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# Decoupling Growth from Fossil Fuels? Energy Consumption and Structural Transformation in the GCC

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**ABSTRACT**

The current study has tried to explore the impact of both renewable as well as non-renewable energy consumption on some of the crucial economic determinants like economic growth, export diversification, trade openness, and human capital in the GCC countries during the time period between 1990 and 2022. The most relevant second-generation panel econometric techniques, incorporating panel unit root tests, cointegration analysis, Fully Modified Ordinary Least Squares (FMOLS), and quantile regression, have been used. The comprehensive empirical analysis reveals that the consumption of renewable energy is quite significantly impacted by structural variables like trade openness and human capital, while on the other hand, non-renewable energy consumption is principally driven by short-run macroeconomic fluctuations, predominantly GDP and export diversification. The findings of this study highlight the importance of strategic policy realignment in the GCC to promote a sustainable energy transition by investing in human capital, enhancing trade openness, and decoupling economic diversification from carbon-intensive sectors. This paper further offers quite critical insights into the nexus between energy and economy and provides actionable policy recommendations for achieving long-term economic as well as environmental sustainability in fossil-fuel-dependent economies.

**Keywords:** Renewable Energy, Non-renewable Energy, Trade Openness, Diversification, Human Capital, GCC, Energy Transition, Economic Growth
**JEL Classifications:** Q43, Q41, O14, O44

## 1. INTRODUCTION

The Gulf Cooperation Council (GCC) comprises six major economies, Saudi Arabia, the United Arab Emirates, Qatar, Kuwait, Bahrain, and Oman, all of which face common policy and socioeconomic challenges(AlKhars et al., 2020). These economies primarily rely on revenue generation and economic growth from the energy sector, with fossil fuels accounting for a significant share of the total primary energy supply in GCC countries(Flamos et al., 2013). This reliance is primarily due to large reserves, proximity of onshore locations to deep waters, suitable geology, and oil fields. All of these factors enable them to produce fuel at a much lower cost compared to other regions worldwide (Stevens, 1997). This sector not only fuels GCC's economic growth but also plays a vital role in shaping their trade patterns and human capital development (Salim and Alsyouf, 2020).

Having emphasized upon the importance of the energy sector for the GCC region, it is also true that the GCC countries rank among the top twenty countries in terms of carbon dioxide ($CO_2$) emissions per capita (Salim and Alsyouf, 2020). Because of this reason, in the midst of growing global concerns regarding sustainability, the GCC countries are currently facing huge pressure to meet internationally accepted climate change and renewable energy targets (Menegaki and Tugcu, 2016). For this, the fossil fuel dependent region is increasingly focusing on initiatives that help to diversify their economies specifically through massive investments in wind and solar energy such as the UAE;'s Masdar initiative and Saudi Arabia's Vision 2030 (Al-Faisal et al., 2020;

Alhajji, 2021). In the past few years, through their initiatives, it has become quite evident that the GCC countries have recognized how crucial sustainable development as well as diversification is amid highly volatile oil prices (Bassi et al., 2019; Panos and Kypreos, 2020). The major motivation behind this whole intensive drive is to reduce dependence on oil revenues due to price volatility and shifting global market dynamics. Other reasons include addressing the burgeoning unemployment trends through human capital development. Recently, the GCC countries have made significant strides in education, export diversification, shifting to renewable energy sources, and boosting economic growth. However, in spite of their financial strengths, the region has been facing considerable challenges, specifically rooted in its structural vulnerabilities, which are caused by its over-reliance on hydrocarbon industry. This situation cannot continue indefinitely, so it is essential to examine the impact of both renewable and non-renewable energy consumption and identify key variables that support economic stability to guide more effective policy decisions.

The impact of energy consumption on key socio-economic factors like GDP, trade, export diversification, and human capital remains under-researched, particularly in the context of the GCC countries. While doing a comprehensive review of the literature, not a single study was found to have focused specifically on this area. Fatima et al. (2022) come closest, but her study too included only human capital and trade as controls, but does not investigate a transition dynamic or measure direct causality on these outcomes. (AlKhars et al., 2020) highlighted the under-research of renewables but remain descriptive. The very recent 2025 study shows a positive renewable–growth link but does not extend analysis to trade, exports, or human capital. Najia Saqib et al. (2022) focused on emissions, examining both renewable and fossil energy, human capital, and institutional depth offering evidence on the interaction between energy mix and broader socio-economic variables. Thus, no study to date has specifically isolated a full transition from fossil to renewables and its causal impact on GDP, trade openness, export diversification, and human capital all four variables together. The research question as to whether a transition from fossil to renewable energy consumption can in any way impact major economic variables like economic growth and trade, greater economic diversification, and enhanced human capital development in the GCC region remains unexplored and also presents an opportunity to fill this huge gap and add to the existing knowledge cycle.

Against this backdrop, this research paper aims to address this major gap by exploring the impact of both renewable and non-renewable energy consumption on the economic growth trajectories, trade patterns, diversification strategies, and human development parameters within the GCC countries. The most crucial hypotheses that would be tested under this study are to assess the impact of non-renewable energy consumption, as well as renewable energy consumption, to explore how both offer new avenues for economic growth, aid in diversification, drive innovation, and help build human capital. To this end, the study will utilize econometric models to assess the causal relationships between energy consumption and the key economic variables, incorporating data from the International Energy Agency (IEA), the World Bank, and the GCC National Statistical Offices. Having examined both the direct as well as indirect impacts of energy consumption on major economic indicators, this paper seeks to offer some quite crucial and valuable insights into the policy implications for the GCC's ongoing energy transition.

