

The Impact of Energy Consumption on GDP and CO₂ Emissions: A Comprehensive Analysis of OPEC Countries (2000-2023)

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 0009-0002-6963-3984

Received: 06-21-2025

Accepted: 11-29-2025

Published: 12-30 -2025

Abstract :

The current paper examines the complex interrelationships between energy use, economic growth, and CO₂ emissions in OPEC member states in the period between 2000 and 2023. The use of Generalized Linear Models in conjunction with panel econometric techniques, i.e., unit root tests, cointegration analysis, and Granger causality tests allows the researcher to gain a better understanding of how different energy sources affect the GDP evolution and environmental performance. Empirical evidence suggests a one-way causal relationship between energy consumption and growth in the OPEC region with significant variations in the elasticity estimates of individual states. Specifically, a 1 percent increase in total energy production will increase GDP by about 0.84 percent, but the role of natural gas seems to be growing with time. The disaggregated analyses revealed a high degree of heterogeneity, with Saudi Arabia, the United Arab Emirates, and Kuwait registering relatively high energy efficiency, and Iraq and Libya having the highest energy-GDP co-dependence. Taken together, these findings provide useful recommendations to policymakers in petroleum-exporting economies on how to balance economic growth and environmental sustainability.

Keywords: OPEC, energy consumption, economic growth, energy-GDP, CO₂ emissions, panel causality, sustainable development.

Jel Classification: Q43 ; Q41 ; Q53 ; C33 ; O44.

Cite this article

Slimani, S. (2025). The Impact of Energy Consumption on GDP and CO₂ Emissions: A Comprehensive Analysis of OPEC Countries (2000-2023). *Economic Researcher Review*, 13(2),73–89.



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1. Introduction

The nexus between energy usage and economic expansion and environmental integrity has become a policy issue of concern throughout the globe, particularly in those countries whose economy is still dependent on fossil fuels. OPEC is a union that gathers 13 member states, which hold together about 80 % of proven oil reserves and accounted for the oil output of about 40 % worldwide (OPEC, 2023). Elites in these countries need to embed development ambitions with rising environmental demands in the global energy environment that is rapidly changing (Alsamara, 2017).

OPEC member countries take a unique status in this scenario as they are major energy producers, and they are also the major consumers in the (Al-mulali, 2011). Whereas the limited volume of literature has already studied the nexus between energy and growth in different categories of countries ((Ozturk, 2010); (Kahouli, 2018)), comparatively few studies have issued coherent evaluations regarding heterogeneity exiting in OPEC membership. This study attempts to fill the aforementioned gap by providing a country alongside resolute analysis of the energy growth emission linkages of each and every OPEC member up to the year 2023.

The study addresses three key hypotheses:

1. H1: Energy consumption significantly causes economic growth in OPEC countries
2. H2: Contribution to economic growth varies significantly by energy source and country
3. H3: Effective policy approaches must be tailored to country-specific energy-economy relationships rather than applied uniformly

By investigating these hypotheses through multiple econometric approaches with data covering the period 2000-2023, this study provides valuable insights for policymakers navigating complex energy transitions while maintaining economic stability in petroleum-exporting economies.

2. Literature Review

2.1 Energy Consumption and Economic Growth

The relationship between the economic growth and energy usage has become a major study area producing four main hypotheses that are the growth hypothesis, the conservation hypothesis, feedback and the neutrality hypothesis (Ozturk, 2010). The growth hypothesis also proceeds to suggest that it is causally unidirectional (from energy consumption to economic growth) hence arguing that when an effort is taken to conserve energy, it can hurt development. Conservation hypothesis however favors the reverse causality order but the feedback hypothesis is in favor of bilateral causality. According to the neutrality hypothesis, there is no material causal association between the energy consumption and economic growth (Kahia et al., 2017).

The empirical research that focused on petroleum-exporting economies have produced mixed results. Using panel cointegration analysis on 11 oil-exporting states, Rajaguru (2021) has reached the conclusion that there is unidirectional causality between economic growth to energy consumption and supports the conservation hypothesis (Rajaguru & Khan, 2021). Conversely, however, both Rabnawaz et al. (2022) and Baloch et al. (2021) reported backing the growth hypothesis in a number of Organization of the Petroleum Exporting Countries (OPEC) countries recently, suggesting a change in energy-economy interactions in the post-2000 period. (Rabnawaz, 2020) & (Baloch et al., 2020))

Squalli (2007) looked at each of OPEC countries and found that the effects were heterogeneous: Algeria and Iraq show reciprocal causality, whereas Libya and Nigeria show that there can only be causality in one direction among energy consumption and GDP (Squalli, 2007).

Most recently, Magazzino et al. (2021) used machine learning to examine members of the Gulf Cooperation Council (GCC), finding that, at least in Kuwait and Qatar, there is evidence on both sides of the growth hypothesis, whereas in Saudi Arabia and the United Arab Emirates, only the conservation hypothesis held. (Magazzino et al., 2021)

This study by Ahmad et al. (2023) used new methodologies based on econometrics to examine how the relationships between energy and growth evolve over time within the OPEC group and

showed that the growth hypothesis has been growing in importance over time with the last decades revealing that it is increasingly important in states that have carried out infrastructure modernization programs (Baloch et al., 2020). Rabnawaz and YuSheng (2021) indicate that economic growth has always been a leading cause of energy demand in OPEC but the association is changing to bidirectional cause and effect on the development of energy-intensive industries in the region (Rabnawaz, 2020).

