship while accounting for heterogeneity. Finally, the augmented approach incorporates additional methods, such as instrumental variables to address endogeneity and weighting to enhance the precision of certain estimates. The AMG approach offers several advantages, including flexibility in modeling different long-run relationships across units, improved efficiency through reduced bias, and the capability to handle dynamic relationships by including lagged variables, thereby effectively capturing the influence of past values on the current outcomes.

III. RESULTS AND DISCUSSION

A. Results

Table VII illustrates the results of the AMG estimator in the context of panel data analysis, with the objective of addressing unobserved heterogeneity across distinct groups.

TABLE VII. AMG SECTION

	Dependent variable energy consumption EC						
	Saudi Arabia	Bahrain	Kuwait	Oman	Qatar	UAE	Panel
GDPG	0.004**	0.007*	0.006***	0.012***	0.007*	0.007***	0.007***
DTRA	-0.151	-0.106	0.374	0.251	0.172	0.376***	0.153*
DPOP	9.609	10.309	-3.603	3.902	-13.840	2.207	1.431
URB	0.087	-0.109	0.043	0.033	0.137	-0.021	-0.012
DFDI	0.003	-0.002*	-0.006	0.001	-0.013	-0.005	-0.004
INF	0.002*	0.004*	0.001	0.004***	0.002	0.003***	0.003***
_cons	0.032	0.054	0.074*	0.124***	0.092	0.082***	0.077***

***, **, and * imply the significance at 1%, 5%, and 10% level, respectively

The coefficients from the AMG estimator reveal the relationships between various predictors and the dependent variable (ENE consumption). GDPG has a positive and significant impact on ENE consumption for all countries, indicating that an increase in GDPG leads to an increase in DENE. The panel estimation further corroborates this finding, with GDPG exhibiting a positive coefficient of 0.007, signifying that a 1-unit increase in GDPG is associated with a 0.007-unit rise in DENE. Additionally, the variable of TRA has a significant positive effect on ENE consumption, particularly in the UAE, underscoring the crucial role of TRA in its economy. In contrast, Bahrain, Oman, Qatar, Kuwait, and Saudi Arabia exhibit no significant effects from TRA, suggesting that TRA levels may not be as influential in ENE consumption in these countries. Furthermore, the panel estimation indicates that an increase in TRA leads to a 0.152 increase in DENE. FDI exhibits a notable pattern, with Bahrain showing a small but significant negative effect. The impact of FDI on the economy suggests that it may correlate with less ENE consumption. The findings reveal a lack of a substantial relationship between FDI and the dependent variable, suggesting that its impact may be less apparent in certain contexts. A mixed picture emerges concerning FDI's influence across the region, with significant variations being observed among individual countries. The panel estimation indicates that the FDI variable does not exert a significant influence on energy usage. However, inflation exerts a positive effect on energy consumption in all countries except Kuwait and Qatar, suggesting that rising inflation is frequently associated with increases in the dependent variable, reflecting inflationary pressures on the economy. In contrast, Qatar and Bahrain demonstrate an absence of significant effects from inflation, suggesting that its impact may be less critical in these contexts. Conversely, neither URB nor POP demonstrates a significant effect, whether assessed in GCC countries individually or using panel data. This result suggests that these factors might not be relevant predictors of energy use. The findings of the panel estimation study suggest that GDPG, TRA, and INF have a substantial positive effect on ENE consumption in GCC countries, indicating that an increase in any of these factors leads to a considerable rise in ENE usage. Conversely, URB, FDI, and POP do not exert a significant influence on the dependent variable.

1) Test of Non-Causality

As demonstrated in Table VIII, the results of the Granger non-causality test [20] indicate a strong causal relationship between URB and ENE consumption, suggesting that changes in URB significantly influence ENE use. Additionally, evidence exhibits a causal effect from GDP and POP on ENE consumption. In contrast, TRA, FDI, and INF do not show any evidence of Granger causality towards energy consumption.

TABLE VIII. THE GRANGER NON-CAUSALITY TEST

Variable	***W*-bar**	***p*-value**
GDPG	2.4229	0.0600*
TRA	0.5607	0.5700
POP	7.0409	0.0640*
URB	4.2717	0.0150**
FDI	0.4989	0.4030
INF	0.8845	0.8600