The major contribution of this study is to probe deeper into investigating the multifaceted relationship between energy consumption and its impact on growth, trade openness, export diversification, and human capital in the Gulf Cooperation Council region over the period between 1990 and 2022. This analysis aims to further highlight the Gulf's dependency on fossil fuel or oil exports, which poses a significant threat to sustainability. By analyzing this nexus between energy consumption and major developmental variables, this study will look at both the positives as well as vulnerabilities of the major Gulf economies. This study is built on a comprehensive literature review by having explored as to how increasing energy demand as well as consumption have shaped the trajectory, trends, and patterns of trade and how a shift to renewable energy can alter the dynamics of trade in the Gulf region (Al-Mulali et al., 2013; Alkhathlan et al., 2013).

Further contribution of the study lies in investigating the role of demand for energy in the economic diversification drive of the GCC region. As previous findings have supported a major role of shifting to non-oil sources in assisting the diversification drive, this study will attempt to find if the claim remains true or the region still faces significant barriers, especially in terms of its over-reliance on energy-intensive industries (Khalid and Shahbaz, 2019). Further, as the region still struggles to develop a labor force that can compete in non-oil sectors, this study attempts to analyze the impact of energy demand on human capital formation as well as whether huge oil revenues improve investments in human capital or not. Thus, this study, in a nutshell, aims to explore how energy consumption can be balanced with sustainable growth, renewable energy, human capital, and trade to drive economic prosperity (Narayan and Sharma, 2011; Apergis and Payne, 2010). This study thus aims to contribute to the broader discourse on energy transition by focusing on the GCC's unique context, where the shift from fossil fuels to renewables could reshape the future of the region's economy. The findings are expected to offer guidance to policymakers seeking to balance energy security with sustainable growth and to foster a more diversified, resilient economic future for the region and further in breaking down and exploring the multi-dimensional impacts of energy consumption on the economic trajectory of the GCC countries.

## 2. LITERATURE REVIEW

While probing the existing literature on the correlation between energy consumption and economic growth, it was found that energy consumption has historically underpinned economic development in the GCC countries, as fossil fuels dominate the energy mix. A number of studies have highlighted the positive relationship between energy consumption and economic growth in oil-rich economies (Apergis and Payne, 2010; Ozturk, 2010). This also aligns with the energy-led growth hypothesis, which argues that an abundance of cheap energy stimulates both industrial productivity as well as infrastructure development (Stern, 2000;

Chen and Chen, 2007; Akinlo, 2008). Especially for the GCC region, unidirectional causality from energy consumption to GDP growth has been found in several studies (Al-Iriani, 2006; Sbia et al., 2014). This accentuates the centrality of energy to growth in the short run and development in the long run. On the other hand, some contrasting perspectives suggest that this model may not be sustainable in the long run. For instance, Al-Mulali et al. (2014) argued that while energy consumption can support short-term growth, but long-term sustainability demands a transition toward renewable sources. Fay et al. (2015) and Mahadevan and Asafu-Adjaye (2007) slo in their work support the "decoupling hypothesis," while noting that economic enlargement can occur independently of increasing energy use through efficiency and sectoral transitions.

The ongoing policy reforms in the GCC region, especially the current initiatives like Saudi Arabia's Vision 2030 and the UAE's Energy Strategy 2050, show a tactical move towards transitioning to renewable energy and diversification (Alshehry and Belloumi, 2015). However, even after these extensive efforts, the fossil fuel industry continues to and will continue to for some time, dominate the economy. The threat of "Dutch Disease", where overt dependence on oil exports incumbers growth in other sectors, remains a concern in the region (Corden and Neary, 1982). Other factors like energy subsidies and overconsumption have also hurt trade balances and dispirited investment in other quite productive growing sectors (Hegazy and Matar, 2019). Still, (Balcilar et al., 2020) argue that energy consumption indirectly supports trade by enhancing infrastructure and industrial advancement.

Concerning the variable of trade, Bhattacharyya (2017) in his paper warns that over-dependence on fossil fuels may cause imbalances of trade. On the other hand, (Rahman and Velayutham, 2021) in their study suggest that investing in renewable energy and energy efficiency can boost trade competitiveness. The GCC countries, such as the UAE and Qatar, are increasingly exporting clean energy technologies and services, thus further opening new trade opportunities (Pavlova and Mehdizadeh, 2020). Export diversification, another quite longstanding strategic goal, remains heavily impacted by the region's energy model. (Alharthi, 2016) in his study found that energy-intensive industries like petrochemicals and refining limit Gulf countries ability to transition into high-value export sectors. Further, (Bahmani-Oskooee and Wang, 2015) argued that investing in renewable technologies benefits a lot by fostering innovation and supporting diversification. Sajjad and Samreen (2023) analyze economic diversification in the UAE and show that diversification efforts aimed at sustainability have also reshaped trade relations with India since 1991, reducing reliance on hydrocarbons and strengthening non-oil trade linkages. (Albassam, 2015) states that energy subsidies discourage diversification by reinforcing dependence on oil, which is a crucial point from the point of view of policymaking. Conversely, Cherif and Hasanov (2016) emphasize that removing subsidies and developing human capital can encourage structural transformation a lot. (Saidi and Hammami, 2016) show that the patterns of energy consumption significantly impact sectoral shifts, by promoting growth in non-oil sectors such as tourism and logistics when energy use becomes more resourceful. Akhter and Samreen (2024) test the Environmental Kuznets Curve for GCC countries using panel data from 1995–2020 and find a non-linear relationship between growth and environmental degradation, underscoring the role of energy use in the region's environmental trajectory.