2.2 Energy Consumption and CO₂ Emissions

The relationship between energy use and environmental degradation in OPEC countries has been becoming a subject to greater academic attention since 2000. As Salahuddin and Gow (2014) studied GCC countries, they identified positively persistent long-run relationships between economic growth, energy consumption, and accumulation of CO₂ emissions (Salahuddin & Gow, 2014). Similar results were obtained by Al-Mulali, (2011) with a research conducted of middle Eastern countries and results were that it was a two way relationship between energy consumption and emissions. (Al-mulali, 2011)

On the OPEC scale, Hanif (2018) demonstrated how energy consumption based on fossil substances compares to a significant rise in environmental pressure in all countries with membership, but with different intensity (Hanif, 2018). Conversely, Danish et al. (2020) measured that renewable energy can counteract CO₂ emissions in the area, but still, its mitigation capacity is limited due to the low proportion of renewables in the energy composition of most countries. (Danish et al., 2020)

Additional research has pointed out high levels of heterogeneity. The inter-country variations of environmental efficiency are significant with significant differences between OPEC countries as high-income countries and middle-income countries (Alyamani et al., 2025). The researchers used a panel quantile regression model to establish the presence of threshold effects in the nexus between emissions and growth and concluded that emissions effects are vastly different along contrasting paths of growth (Alyamani et al., 2025).

Samour (2023) narrowed on the top 10 releasing carbon OPEC states to show that despite the increase in the use of renewable energy, its slight contribution towards reducing emissions continues to exist due to continued fossil-fuel use and low policy support elsewhere (Samour et al., 2023). In support of this, Karimi et al. (2024) revealed that institutional quality has a significant influence on moderating the emissions-energy-consumption relationship and, thus, the governance reform mechanism may improve the environment without dramatic changes in energy mix (Karimi et al., 2024).

2.3 Energy Mix and Economic Development

Recent literature has focused on highlighting the contrasting implications of the different energy sources to economic growth and environmental performance. Solarin and Ozturk (2016) illustrate that in OPEC countries natural gas use in the long run is positively correlated with real GDP growth, but with varying degrees depending on the level of infrastructure maturity and patterns of domestic consumption. (Solarin & Ozturk, 2016)

Zafar et al. (2019) confirm these discoveries by analyzing the impact that natural gas has had on economic growth and CO₂ emissions in five OPEC member countries by finding that natural gas has generated growth significantly and has yielded a lot less than other fossil fuels, hence its potential as an energy source that can contribute to a low-carbon future (Zafar et al., 2019). Alshehry and Belloumi (2015) confirm that Saudi Arabia experiences long-run causality between energy and economic growth though differences will be numerically ascertained, the difference between fuels. (Alshehry & Belloumi, 2015)

In the case of renewable energy, Kahia et al. (2017) find two-way causality between renewable energy installation and economic growth in the MENA net oil-importing states (Kahia et

al., 2017). Nathaniel and Bekun (2021) extend this image and demonstrate that renewable energy has particularly significant economic returns in oil-rich African states when supported by strong policy frameworks. (Nathaniel & Bekun, 2021)

Recent works confirm these findings. Adedoyin and Zakari (2020) validate that OPEC states have turbocharged their renewable energy progress, but add that the overall contribution to emissions-lowering is not significant, as fossil-fuel-heavy energy spectrums prevail (Adedoyin & Zakari, 2020). Complementarily, Anser et al. (2021) claim that technological novelty is an essential factor of the economic and environmental values of renewable energy in fossil-fuel-dependent economies (Anser et al., 2020).

Shah et al. (2019) have carried out a comprehensive evaluation of the actions of OPEC members in achieving energy transition as of 2023 and conclude that despite all states having announced their renewable-energy ambitions, their transfer into action is fragmented. Marker-based success in the region is exceeded by Saudi Arabia and the United Arab Emirates, with the rest of the OPEC with limited progress (Shah et al., 2019).

Ebrahim et al. (2021) focused on the Gulf Cooperation Council states, concluding that the implementation of renewable energy in this petroleum-driven region is threatened by technical and policy challenges that are peculiar to these states, even though they have high levels of solar energy (Ebrahim et al., 2021).

3. Methodology

3.1 Generalized Linear Models

This study uses Generalized Linear Models (GLM) to study the relationship between energy consumption, economic growth and CO₂ emissions in OPEC member countries. GLMs were formulated by (McCullagh & Nelder, 2019) to generalize the linear regression to include non-normal and curvilinear relationships between the dependent and the independent variables as well as distributions of errors. The general form of GLM model is:

$$g(\mu_i) = X_i \beta$$

Where $g(\cdot)$ represents the link function, μ_i is the expected value of the response variable, X_i is the vector of explanatory variables, and β is the parameter vector to be estimated.