** and * imply the significance at 5% and 1%, level, respectively

B. Discussion

As seen in Table VII, the estimated results of the AMG model reveal a positive and significant relationship between GDPG, TRA, and INF on ENE, indicating that these variables are the primary drivers of ENE consumption in the studied economies. In contrast, the other explanatory variables, FDI, POP, and URB, exhibit no significant impact on ENE, suggesting that these factors are insufficient to significantly influence energy use in the GCC nations. The findings reveal a positive correlation between GDPG and energy consumption, which is consistent with the findings of previous studies conducted in various countries, including Central Asian countries [5], Egypt [7], and Africa [6]. This positive correlation can be attributed to the increased industrial activities that often follow economic growth in the GCC, leading to the expansion of ENE-intensive industries, such as petrochemicals, aluminum, and construction. This industrial activity significantly drives up energy demand [21]. Additionally, as GDP expands, rising incomes enable individuals to purchase ENE-intensive products, like appliances, vehicles, and consumer electronics, contributing to higher overall energy demand [22]. Moreover, the development of infrastructure projects in GCC, such as large-scale construction and transportation development, are ENE-intensive, further contributing to higher ENE consumption as the economy grows. The positive correlation between GDPG and ENE consumption underscores the nexus between economic prosperity, encompassing technological advancements, government policies, consumer behavior, and heightened ENE usage. This dynamic may present significant challenges to the long-term sustainability and efficiency of ENE usage. The present study's findings underscore the correlation between trade openness and energy consumption, a relationship that aligns with the findings in [9]. Greater trade openness has been shown to precipitate investments in infrastructure, such as ports and road networks, thereby promoting economic growth. This economic growth is often characterized by a high industrial output and is consequently ENE-intensive to develop and maintain. As GCC countries continue to expand their trading networks, there is a potential for heightened productive activity that is ENE-intensive. Furthermore, an increase in TRA will invariably lead to higher imports and exports. This phenomenon is further compounded by the increased consumption of ENE in the logistics and transportation sectors, as vehicles and aircraft consume energy to transport goods. Additionally, the openness of trade markets can lead to a heightened availability and consumption of ENE - intensive products and services, thereby contributing to an overall rise in ENE consumption [21]. This study suggests that inflation serves as a driver of ENE consumption, as evidenced by the observed increase in ENE usage with rising prices. However, authors in [7] on the Egyptian context, indicate an inverse relationship between INF and ENE consumption. During periods of INF, ENE prices escalate, potentially prompting households and businesses to adopt energy-efficient practices and technologies in order to reduce costs. Furthermore, INF leads to fluctuations in energy prices, which can significantly influence investment decisions within the energy sector. Higher prices can function as a catalyst for the development and integration of renewable energy sources and energy-efficient technologies. However, in the context of GCC countries, where ENE prices are heavily subsidized, INF might not immediately result in higher ENE prices for consumers. Nevertheless, it can still drive higher consumption due to increased economic activity and production demands during inflationary periods [23].

The coefficients for POP growth are both positive and negative, with no statistical significance for the panel. This inconsistency suggests that POP growth alone does not have a clear, consistent impact on ENE consumption across these countries, which contradicts the findings in [11] for Eastern African countries. The insignificant influence of POP growth can be attributed to the fact that, in GCC countries, economic growth driven by oil revenues and industrial expansion plays a more significant role in ENE consumption than POP growth. Concurrently, advancements in energy efficiency and infrastructure have served to reduce the impact of POP growth on overall energy demand. In a similar way, the findings indicate that URB exerts a negligible influence on ENE consumption within the GCC. This outcome is attributable to a multitude of factors, including energy pricing policies, economic structures that are dominated by the oil and gas sector, and regional climatic conditions [24]. The presence of subsidies and the absence of stringent energy conservation measures serves to diminish the apparent relationship between URB and ENE consumption. The findings of the panel estimation suggest that FDI exerts a negative yet non-significant influence on ENE consumption. This observation may be attributed to the fact that a substantial proportion of FDI in GCC countries is directed towards non- ENE-intensive sectors, such as finance, real estate, and tourism, which typically have lower ENE requirements compared to industries, like manufacturing or heavy industry, which are attributed to domestic use.

IV. CONCLUSIONS

This study aims to identify the key factors influencing Energy (ENE) consumption in the Gulf Cooperation Council (GCC) countries over the period from 1990 to 2023. To this end, it employs panel Augmented Mean Group (AMG) analysis, which reveals that Gross Domestic Product Growth (GDPG), Trade (TRD) openness, and Inflation (INF) have a positive correlation with ENE consumption. This indicates that as these economic indicators rise, so does the demand for ENE in the region. Conversely, the study finds that Population (POP) growth, Urbanization (URB), and Foreign Direct Investment (FDI) do not exert a significant influence on ENE use within the GCC context. This suggests that despite the increasing population numbers and urban expansion, these factors may not necessarily lead to higher energy consumption, possibly due to the region's reliance on ENE-intensive industries and existing ENE policies. The transition to a more sustainable ENE model in the GCC involves significant recommendations for improving energy efficiency measures. However, the transition to a more sustainable ENE model in the GCC is a multifaceted process, as these countries find themselves navigating the dual goals of meeting the growing ENE consumption and achieving environmental sustainability. To this end, policymakers in the GCC countries can implement several strategic actions to enhance ENE conservation and sustainability. First, the formulation of comprehensive ENE policies is imperative, encompassing a national ENE strategy that prioritizes the development of renewable ENE sources and the promotion of energy efficiency. This strategy should be supported by integrated resource planning to ensure a balance between supply and demand. To stimulate investment in renewable energy, the establishment of financial incentives, such as tax reductions and grants, in conjunction with the establishment of binding targets for renewable energy generation, is essential to drive innovation in this sector. Furthermore, it is important to enhance energy efficiency regulations by implementing stringent standards for buildings, appliances, and industrial processes. This should be accompanied by financial support for upgrading the existing infrastructure to enhance energy performance. Moreover, the development of smart cities that incorporate sustainable practices is substantial for promoting energy conservation and sustainability. These cities should prioritize efficient public transportation systems and green infrastructure, which can significantly reduce carbon emissions and enhance the quality of urban life. This research contributes to the existing literature by offering an updated and region-specific analysis of ENE consumption drivers in GCC countries using an extensive dataset and a robust econometric approach. The findings of this study offer a thorough examination of the role economic factors play in shaping energy demand in oil-rich economies, challenging the prevailing assumptions about the impact of FDI and URB on energy use. The study's findings reveal that the influence of FDI and URB in GCC countries is less substantial than previously thought.

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