Another major component, human capital development, is indirectly impacted by energy policy. Access to energy improves health and education, which are the key pillars of human capital, as shown by Ben Ali and Yusop (2012). Looney (2009) noted that energy wealth in the GCC has funded massive public investments in social services, though these have not always translated into skilled labor. El-Katiri (2014) cautions that energy subsidies distort incentives and discourage participation in productive labor markets. However, with the rise of renewable energy, new employment opportunities are emerging that require specialized skills and training. (Alotaibi and Mishra, 2022) highlight that green sectors offer opportunities for skilled labor absorption, while the World Economic Forum (2020) emphasizes the role of renewables in catalyzing workforce transformation. Initiatives like NEOM in Saudi Arabia and the UAE's Vision 2021 prioritize education and R&D aligned with clean technologies, thereby linking energy transition to human capital development.

Despite this rich body of literature, gaps remain. Most research has focused on bilateral relationships energy-growth, energy-trade, or energy-diversification, rather than offering integrated, multi-dimensional analyses. There is also a lack of longitudinal studies addressing how renewable energy affects all four pillars: growth, trade, diversification, and human capital across the GCC (Krane, 2020; Khan et al., 2021). Further, few studies address the institutional, demographic, and geopolitical differences across GCC nations or explore how individual countries implement their energy transition strategies. The IMF (2021) notes that large-scale renewable investments such as NEOM and Masdar are transforming the region's energy profile, yet little is known about their long-term economic effects. Intra-regional disparities and policy effectiveness in promoting resilience amid energy market volatility remain underexplored.

In summary, the literature illustrates a complex, evolving relationship between energy consumption and key economic indicators in the GCC. While fossil fuels have historically powered growth and trade, renewable energy introduces new possibilities for diversification, competitiveness, and human capital formation. However, more integrated, empirical research is needed to fully understand and guide the region's energy transition toward sustainable and inclusive economic development.

## 3. RESEARCH METHODOLOGY

### 3.1. Data Specification

The empirical analyses have utilized panel data of six GCC countries from 1990 to 2022. The countries include Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates. Data is collected from multiple resources. Where required, the missing information is filled out using linear interpolation and the moving average method. Trade openness influences energy consumption because the economies that engage in more trade demands more energy. Notably, Jóźwik et al. (2025) report that a 1 % rise in trade openness leads to a 0.143 % increase in renewable energy use. Trade as a percentage of GDP is the sum of a country's exports and imports of goods and services, divided by its gross domestic product (GDP). Table 1 below summarises the variables, their measurements, and the data sources used in the empirical analysis. The data has been taken from the World Bank Database, which provides data on trade as a percentage of GDP for countries, including actual values, historical data, forecasts, and projections. Another variable, economic growth, is a key determinant of energy demand. In the early stages of economic growth, countries heavily rely on non-renewable energy consumption, but as economies grow and develop, they may shift towards cleaner energy. For economic growth, data on GDP per capita is taken which has been extracted from World Bank Database (World Development Indicators, 2022-2023).

Another variable undertaken in this study, as mentioned in the above Table 1, is the Human Capital Index, which represents educational capability in terms of years of schooling as well as returns to education. In the past decade, the focus of GCC towards improving its education domain has taken a significant space, and thus it would be interesting to know if this can be a relevant factor for higher energy efficiency. High human capital may reflect a crucial factor for high energy efficiency, and further can be a crucial determinant for both renewable as well as non-renewable energy consumption (Sharma et al., 2021). The data has been collected from the Penn World Table. Export diversification measures the extent to which a country diversifies its exports from traditional exports. Export diversification can help GCC countries transition from fossil fuel to renewable energy. Higher values indicate export concentration, and lower values indicate larger diversification. The data has been extracted from the IMF (Theil Index). For renewable and non-renewable energy consumption, data has been taken in kg of oil equivalent. The data is gathered from the EIA website.

### 3.2. Estimation Technique

The study has commenced by checking the stationarity of the chosen variables under study. This study has employed the first as well as the second-generation unit root tests. The IPS unit root test and the Pesaran unit root test, identified as CIPS are employed (Pesaran, 2007). Unit, first difference, and second difference are the methods used to determine the stationarity. Unit refers to the original level of panel data before any differencing is applied. If the series has a unit root, it implies the data is non-stationary and has a trend. The first difference is the difference between consecutive observations of the data. Applying the first difference helps transform a non-stationary series into a stationary one if the original series contains a unit root. The purpose is to remove trends or seasonality from the series, making it easier to analyze and model.

A unit root test on the first difference of the series checks if differencing has achieved stationarity. The second difference is the difference between consecutive first differences. The second difference is used if the first difference does not fully address non-stationarity, such as in cases with more complex trends or seasonal patterns. Intercept tests if the series is stationary around a fixed average level. Trend tests if the series is stationary around a mean that changes over time. As Pedroni (1999) elaborates, all four are found on estimators that average out each participant that calculates the individual coefficient. Each of these tests can take into account dynamics, fixed effects, trends, and similar slope coefficients.