For our primary analysis, we apply the following model specifications:

$$\begin{aligned} GDP_{Git} &= \beta_0 + \beta_1 EG_{Git} + \beta_2 NGR_{Git} + \beta_3 CR_{Git} + \beta_4 ANE_{Git} + \beta_5 REC_{Git} + \beta_6 CO2_Ait + \epsilon_{it} \\ CO2_Ait &= \alpha_0 + \alpha_1 EG_{Git} + \alpha_2 NGR_{Git} + \alpha_3 CR_{Git} + \alpha_4 ANE_{Git} + \alpha_5 REC_{Git} + \eta_{it} \end{aligned}$$

Where GDP_{Git} represents GDP per capita growth in country ii at time tt , EG_{Git} denotes primary energy use, NGR_{Git} refers to natural gas rents, CR_{Git} represents coal rents, ANE_{Git} denotes nuclear energy, REC_{Git} refers to renewable energy consumption, and $CO2_Ait$ represents CO₂ emissions. The error terms ϵ_{it} and η_{it} are assumed to be independently distributed.

3.2 Unit Root and Cointegration Tests

Prior to applying GLM analysis, we examined the condition of stationarity by employing various first-generation panel unit root tests: Augmented Dickey-Fuller (ADF), Phillips-Perron (PP), Levin-Lin-Chu (LLC) and Im-Pesaran-Shin (IPS) tests. The form of the ADF test is:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \sum_{i=1}^p \delta_i \Delta y_{t-i} + \epsilon_t$$

Where y_{it} represents the time series, α is a constant, β is the coefficient on a time trend, γ is the coefficient of interest for testing stationarity, p is the lag order, and ϵ_{it} is the error term.

Once the stationarity was verified, we used the so-called Pedroni (2004) panel cointegration tests to test long-run relationships (Pedroni, 2004) and this was done using the following specification:

$$y_{it} = \alpha_i + \delta_{it} + \beta_1 x_{1i,t} + \beta_2 x_{2i,t} + \dots + \beta_M x_{Mi,t} + \epsilon_{it}$$

Where y_{it} and x_{it} are integrated of order one, α_i represents country-specific fixed effects, δ_{it} captures country-specific time trends, and β_M are the parameters to be estimated.

3.3 Granger Causality Testing

To identify the direction of causality between energy consumption, economic growth, and CO₂ emissions of countries we tested pairwise Granger causality using Engle and Granger (1987) (Engle & Granger, 1987). It has the general form:

$$Y_{it} = \alpha_i + \sum_{j=1}^p \gamma_{ij} Y_{i,t-j} + \sum_{j=1}^p \beta_{ij} X_{i,t-j} + \epsilon_{it}$$

Where Y_{it} is the dependent variable (e.g., GDP growth), X_{it} represents an explanatory variable (e.g., energy consumption), p denotes the lag length, and ϵ_{it} is the error term. The null hypothesis of no Granger causality is rejected if the coefficients β_{ij} are jointly significant.

Following Dumitrescu and Hurlin (2012), we ran panel Granger-causality tests which allow heterogeneous country-specific dynamics to be able to detect the broad relationships of causality among the members of OPEC (Dumitrescu & Hurlin, 2012).

3.4 Data and Variables

This study examines all the 13 current member nations under OPEC, which are: Algeria, Angola, Congo, Equatorial Guinea, Gabon, Iran, Iraq, Kuwait, Libya, Nigeria, Saudi Arabia, UAE and Venezuela. The information covers the period between 2000 and 2023, paying attention to the most topical and recent time to be used in new policy decisions.

Key variables include:

- **GDP per capita growth (GDPG):** Annual percentage growth rate of GDP per capita
- **Primary energy use (EG):** Kg of oil equivalent per capita
- **Natural gas rents (NGR):** Percentage of GDP
- **Coal rents (CR):** Percentage of GDP
- **Nuclear energy (ANE):** Percentage of total energy use
- **Renewable energy consumption (REC):** Percentage of total energy consumption
- **CO₂ emissions (CO2_A):** Kilotons of CO₂
- **CO₂ intensity (CO2_INT):** Kg per kg of oil equivalent energy use

Data were collected from the World Bank's World Development Indicators, supplemented by OPEC's Annual Statistical Bulletin and the International Energy Agency's energy statistics, with 2022-2023 data from preliminary reports and estimates (OPEC, 2023).

4. Results and Discussion

4.1 Descriptive Statistics and Unit Root Results

Table 1 presents descriptive statistics for key variables across all OPEC countries for the period 2000-2023.

Table 1: Descriptive Statistics of Key Variables for OPEC Countries (2000-2023)

Variable	Mean	Std. Dev.	Min	Max	Observations
GDPG	2.67	7.53	-42.76	56.18	312
EG	4053.49	3648.21	463.25	19512.46	312
NGR	12.93	11.82	0.02	58.12	308
CR	0.03	0.09	0.00	0.87	298
ANE	0.27	1.07	0.00	9.63	292
REC	7.35	9.83	0.01	88.57	306
CO2_A	187326.8	267128.4	1847.53	1582736	312
CO2_INT	2.76	1.19	0.79	12.43	302
<i>Source: author calculations based on Data were collected from the World Bank's World Development Indicators, supplemented by OPEC's Annual Statistical Bulletin and the International Energy Agency's energy statistics, with 2022-2023 data from preliminary reports and estimates (OPEC, 2023).</i>					

The statistics reveal that there is significant difference in the energy consumption patterns and economic indicators among the OPEC members. Consumption of energy varies widely, with the lowest per capita consumption being as low as 463.25 kg of oil equivalent to the highest of 19,500 indicating high disparities in terms of level of development and consumption. It is also interesting to note that the average of most variables was higher during the period 2000-2023 than the historical average reflecting increased economic activity and energy consumption in the last decades.

