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Interlinkages Between Economic Diversification and Energy Transition in Oman: A Long-Run and Short-Run Analysis

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ABSTRACT

The economies of Gulf Cooperation Council (GCC) countries, including Oman, have historically depended on hydrocarbon resources for growth, which has introduced significant vulnerabilities such as exposure to global oil price fluctuations and sustainability concerns. As global energy transitions toward decarbonization, hydrocarbon-dependent economies face the dual challenge of economic diversification and energy transition. This paper investigates whether economic diversification or the transition to clean energy leads the change in Oman, providing insights into how these interrelated transformations are shaping Oman's progress under Vision 2040. Utilizing econometric models, including Cointegration tests and error correction models, the research explores the long-term equilibrium relationships and short-term dynamics between variables such as carbon emissions, economic diversification, and energy use. The findings highlight the challenges Oman faces in achieving both diversification and sustainable energy, including financial constraints and regulatory barriers. By understanding these dynamics, the study offers strategic policy recommendations for fostering sustainable growth and enhancing resilience in Oman, contributing to the broader sustainable development goals of reducing carbon dependency while driving economic diversification.

Keywords: Economic Diversification, Energy Transition, CCR, FMOL DOLS, VEC, Oman

1. INTRODUCTION

1.1 Background

The economies of the Gulf Cooperation Council (GCC), including Oman, have long been defined by their heavy reliance on hydrocarbon resources. Since the discovery of oil and gas, these resources have powered rapid economic growth, significant infrastructure development, and improvements in the quality of life. However, this dependency has also introduced vulnerabilities, such as susceptibility to fluctuations in global oil prices and concerns about environmental sustainability. As the global energy landscape shifts toward decarbonization and sustainability, hydrocarbon-dependent economies like Oman face increasing pressure to diversify their economies and transition towards cleaner energy sources (World Bank, 2021; IRENA, 2022).

Globally, the energy sector is undergoing a major transformation driven by efforts to mitigate climate change and reduce greenhouse gas emissions. Renewable energy sources, such as solar, wind, and hydrogen, are becoming increasingly cost-effective and technologically viable, contributing to a global shift towards a low-carbon future. For hydrocarbon-dependent nations like Oman, this shift presents both challenges and opportunities to leverage clean energy to drive new industries and reduce emissions (IRENA, 2021). Oman's geographic location and climatic conditions make it well-suited for renewable energy, with high solar radiation levels and substantial wind energy potential. The government has also recognized the potential of green hydrogen, which could become a major export and a sustainable domestic energy source (Oxford Business Group, 2023).

Economic diversification and the transition to clean energy are both essential and interconnected transformations for hydrocarbon-based economies. Economic diversification involves reducing reliance on hydrocarbon revenues by

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expanding other sectors, while the clean energy transition focuses on adopting renewable and low-carbon energy sources. Both goals align with broader sustainable development objectives, requiring substantial investments, policy reforms, and strategic planning. In Oman, these imperatives are embodied in Vision 2040, a national development strategy that seeks to diversify the economy, enhance human capital, and reduce the carbon intensity of its energy sector (Oman Vision 2040, 2020).

Oman has faced both challenges and opportunities in reducing its dependency on hydrocarbons. Oil and gas still contribute significantly to the nation's GDP, exports, and government revenues, leaving the economy exposed to global oil market fluctuations (IMF, 2022). Periods of low oil prices, such as the downturn from 2014 to 2016, highlighted the vulnerabilities of this economic model, emphasizing the need for a diversified economic structure to ensure fiscal stability and economic resilience (IEA, 2020). Vision 2040 reflects the country's strategic response to these challenges, aiming to expand sectors like tourism, logistics, fisheries, and manufacturing in alignment with sustainable development goals (Oman Vision 2040, 2020).

Economic diversification and the clean energy transition are inherently linked, as both contribute to fostering sustainable economic structures and enhancing resilience to external shocks. Diversification reduces fiscal dependence on oil and gas by creating revenue streams from sectors like manufacturing, tourism, and services, which can support clean energy development through increased fiscal space and foreign investment. At the same time, clean energy industries—such as solar, wind, and hydrogen production—can drive diversification by creating new sectors, jobs, and technological advancements (UNDP, 2022). However, balancing these objectives is challenging, as both require significant investments, skilled workforce development, and supportive regulatory frameworks.

Given these complexities, this paper explores which of these transformations—economic diversification or clean energy transition—is currently leading the change in Oman. Is diversification acting as the primary driver, enabling the clean energy transition, or is the move towards clean energy fostering new sectors and stimulating diversification? Understanding these dynamics is crucial to developing effective policy strategies for sustainable and balanced growth in Oman (World Bank, 2021).

This paper investigates the interplay between economic diversification and the clean energy transition in Oman, exploring which transformation—diversification or energy transition—may lead the other. Understanding this dynamic is critical for policymakers, investors, and stakeholders aiming to establish a resilient and sustainable economy for Oman. The study examines Oman's progress, challenges, and strategies in both economic diversification and clean energy transition, providing insights and policy recommendations to support balanced growth and sustainable development

1.2 The research problem

The research problem addresses Oman's challenge in achieving both economic diversification and a transition to clean energy. As a hydrocarbon-dependent economy, Oman faces risks from volatile oil markets and sustainability concerns. This study seeks to understand which transformation—diversification or clean energy transition—will lead the other in Oman's pursuit of a resilient economy under Vision 2040. By examining the relationship between these goals, the research aims to provide strategic insights and policy recommendations for sustainable development in Oman.