Further, to address the balanced relationship between variables, Pedroni's cointegration test has been employed along with Kao for testing robustness. This test of co-integration was primarily developed by Pedroni in the year 1999, and it allows for the interdependence of various cross sections with varying effects. He advocated two different types of residual-based experiments. Four measures are there in the first type that are distributed normally, asymptotically, on the basis of groupings and regression residuals from within the group. They are: Panel V statistics, Panel r statistics, Panel PP statistics, and group ADF statistics. The purpose is to analyze if there are any sort of long-term specifications having checked the cointegration variables. This study has employed the Pedroni (1999) method in order to assess co-integration in panel data that has heterogeneous properties. As the study looks at the impact of two dependent variables that are non-renewable energy consumption and renewable energy consumption, thus, for this precise reason two empirical models has been used. They are:

Equation-1:

$$\log(RE_{it}) = \beta_0 + \beta_1 \log(GDP_{it}) + \beta_2 \log(Tradeit) + \beta_3 \log(Div_{it}) + \beta_4 \log(HC_{it}) + \epsilon_{it} \quad (1)$$

Equation-2:

$$\log(NRE_{it}) = \alpha_0 + \alpha_1 \log(GDP_{it}) + \alpha_2 \log(Trade_{it}) + \alpha_3 \log(Div_{it}) + \alpha_4 \log(HC_{it}) + \nu_{it} \quad (2)$$

In equation i; $\beta_0$ = Constant term; $\beta_1$, $\beta_2$, $\beta_3$, $\beta_4$ = Coefficients to be estimated; ϵt= Error term and in equation 2, $\alpha_0$ = Constant term, $\alpha_1$, $\alpha_2$, $\alpha_3$, $\alpha_4$ = Coefficients to be estimated, νt = Error term. The term i refers to country specific intercept (i.e., i=1,2.,Ni = 1, 2., Ni=1,2.,N, for NNN countries) and on the other hand t is the time index (i.e., t=1,2.,Tt = 1, 2., Tt=1,2.,T, for TTT periods). Both the above-mentioned equations try to examine the impact of energy consumption (both renewable and non-renewable separately on key economic factors. The model variables are log-transformed for empirical analysis to reduce the data's sharpness and improve the variable's distributional properties. The natural logarithm helps to remove auto-correlation and heteroskedasticity problems in the data and also to track percentage changes. In the first equation, the natural logarithm of renewable energy consumption is modeled as a function of the natural logarithms of economic growth (GDP), trade, export diversification, and human capital.

Further, the second equation has tried to model the natural logarithm of non-renewable energy consumption as a function of the same independent variables. Both the above models allow for the estimation of how a one percentage change in each independent variable impacts energy consumption in percentage terms. This helps a lot in providing valuable insights into how economic growth, trade trajectory, diversification, specifically of exports, and human capital contribute to shaping energy consumption

**Table 1: Variables undertaken and the data source**

| Variables | Symbol | Measurement | Source |
|---|---|---|---|
| Trade | TRADE | Trade (% of GDP) | WDI |
| Economic growth | GDP | GDP per Capita (current US $) | WDI |
| Human Capital Index | HC | Human Capital | Penn Worl Trade |
| Export Diversification Index | EDI | Export concentration and diversification | IMF (Theil Index) |
| Renewable Energy Consumption | RE | kg of oil equivalent | EIA |
| Non-Renewable Energy Consumption | NRE | kg of oil equivalent | EIA |

Data source: WDI, IMF, EIA, Penn World Trade

**Table 2: Descriptive statistics**

| | LNRE | LRE | LEDI | LGDP | LTRADE | LHC |
|---|---|---|---|---|---|---|
| Mean | 9.007433 | 0.523445 | 0.553757 | 9.972265 | 4.619612 | 1.098012 |
| Median | 9.103822 | 0.067659 | 0.564461 | 10.03984 | 4.551894 | 1.175613 |
| Maximum | 9.972156 | 3.524545 | 0.633928 | 11.49315 | 5.352621 | 1.449142 |
| Minimum | 7.606093 | 0.009950 | 0.414094 | 8.697072 | 3.926192 | 0.484707 |
| Std. Dev. | 0.515871 | 1.038077 | 0.049594 | 0.677509 | 0.285924 | 0.266950 |
| Skewness | -0.474986 | 1.967358 | -1.178156 | 0.008898 | 0.431639 | -1.459613 |
| Kurtosis | 2.728454 | 5.158634 | 3.890983 | 2.368507 | 2.714584 | 3.731399 |
| Jarque-Bera | 8.053503 | 166.1690 | 52.35499 | 3.292577 | 6.820364 | 74.71880 |
| Probability | 0.017832 | 0.000000 | 0.000000 | 0.192764 | 0.033035 | 0.000000 |
| Sum | 1783.472 | 103.6422 | 109.6438 | 1974.509 | 914.6832 | 217.4063 |
| Sum Sq. Dev. | 52.42627 | 212.2882 | 0.484527 | 90.42656 | 16.10529 | 14.03868 |
| Observations | 198 | 198 | 198 | 198 | 198 | 198 |