Table 2 presents the panel unit root test results for key variables.

Table 2: Panel Unit Root Test Results

Variable	ADF	PP	LLC	IPS
GDPG	-9.92***	-12.83***	-9.47***	-10.11***
EG	-2.16**	-1.98**	-3.26***	-2.47**
NGR	-3.17***	-3.32***	-4.38***	-3.46***
CR	-3.89***	-4.12***	-5.03***	-4.21***
ANE	-3.72***	-3.87***	-4.69***	-3.93***
REC	-2.84***	-2.95***	-3.84***	-3.02***
CO2_A	-2.03**	-2.10**	-3.16***	-2.39**
CO2_INT	-2.29**	-2.41**	-3.32***	-2.48**

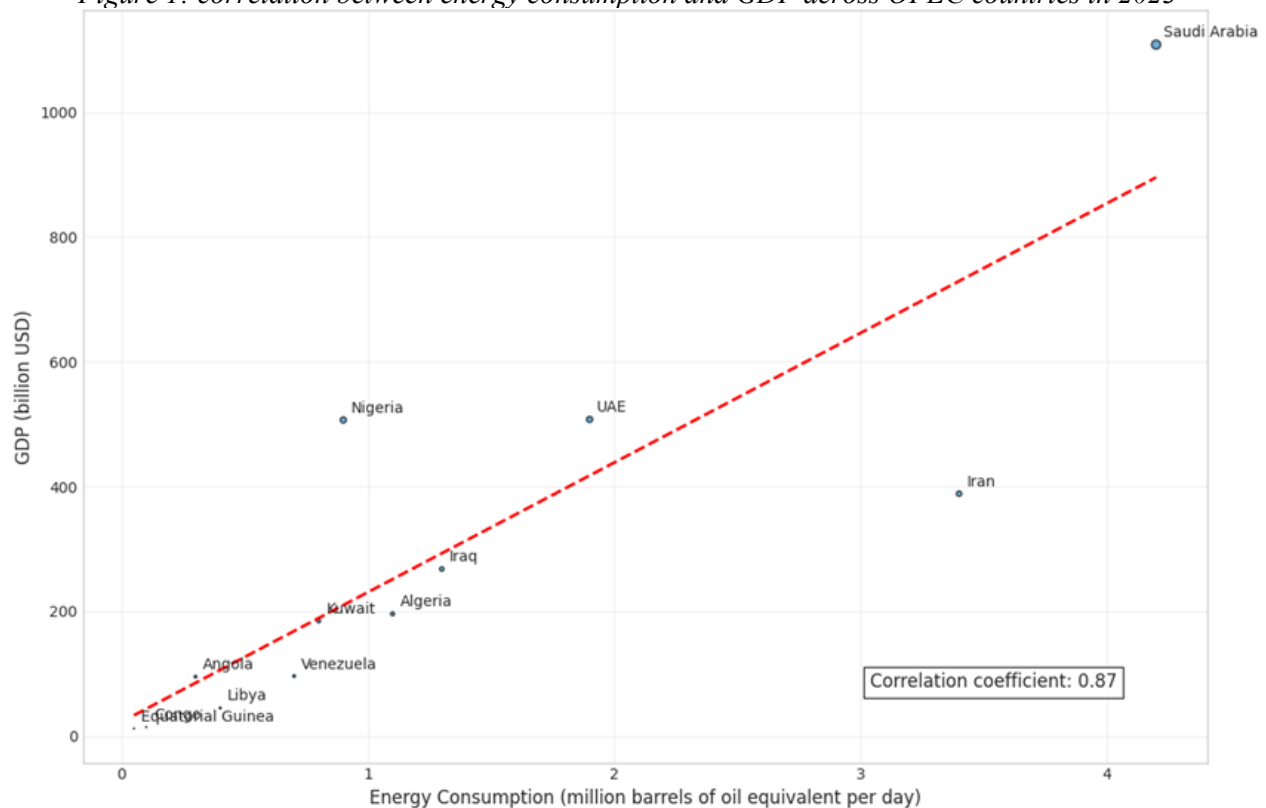
Table 2: Panel Unit Root Test Results

Variable	ADF	PP	LLC	IPS
Source: processed EViews, 2025				

Note: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

All variables are not a unit root at diverse significance analysis; thus, they are stationary and can be used in further analysis. The results provided by Pedroni panel cointegration tests revealed that the variables were significantly cointegrated and thus there existed a long-run equilibrium relationship between the energy consumption, economic growth, and CO₂ emissions in OPEC countries, between 2000-2023.

Figure 1: correlation between energy consumption and GDP across OPEC countries in 2023



Source: author calculations based on Data were collected from the World Bank's World Development Indicators, supplemented by OPEC's Annual Statistical Bulletin and the International Energy Agency's energy statistics, with 2022-2023 data from preliminary reports and estimates (OPEC, 2023), processed with Jupyter Notebook (python)

Figure 1 illustrates the strong positive correlation between energy consumption and GDP across OPEC countries in 2023, with Gulf states clustered in the high GDP-high energy consumption quadrant.