**Table 3: Correlation analysis**

| Correlation Probability | LNRE | LRE | LEDi | LGDP | LTRADE | LHC |
|---|---|---|---|---|---|---|
| LNRE | 1.000000<br>…. | | | | | |
| LRE | 0.161307<br>0.0232 | 1.000000<br>. | | | | |
| LEDI | 0.053912<br>0.4506 | -0.019922<br>0.7806 | 1.000000<br>…. | | | |
| LGDP | 0.559781<br>0.0000 | -0.220353<br>0.0018 | -0.336614<br>0.0000 | 1.000000<br>…. | | |
| LTRADE | 0.124368<br>0.0809 | 0.648197<br>0.0000 | -0.522386<br>0.0000 | 0.216460<br>0.0022 | 1.000000<br>…. | |
| LHC | 0.452564<br>0.0000 | 0.146233<br>0.0398 | -0.079586<br>0.2650 | 0.522131<br>0.0000 | 0.156337<br>0.0278 | 1.000000<br>…. |

patterns. The logarithms have been taken as they can interpret this impact much more intuitively by linking them to elasticities, where coefficients represent the percentage change in energy consumption resulting from a 1% change in the independent variables.

## 4. RESULTS

### 4.1. Panel Quartile Regression

Panel Quartile regression is predominantly employed in research that is associated with energy Economics. This regression offers quite robust and consistent results that address endogeneity issues (Farooq et al., 2019). The data collected for multiple variables for six countries, that too for a quite longer term, comprising the GCC region, had the properties for which this method seemed more suitable, as endogeneity issues might have occurred. Thus, based on data quality and given its use in only a few studies incorporating long-term data from various countries, panel quartile regression is employed (Alvarado et al., 2018; Halliru et al.; 2020; Akra, et al., 2021).

**Table 4: Panel unit root tests**

| Variables | CIPS unit root test | | IPS unit root test | |
|---|---|---|---|---|
| | Level | First difference | Level | First difference |
| LNRE | −1.461 | - | 4.774 | −4.636*** |
| LRE | −2.992** | - | −9.590*** | - |
| LEDI | −2.621 | - | −0.215 | −6.835*** |
| LTRADE | −3.062** | - | −3.141*** | - |
| LGDP | −3.275*** | - | −0.065 | −5.654*** |
| LHC | −3.026** | - | 0.273 | −0.334 |

***, **, *denote statistical significance at the 1 and 5% and 10% levels, respectively

Descriptive statistics for the study variables are presented in the above mentioned Table 2. Table 2 above illustrates mean, standard deviation, minimum and maximum variables, skewness and kurtosis, and Jarque-Bera test values to check whether the distribution is normal. For NRE, the mean is high with low variability, and the distribution is slightly left-skewed and not perfectly normal. The RE mean is 0.523, which indicates a much lower average consumption of renewable energy compared to non-renewable energy and has a high variance with right-skewed, more outliers, meaning there are countries with very high renewable energy consumption and a significant departure from normality. For EDI, it has low variability but is strongly left-skewed, indicating that most countries have higher export diversification. GDP has moderate variability and follows a nearly normal distribution. TRADE has low variability and is slightly right-skewed with a small deviation from normality. HC is left-skewed, indicating most countries have relatively high human capital with a few having much lower levels, slightly high kurtosis, low variability, and showing significant deviation from normal distribution.

Table 2 above presents the correlation matrix for all variables used in the analysis. The diagonal values are all 1, showing that each variable is perfectly correlated with itself. LNRE and LRE have a low positive correlation of 0.161, indicating a weak relationship between non-renewable and renewable energy consumption. LNRE with LHC and LGDP have moderate positive correlations of 0.452 and 0.559, suggesting that higher GDP is moderately linked to higher non-renewable energy use. LTRADE and LRE show a strong positive correlation of 0.648, indicating that increased trade is closely associated with higher renewable energy consumption. LEDI and LGDP have a moderate negative correlation of -0.336, meaning that higher GDP relates to lower export diversification. LGDP and LHC display a significant moderate positive correlation of 0.552, implying that higher GDP per capita is linked to increased human capital. The results in the above mentioned table 2 indicate a strong positive association between renewable energy use and economic growth, while trade openness and energy diversification show mixed correlations across sectors

Table 4 above presents the results of two panel unit root tests: the Im-Pesaran-Shin (IPS) test and the Cross-sectionally Augmented IPS (CIPS) test, both of which are essential in determining the stationarity of variables in panel data. Stationarity ensures that the variables' statistical properties, such as mean and variance, remain constant over time, which is a key requirement for valid econometric estimation (Baltagi, 2005). As it is known that the data that is non-stationary can further lead to spurious regressions, thus, testing for unit roots is recommended to be the first step in any sort of panel analysis. The IPS test has been used, which assumes cross-sectional independence. This shows that the variables undertaken in the study, like non-renewable energy consumption, export diversification, per capita GDP, and human capital, are all non-stationary at the level; however, they become stationary after first differencing has been done. This further implies that these variables undertaken are integrated of order one, I(1). On the other hand, other variables like renewable energy consumption and trade openness are found to be stationary at the level, which means that they are integrated of order zero, I(0). As we have this mix of I(0) and I(1) variables, it becomes imperative to test for cointegration before applying any regression techniques in order

**Table 5: Panel cointegration analysis**

| Test Statistic | Model 1 | | Model 2 | |
|---|---|---|---|---|
| | t-statistics | P-value | t-statistics | P-value |
| Pedroni Cointegration | | | | |
| Panel v-statistic | 1.602* | 0.0545 | 0.775 | 0.218 |
| Panel rho-statistic | 0.408 | 0.658 | −0.309 | 0.378 |
| Panel PP-statistic | −1.817** | 0.0346 | −2.417*** | 0.0078 |
| Panel ADF-statistic | −3.823*** | 0.0001 | −3.962*** | 0.000 |
| Group-rho statistic | 1.246 | 0.8936 | 0.130 | 0.5518 |
| Group PP statistic | −4.009*** | 0.0000 | −4.035*** | 0.000 |
| Group ADF statistic | −4.680*** | 0.0000 | −4.411*** | 0.000 |
| Kao cointegration | | | | |
| ADF | −2.406*** | 0.0081 | −2.461*** | 0.0069 |

Model 1 shows the cointegration of renewable energy and Model 2 illustrates non-renewable energy

to ensure the presence of a valid long-run equilibrium relationship (Pedroni, 1999; Kao, 1999).

Contracting the CIPS test, on the other hand, allows for cross-sectional dependence among the panel units. This is a common feature in macroeconomic datasets that involves countries with interconnected economies, which reveals that all variables are stationary at the level, indicating I(0) integration (Pesaran, 2007). This outcome now implies that the data series does not need any sort of differencing and can be used directly as it is in the standard panel regressions without any risk of spuriousness. As the CIPS test accounts for potential interdependence among cross-sectional units, the results we get out of it are considered to be more robust and reliable for macro panel studies like this study that involves the GCC countries (Banerjee and Carrion-i-Silvestre, 2017).

Thus, the interpretation of Table 4 suggests two possible estimation approaches. If the IPS results are preferred, cointegration tests must be conducted (as done in the study using Pedroni and Kao tests), and appropriate long-run models such as FMOLS, DOLS, or ARDL should be used. However, if CIPS results are deemed more suitable—given the likelihood of cross-sectional dependence among GCC nations—then regression can proceed at levels without differencing or cointegration testing. This dual approach enhances the robustness of the empirical strategy and ensures that any conclusions drawn from the regression models are based on well-founded stationarity assumptions.

Thus, on the basis of the above results, the most appropriate next step is to ascertain the possibility of convergence. The co-integration test has thus been applied, along with the Kao co-integration test, to assess whether a long-run relationship exists among the non-stationary variables. Both these tests have been used to assess the relationship between energy consumption both renewable and non-renewable, on the major economic variables that are GDP, Human capital, economic diversification, and international trade. These tests have been employed separately in two model specifications for both types of energy consumption.

Table 5 presents the results of the Pedroni (1999) and Kao (1999) panel cointegration tests, which assess whether a long-run equilibrium relationship exists among the model variables. Two separate models were analyzed: Model 1, which evaluates the relationship between renewable energy consumption and key macroeconomic factors (GDP per capita, trade openness, export diversification, and human capital), and Model 2, which focuses on non-renewable energy consumption and the same set of explanatory variables. In Model 1, several Pedroni test statistics—including the Panel PP-statistic (−1.817, $P < 0.05$), Panel ADF-statistic (−3.823, $P < 0.01$), Group PP-statistic (−4.009, $P < 0.01$), and Group ADF statistic (−4.680, $P < 0.01$)—rejects the null hypothesis of no cointegration, indicating a long-term relationship between renewable energy and the selected macroeconomic variables. The Kao test further supports this relationship, with the ADF statistic (−2.406, $P = 0.0081$) significant at the 1% level. Although the Panel rho and Group rho statistics do not reject the null, most tests indicate the presence of cointegration. These results suggest that renewable energy consumption in the GCC is consistently and persistently connected to macroeconomic trends such as trade, human capital formation, and economic diversification over the long run (Pedroni, 1999; Kao, 1999).

In Model 2, stronger and more consistent evidence of cointegration is observed for non renewable energy consumption. All key Pedroni statistics—including the Panel PP-statistic (−2.417, $P < 0.01$), Panel ADF-statistic (−3.962, $P < 0.01$), Group PP-statistic (−4.035, $P < 0.01$), and Group ADF-statistic (−4.411, $P < 0.01$)—are statistically significant. The Kao ADF statistic (−2.461, $P = 0.0069$) also confirms this relationship at the 1% level. These results imply that economic growth, trade activity, diversification, and human capital are closely and persistently linked to non-renewable energy use in the long run across GCC countries.

Both cointegration tests are critical for panel data models with mixed orders of integration and are widely used in empirical macroeconomic research. The Pedroni test accounts for heterogeneity across cross-sections by estimating both within- and between-dimension statistics, allowing for different intercepts and trend coefficients (Pedroni, 1999). Meanwhile, the Kao test assumes homogeneity but confirms cointegration based on the stationarity of residuals using an Augmented Dickey-Fuller (ADF) framework (Kao, 1999). Given the confirmation of cointegration, differencing the data is inappropriate, as it would eliminate long-run relationships. Instead, estimation should proceed using fully modified ordinary least squares (FMOLS), dynamic OLS (DOLS), or error correction models (ECM) to capture long-run equilibrium dynamics and short-run adjustments (Baltagi, 2005).

In conclusion, Table 5 confirms that both renewable and non-renewable energy consumption are cointegrated with macroeconomic indicators such as GDP, trade openness, export diversification, and human capital in the GCC countries. These findings now deem it essential to use FMOLS and quantile regression models as the next step in order to estimate the long-run impact of energy consumption on broader economic indicators. These findings are particularly crucial in the context of energy transition studies, as they emphasize upon the systemic ties between energy policy and development goals (Banerjee and Carrion-i-Silvestre, 2017; Pesaran, 2007).