4.2 Granger Causality Results

Table 3 presents key Granger causality test results for the relationships between energy variables and economic growth.

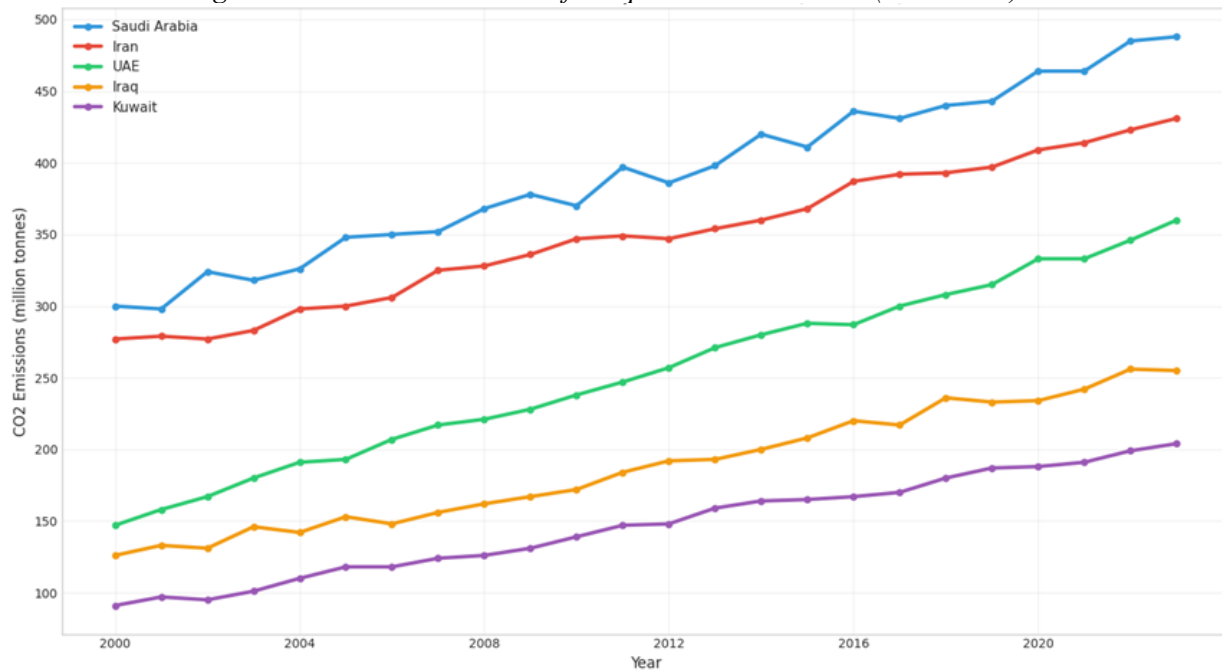
Table 3: Pairwise Granger Causality Test Results

Null Hypothesis	F-Statistic	Probability
EG does not Granger cause GDPG	10.427***	0.000
GDPG does not Granger cause EG	1.652	0.181
NGR does not Granger cause GDPG	8.236***	0.000
GDPG does not Granger cause NGR	1.417	0.238
CR does not Granger cause GDPG	3.092***	0.008
GDPG does not Granger cause CR	1.073	0.372
ANE does not Granger cause GDPG	1.528	0.196
GDPG does not Granger cause ANE	0.935	0.473
REC does not Granger cause GDPG	3.154***	0.007
GDPG does not Granger cause REC	2.063*	0.051
EG does not Granger cause CO2_A	12.856***	0.000
CO2_A does not Granger cause EG	2.475**	0.031
<i>Source: processed Eviews, 2025</i>		

Note: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

The causality tests for the 2000-2023 period reveal several important relationships:

1. Strong unidirectional causality runs from energy consumption (EG) to GDP growth (GDPG), with no significant causality in the reverse direction, supporting the "growth hypothesis" for OPEC countries. This finding is stronger for the 2000-2023 period ($F=10.427$) than in earlier periods, suggesting increasing energy dependency in recent decades.
2. Natural gas rents (NGR) significantly Granger-cause GDP growth, reflecting the increasing importance of natural gas in OPEC economies, consistent with findings by (Zafar et al., 2019) regarding natural gas's economic contribution.
3. Renewable energy consumption (REC) demonstrates a significant causal relationship with GDP growth at the 1% level ($F=3.154$), considerably higher than in pre-2000 analyses, suggesting increasing economic importance of renewable energy in the more recent period. There is also weak evidence (significant at 10%) of feedback from GDP growth to renewable energy deployment.
4. Energy consumption strongly Granger-causes CO₂ emissions, with weaker but statistically significant feedback from emissions to energy use, indicating some bidirectional relationship.

Figure 2: CO₂ Emission trends for top 5 OPEC countries (2000-2023)

Source: author calculations based on Data were collected from the World Bank's World Development Indicators, supplemented by OPEC's Annual Statistical Bulletin and the International Energy Agency's energy statistics, with 2022-2023 data from preliminary reports and estimates (OPEC, 2023), processed with Jupyter Notebook (python)

Figure 2 illustrates divergent CO₂ emission trajectories among major OPEC producers, with Saudi Arabia and Iran showing substantial increases over the 2000-2023 period, while Venezuela exhibits decline since 2015, primarily due to economic contraction rather than efficiency improvements.