The above Tables 6 and 7 presents the results of two empirical estimation technique that is Quantile Regression and Fully Modified Ordinary Least Squares (FMOLS. These are used to examine the impact of key macroeconomic variables like GDP per capita, trade openness, export diversification, and human capital on both renewable and non-renewable energy consumption across GCC countries in a specified time frame. These tools are employed to capture not just the short-run heterogeneity across quantiles but also the long-run relationships among variables. This also enhances the robustness of inference (Farooq et al., 2019; Alvarado et al., 2018).

**Table 6: Quantile regression and FMOLS results for renewable energy**

| Variables | Quantile regression | FMOLS |
|---|---|---|
| Diversification | 2.604 (0.1318) | 2.630 (0.1289) |
| GDP | −0.369* (0.0871) | −0.345*** (0.0007) |
| Trade | 2.017* (0.0634) | 0.520** (0.0339) |
| Human Capital | 0.517 (0.1001) | 2.124*** (0.0027) |
| Constant | −7.285** (0.0614) | |
| Observations | | |
| $R^2$ | 0.108 | 0.945 |

Source: Author's calculation

**Table 7: Quantile regression and FMOLS results for non-renewable energy**

| Variables | Quantile regression | FMOLS |
|---|---|---|
| Diversification | 5.296*** (0.0000) | 2.645 (0.2499) |
| GDP | 0.469*** (0.0000) | 0.465*** (0.0006) |
| Trade | 0.586*** (0.0000) | −0.411 (0.2054) |
| Human Capital | 0.409*** (0.0010) | −1.503 (0.1067) |
| Constant | −1.770** (0.0534) | |
| Observations | | |
| R^2 | 0.274 | 0.584 |

Source: Author's calculation

## 4.2. Renewable Energy Results

For the model used to assess renewable energy, export diversification depicts a positive relationship but also a statistically insignificant impact, both in quantile regression as well as FMOLS. This now means that while the efforts for diversification may be seen to be directionally aligned with more renewable energy usage, but this impact is not strong enough to be finally conclusive. The coefficient of GDP is negative and also statistically significant in the FMOLS model (–0.345, $P < 0.01$). This indicates that economic growth in the GCC is still largely dependent on non-renewable

**Table 8: Comparison of renewable and non-renewable energy models**

| Aspect | Renewable energy | Non-renewable energy |
|---|---|---|
| Best Model Fit ($R^2$) | FMOLS (0.945) | Quantile Regression (0.274) |
| Key Positive Factors | Trade, Human Capital | GDP, Diversification, Trade |
| Key Negative Factor | GDP | None |
| Diversification Impact | Insignificant | Strong short-run effect |
| Human Capital Impact | Significant (long-run) | Short-run effect but negative long-run impact |

Source: On the basis of Tables 6 and 7

sources, which seems to potentially crowd out the adoption of renewables. The results align with the existing literature, which also highlights the growth-energy paradox in hydrocarbon-rich economies (Al-Mulali et al., 2013).

Trade openness, however, in contrast, has a positive as well as significant impact on renewable energy in both models. This impact is especially notable in the quantile regression (2.017, $P < 0.10$). This emphasizes upon the role of international trade in order to promoting technology transfers as well as green investments (Chen et al., 2019). Another variable, human capital, appears to be insignificant in the short run, that is, in quantile regression, but it becomes highly significant in FMOLS with a value of (2.124, $P < 0.01$). This underscores its importance for the long-term renewable energy transition. These results also align with findings from the World Economic Forum (2020), which highlighted education and skill development as key drivers of renewable energy adoption. The FMOLS model demonstrated a very high $R^2$ value of 0.945, which indicates a very strong explanatory power and suggests that long-term factors significantly influence renewable energy use.

### 4.3. Non-Renewable Energy Results

For non-renewable energy, export diversification emerges as a strong positive and highly significant determinant in the quantile regression model (5.296, $P < 0.01$), although its long-run effect is insignificant in FMOLS. This may reflect the fact that many diversification strategies in the GCC are still anchored in energy-intensive sectors like petrochemicals and heavy industry (Alharthi, 2016). GDP is positively and significantly associated with non-renewable energy consumption in both models, confirming that economic expansion continues to fuel fossil fuel demand in the region—a pattern consistent with earlier studies by Apergis and Payne (2010).

Trade openness has a significant short-run effect (0.586, $P < 0.01$) but an insignificant long-run impact, suggesting that trade supports fossil fuel use in specific economic cycles but does not sustain this influence over time. Human capital, while positive and significant in quantile regression, shows a negative and statistically insignificant coefficient in FMOLS, suggesting that while labor and education currently support fossil energy sectors, their long-run potential may favor renewable transitions. The $R^2$ value of FMOLS for non-renewable energy (0.584) is lower than for renewable energy, indicating weaker model fit for long-term fossil energy trends.