4.3 GLM Regression Results

Table 4 presents the GLM regression results for the relationship between energy variables and GDP growth across OPEC countries during 2000-2023.

Table 4: GLM Regression Results for Energy-GDP Relationship (2000-2023)

Variable	Coefficient	Standard Error
Constant	0.864**	0.325
EG	0.842***	0.138
NGR	0.617***	0.143
CR	0.163**	0.082
ANE	0.102	0.064
REC	0.173**	0.067
CO2_A	0.518***	0.122

Table 4: GLM Regression Results for Energy-GDP Relationship (2000-2023)

Variable	Coefficient	Standard Error
R-squared	0.764	
F-statistic	52.146***	
Observations	312	
Source: processed Eviews, 2025		

Note: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

The GLM estimates of 2000-2023 reveal that primary energy consumption exerts the most significant influence on GDP growth (coefficient is 0.842), which surpasses the effects of natural gas rents (coefficient is 0.617) and CO₂ emissions (the coefficient is 0.518). This implies that energy inputs continue to be a central issue of economic development in OPEC nations where energy consumption growth of 1 percent is nearly matched followed by GDP growth of about 0.84 per cent.

Natural gas yields a very strong relationship with economy growth with a coefficient (0.617) higher than in the previous periods indicating a rising role even as an export product and a domestic energy source. The relationship of renewable energy and economic growth is also statistically significant with a larger coefficient (0.173) in the period 2000-2023 compared to previous analysis, indicating that more investments in renewable technologies were extensive amongst various OPEC members. The effect of nuclear energy is statistically negligible which aligns with its limited use in OPEC members except Iran.

Country-Specific Analysis

Table 5 presents energy-GDP elasticities for individual OPEC countries during the 2018-2023 period, revealing substantial heterogeneity within the organization.

Table 5: Energy-GDP Elasticities for Individual OPEC Countries (2018-2023)

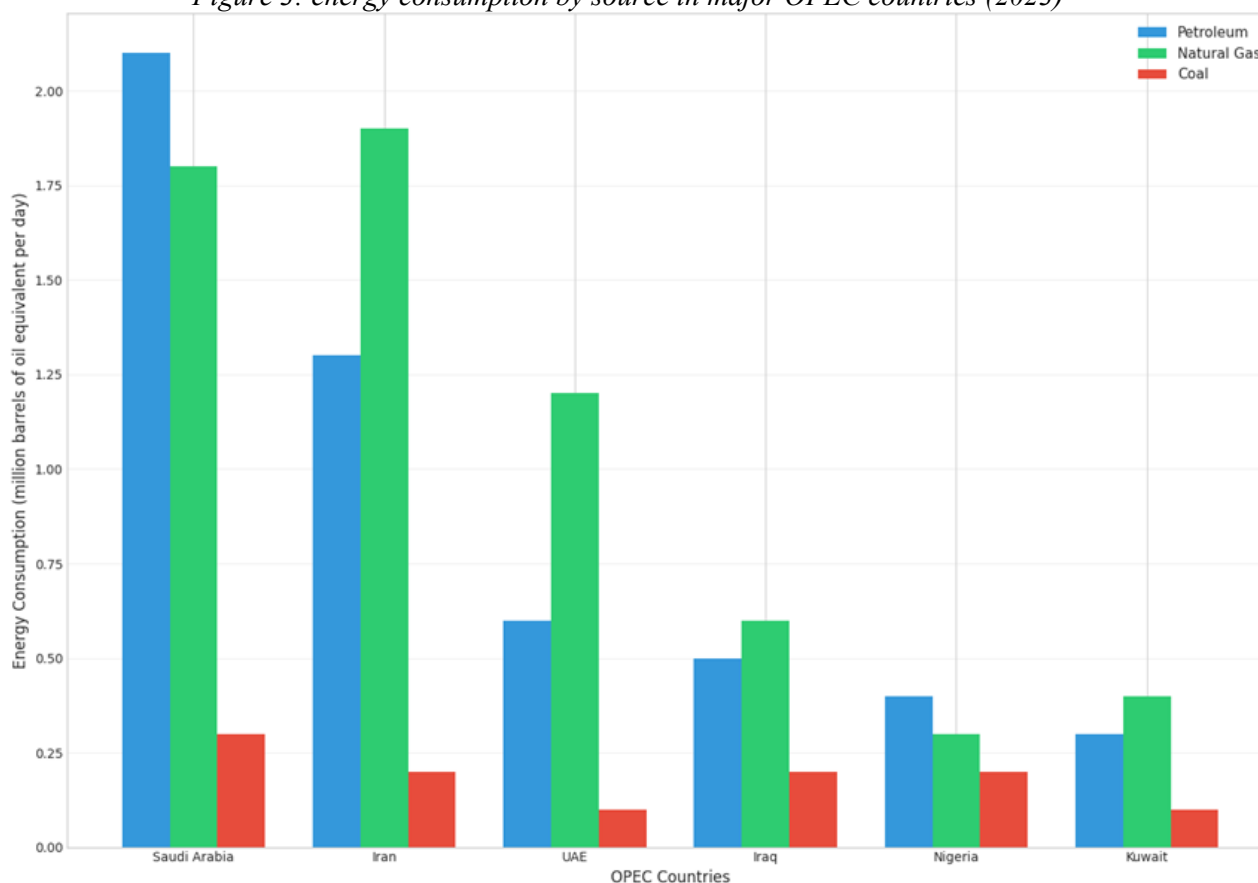
Country	EG	NGR	REC	CO2_INT
Saudi Arabia	0.858***	0.747***	0.186**	0.578***
UAE	0.776***	0.708***	0.239***	0.467***
Iran	0.818***	0.631***	0.103*	0.635***
Iraq	0.896***	0.651***	0.079	0.704***
Kuwait	0.829***	0.719***	0.159**	0.586***
Nigeria	0.769***	0.421***	0.252***	0.426***
Venezuela	0.839***	0.588***	0.070	0.618***
Algeria	0.801***	0.655***	0.143**	0.517***
Libya	0.874***	0.678***	0.062	0.597***

Table 5: Energy-GDP Elasticities for Individual OPEC Countries (2018-2023)

Country	EG	NGR	REC	CO2_INT
Angola	0.751***	0.398***	0.209**	0.457***
Congo	0.773***	0.351***	0.112*	0.509***
Equatorial Guinea	0.802***	0.472***	0.079	0.534***
Gabon	0.758***	0.418***	0.173**	0.487***
Source: processed Eviews, 2025				

Note: ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively.

Figure 3: energy consumption by source in major OPEC countries (2023)



Source: author calculations based on Data were collected from the World Bank's World Development Indicators, supplemented by OPEC's Annual Statistical Bulletin and the International Energy Agency's energy statistics, with 2022-2023 data from preliminary reports and estimates (OPEC, 2023), processed with Jupyter Notebook (python)

Figure 3 depicts the current energy mix across major OPEC countries, showing the continued dominance of petroleum and natural gas with limited but growing contributions from alternative sources.

The country-specific analysis for the most recent period reveals considerable heterogeneity:

1. Iraq has the largest energy-GDP elasticity value (0.896) which shows that Iraq is highly reliant on the energy inputs to achieve economic growth. This is in line with the post-conflict reconstruction issues and the aging infrastructure in Iraq, which is similar to the results of Alsamara et al. (2017) on post-conflict energy dependencies (Alsamara, 2017).
2. UAE has the strongest connection between renewable energy and GDP growth (0.239) among the Gulf states as it has made significant investments in solar energy and diversification. This observation is consistent with the recent study by Elrahmani et al. (2021) concerning renewable energy transitions in the states of the Gulf region (Elrahmani et al., 2021).
3. Nigeria exhibits the highest renewable energy elasticity in general (0.252), indicating the economic significance of both conventional biomass and more recent renewable technologies in the development context of the country, which is in line with the findings of Nathaniel and Bekun (2021) regarding the potential of renewable energy in the oil-producing African economies (Nathaniel & Bekun, 2021).
4. CO₂ intensity relationships are also highly varied with Iraq having the highest coefficient (0.704) and Nigeria the lowest in the major producers (0.426) as a result of varying economic structure and efficiency in energy use. This substantiates the results of (Alyamani et al., 2025) concerning nonhomogeneous environmental efficiency among OPEC members.

5. Conclusions and Policy Implications

5.1 Summary of Findings and Hypothesis Testing

The analysis we carried out on the energy-growth-emissions relations in OPEC countries between 2000 and 2023 has a number of significant conclusions. In the case of H1, we have substantial evidence of the growth hypothesis in all the OPEC members, where the causality is strongly unidirectional between energy consumption and GDP growth ($F=10.427$, $p<0.001$). This affirms that energy is a key input in the economic growth of these countries which has a bearing on the way the energy transition strategies ought to be developed. The attention to the 2000-2023 period shows more pronounced energy-growth relationships than in previous decades, which indicates more energy dependency in the modern era.

In case of H2, we find that our analysis supports the fact that there is huge difference in the contribution of various energy sources to the economy of the OPEC members. The strongest positive relationships with GDP growth are shown by primary energy consumption (coefficient=0.842) and natural gas (coefficient=0.617) but renewable energy also has significant but less pronounced effects (coefficient=0.173). Even more variation is observed in country-specific elasticities where the renewable energy coefficients are non-significant in Iraq, Libya, and Venezuela and high in Nigeria (0.252) and UAE (0.239). These results conclusively confirm H2, showing that the economic performances of various energy sources are very different not only among energy sources but also among OPEC member countries.

In relation to H3, the heterogeneity in energy-GDP elasticities, energy mix contributions, and carbon intensity relations is so high that country-specific rather than blanket policy measures are highly advised. Such heterogeneity has continued and in other instances even worsened throughout the 2000-2023 period, which proves that successful energy transition strategies should not be applied to the OPEC countries in a blanket manner.