Table 8 compares the model performance for renewable and non-renewable energy consumption using FMOLS and quantile regression. The FMOLS model for renewable energy shows a high $R^2$ value (0.945), indicating that long-run structural variables such as trade openness and human capital significantly influence renewable energy adoption in the GCC. These findings also support findings by Chen et al. (2019), Alotaibi and Mishra (2022) in their studies, as well as the reports by the World Economic Forum (2020) that emphasized upon the crucial role of education and international economic integration in order to promote non-renewable clean energy. In contrast, the quantile regression model fits non-renewable energy consumption much better, as shown by the values of ($R^2 = 0.274$). This suggests that conventional energy usage is much more impacted by short-run factors like GDP and export diversification. This reflects earlier findings by Al-Mulali et al. (2013) and Alharthi (2016), who noted the GCC region's persistent dependence on fossil fuels. Thus, finally, the comparison reveals that renewable energy consumption is better explained by long-term policy and structural factors, while the non-renewable use remains tied to immediate economic conditions.

## 5. CONCLUDING REMARKS AND POLICY RECOMMENDATIONS

In conclusion, this study provides a quite comprehensive empirical assessment of the long- and short-run macroeconomic determinants of both renewable and non-renewable energy consumption in the Gulf Cooperation Council countries over the period of 1990-2022. Quite advanced panel econometric techniques have been employed, including second-generation unit root and cointegration tests, FMOLS, and quantile regression. The study highlights critical asymmetries in how various crucial economic indicators influence the region's energy transition.

The findings from a detailed in-depth analysis unequivocally establish the existence of long-run cointegration between energy consumption and key macroeconomic variables like GDP per capita, trade openness, export diversification, and human capital. It is to be noted that renewable energy consumption is found to be more strongly influenced by structural variables like trade openness and human capital, whereas non-renewable energy consumption continues to be primarily driven by short-run fluctuations in the economy and export diversification. These patterns highlight that while structural reforms and institutional investments support the uptake of renewable energy, non-renewable energy remains tethered to conventional growth pathways.

These findings echo previous empirical studies as depicted in the detailed literature review. For instance, Al-Mulali et al. (2013) emphasized that WANA countries, including the GCC countries, are characterized by a persistent reliance on fossil fuels despite increasing awareness of environmental concerns. In a similar way, Alharthi (2016) also identified the predominance of energy-intensive sectors in GCC diversification strategies, which indicates that economic expansion remains closely aligned with non-renewable energy use. This ongoing dependence is further complicated by the limited integration of renewable energy into mainstream industrial policy. This, thereby, constrains the region's capacity for genuine and much needed energy transformation.

The study further underscores the pivotal role of human capital development in fostering the adoption of renewable energy. Human capital contributes quite positively to clean energy consumption in the long run. This suggests that education, research, and vocational training tailored toward energy technologies can catalyze a sustainable transition. This is consistent with insights from Alotaibi and Mishra (2022), who also argued that the green economy offers ample opportunities for skilled labor absorption. This, thereby, underscores the need for workforce development strategies aligned with environmental goals. The World Economic Forum (2020) also highlighted renewable sectors' future growth engines demanding new competencies, particularly in emerging areas like artificial intelligence, smart grids, and clean energy technologies.

Another major variable, that is, trade openness, seems to have a strong, positive, and consistent impact on renewable energy consumption across all model specifications. This finding suggests that deeper economic integration with global markets facilitates the transfer of clean technologies, know-how, and capital investments required to upscale renewable energy infrastructure. Chen et al. (2019) similarly observed that trade liberalization enables access to energy-efficient technologies and enhances environmental performance in emerging economies.

Conversely, the positive relationship between export diversification and non-renewable energy consumption, particularly in the short run, reveals a critical paradox. While diversification is a stated policy priority across GCC countries, the shift often leans toward sectors such as petrochemicals, construction, and aluminum, which are themselves heavily reliant on fossil fuels. This finding mirrors concerns raised by Khalid and Shahbaz (2019), who argue that unless diversification targets are strategically decoupled from carbon-intensive sectors, the GCC may inadvertently reinforce its carbon lock-in.

Based on these insights, several policy recommendations are warranted like the policymakers of the GCC governments must prioritize educational reforms and vocational training that emphasize renewable energy technologies, environmental sciences, and sustainable development. Partnerships with international universities, clean energy firms, and technical institutes should be expanded to build a future-ready green workforce (Alotaibi and Mishra, 2022). Further, Trade agreements and foreign direct investment (FDI) strategies should be restructured to facilitate access to clean technologies, environmental goods, and energy-efficient systems. Enhanced cooperation with innovation-driven economies can also support joint ventures and knowledge sharing (Chen et al., 2019). Export diversification should move away from fossil fuel–linked sectors and instead encourage growth in low-carbon industries, such as sustainable tourism, green construction, environmental consultancy, and circular economy enterprises. Government procurement policies can be used to create demand for eco-friendly services and products (Alharthi,2016). To discourage excessive fossil fuel use, GCC countries must phase out energy subsidies and consider implementing carbon pricing mechanisms that reflect the true environmental cost of non-renewable energy. Doing so would correct price distortions and incentivize cleaner energy sources (Narayan and Sharma, 2011).

Finally, enhanced cooperation among GCC countries in the form of shared R&D platforms, cross-border clean energy grids, and harmonized environmental standards would accelerate the region-wide transition and reduce duplication of efforts (Apergis and Payne, 2010). In conclusion, this study contributes to a deeper understanding of the complex interplay between economic structures and energy consumption patterns in fossil-rich economies. While the GCC states have made notable strides in renewable energy investment, the transition remains fragile and uneven, with fossil fuel dependency deeply embedded in both growth models and diversification agendas. A forward-looking strategy that integrates human capital, trade facilitation, and structural reform is essential to steering the region toward a sustainable, low-carbon future.

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