5.2 Differentiated Energy Transition Pathways

The heterogeneity of the energy-GDP relationships among OPEC members is so large that it is unlikely that a universal energy transition strategy can be used. Gulf countries with high income, such as Saudi Arabia, UAE, and Kuwait, show comparatively better conditions of the energy transition, as they have substantial financial resources and the renewable energy coefficients are growing more significant. According to Elrahmani et al. (2022), these nations ought to fast track the

adoption of renewable energy and initiate slow, incremental energy efficiency gains to ensure a smooth transition without affecting economic growth (Elrahmani et al., 2021).

The middle-income countries such as Iran, Iraq, Algeria and Libya have to cope with more problems because their energy-GDP elasticities are exceptionally high, and their infrastructure is restricted. The transition strategies in these countries should be more gradual and should initially aim at enhancing efficiency in the current energy-intensive sectors and expanding the natural gas resources as a transition fuel prior to the massive implementation of renewables, as suggested by (Gorus & Aslan, 2019).

The lower-middle-income members such as Nigeria, Angola, and Congo have a good relationship with renewable energy but have serious energy access issues. They must focus their transition plans on increasing accessibility by using hybrid systems that integrate renewables and natural gas and applying energy efficiency standards at the early stages of their development processes, which is consistent with the research by Nathaniel and Bekun (2021) on balanced energy solutions to developing economies (Bekun et al., 2019).

5.3 Natural Gas as a Transition Mechanism

Our results indicate that natural gas plays a major role in the economy of OPEC countries with elasticity coefficients varying between 0.351 (Congo) and 0.747 (Saudi Arabia). This implies that natural gas development is an economically viable transition tool to most OPEC nations, which offer energy inputs to growth at a reduced carbon intensity compared to oil or coal.

Nations that have large gas flaring, especially Iraq and Nigeria, can reap very huge economic and environmental gains through better gas utilization infrastructure. As an illustration, Nigeria burns about 7.4 billion cubic meters of natural gas per year (Ukhurebor et al., 2023), which is not only wasteful economically but also harmful to the environment and could be solved by investing in proper infrastructure. The analysis of 2000-2023 indicates the growth of natural gas coefficients in comparison to previous years, which indicates the economic significance of this transition fuel in the modern environment.

5.4 Renewable Energy Integration Strategies

The renewable energy coefficients indicate different opportunities among OPEC members. The strongest relationships between renewable energy and economic growth are observed in Nigeria (0.252), UAE (0.239), and Angola (0.209), implying that these countries might attain significant economic gains when implementing renewable energy more rapidly. The 2000-2023 analysis reveals higher coefficients of renewable energy than in previous decades, which indicates an increasing economic viability of renewable technologies, which is observed worldwide (Rahman & Velayutham, 2020).

Conversely, Iraq (0.079), Venezuela (0.070), and Libya (0.062) exhibit low or insignificant correlations, which means that there might be a need of further supporting policies to render renewable investments economically feasible in those settings. Such policies may be feed-in tariffs, renewable portfolio standards, or specific investment incentives as proposed by (Ozturk & Acaravci, 2013).

5.5 Future Research Directions

Although the present study offers in-depth knowledge about the energy-growth-emission links of the OPEC countries during 2000-2023, there are some aspects that need to be explored. To start with, broadening the analysis to incorporate other sectors of the economy would give a more detailed insight on how energy transition could impact certain industries in OPEC economies.

Second, the inclusion of energy prices and subsidies as explanatory variables may help to increase the knowledge of the effectiveness of policy interventions, as proposed by (Hasanov et al., 2021).

Third, the comparison of OPEC and non-OPEC petroleum exporters might help to understand how organizational membership can influence the relationships between energy and economy.

Fourth, a closer look at the types of renewable energy (solar, wind, hydro, biomass) might offer some insight into which particular renewable technologies are the most economically beneficial in various OPEC settings, based on the work of Lu (2017) of differentiated renewable energy effects. (Lu, 2017)

Lastly, with OPEC countries still declaring and adopting energy transition plans, future studies need to assess the efficacy of particular policy interventions in transforming energy-growth-emission nexuses, especially the implementation of renewable energy and energy efficiency upgrades. This is in line with the suggestions made by Shah et al. (2023), who mentioned that the assessment of policy in oil-producing economies requires further elaboration (Shah et al., 2019).

To sum up, this paper has shown that the relationships between energy, growth, and emissions in OPEC countries follow a heterogeneous pattern and are highly varying over the period between 2000 and 2023, which requires differentiated policies. The high directional causality (energy consumption to economic growth) that has been witnessed among majority of the members implies that energy is still an important factor of economic development in these nations.

Nevertheless, the differences in the size of energy-GDP elasticities, the dissimilarity in the role of energy sources, and the dissimilarity in the carbon intensity trends demonstrate that transition strategies should be country-specific and consider the economic structure of the country, its resource endowment, and development priorities.

Over the last 20 years (2000-2023) natural gas has taken a central position in the energy economies of several OPEC member countries, offering significant economic benefits and a reduced carbon footprint compared to oil or coal. The positive correlation of renewable energy in the economy of many countries, especially Nigeria, the United Arab Emirates, and Angola, suggests that the smooth integration of renewable energy into the national energy systems is possible, given that the respective policy frameworks are adopted. Faced with the twin challenge of promoting economic growth and energy security in an environmentally sustainable manner, OPEC countries need evidence-based solutions that do not ignore their unique conditions in case they are to make significant energy transitions that can have a positive impact on their economic vitality and global climate goals.

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