1.3 Research Motivation and Objectives

This research is motivated by Oman's need to adapt its hydrocarbon-dependent economy to an evolving global energy landscape marked by oil market volatility and a push towards low-carbon, sustainable practices. Oman's Vision 2040 emphasizes reducing hydrocarbon reliance, making economic diversification and a clean energy transition essential for long-term resilience. This study aims to assess Oman's progress and challenges in both areas, examining the interdependence between diversification and clean energy transition to determine which transformation may lead the other. By exploring financial, regulatory, and geopolitical factors, the research provides insights and policy recommendations to support a balanced approach for sustainable development.

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2. ENERGY TRANSITION IN OMAN

Oman has made significant progress in incorporating clean energy into its energy portfolio in recent years, aligning with global sustainability goals and Vision 2040, which emphasizes environmental responsibility and economic resilience. The country's favorable geographical and climatic conditions, such as high levels of solar irradiation and coastal wind resources, provide a robust foundation for developing solar and wind energy projects (IRENA, 2022).

Oman's clean energy initiatives have mainly focused on solar and wind power. The Ibri II solar plant, inaugurated in 2021, is the country's largest photovoltaic project, with a capacity of 500 MW, supplying clean energy to tens of thousands of homes and contributing to CO2 emission reductions (Middle East Solar Industry Association, 2021). In addition, the Dhofar wind farm, with a 50 MW capacity, represents a significant advancement in wind energy utilization, marking an early achievement in Oman's renewable energy production efforts (Oxford Business Group, 2022).

In addition to solar and wind, Oman has begun exploring green hydrogen as a potential clean energy source and export commodity. The government's increasing interest in hydrogen production stems from its versatility and potential as a clean fuel suitable for both domestic use and international markets. For instance, the Hyport Duqm project aims to position Oman as a regional leader in green hydrogen production, utilizing renewable energy sources to produce hydrogen and ammonia for export (Hydrogen Council, 2023). This initiative aligns with Oman's goals of economic diversification, reducing carbon emissions, and building a sustainable energy future.

Despite these advancements, Oman's renewable energy sector faces several challenges. The initial costs for large-scale clean energy projects are high, and Oman's limited financial resources make substantial foreign investment and technology partnerships critical for project success (Al-Badi et al., 2011). Additionally, regulatory support and grid infrastructure upgrades are necessary to facilitate renewable energy integration and ensure a reliable supply for both domestic needs and exports (IEA, 2020).

Oman's commitment to clean energy represents a strategic shift towards sustainable practices that align with global decarbonization trends. The development of large-scale renewable projects and green hydrogen initiatives reflects a balanced approach toward economic diversification and sustainable energy. These efforts hold substantial potential for reducing Oman's reliance on hydrocarbons while contributing to global emissions reduction goals (Tian et al., 2024).

3. LITERATURE REVIEW

This literature review examines three core areas relevant to Oman's transition away from hydrocarbon dependency: (1) economic diversification in hydrocarbon-dependent economies, (2) the transition to clean energy, and (3) the interlinkages between economic diversification and energy transition. This discussion draws on global and regional research to contextualize the challenges and opportunities associated with each theme in relation to Oman.

3.1 Economic Diversification in Hydrocarbon-Dependent Economies

Economic diversification is widely considered a strategic priority for hydrocarbon-dependent economies aiming to reduce their vulnerability to oil price fluctuations and establish sustainable growth (IMF, 2016; Fattouh & Sen, 2021). For countries like Oman, which rely heavily on hydrocarbon exports, economic diversification provides a pathway to long-term resilience by generating alternative income sources, expanding employment opportunities, and reducing fiscal volatility (Hvidt, 2013). Economic diversification typically involves developing other economic sectors such as tourism, manufacturing, agriculture, and financial services to supplement hydrocarbon revenues (Kinninmont, 2017).

For the GCC, economic diversification has been central to national development strategies. Saudi Arabia's Vision 2030 and the United Arab Emirates' Vision 2021, for instance, explicitly prioritize reducing oil dependency through targeted investments in alternative sectors and enhancing the role of the private sector (Hvidt, 2013; Hertog, 2010). Oman has also articulated diversification goals in its Vision 2040, emphasizing sectors such as tourism, fisheries,

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and logistics, which could contribute to stabilizing the economy and mitigating dependency on oil (Oxford Business Group, 2023).

The literature highlights the complexities of diversification for hydrocarbon-dependent economies, noting that achieving diversification is not merely an economic adjustment but also requires structural reforms, labor market adjustments, and private sector engagement (El-Katiri et al., 2011). Significant investments in infrastructure, technology, and human capital are necessary to enable the transition from an oil-based economy to a more diversified economy. For example, many resource-rich countries like Algeria have struggled with diversification due to regulatory constraints, limited institutional capacity, and an insufficiently skilled workforce (Callen et al., 2014). This underscores that diversification in resource-dependent economies often involves overcoming institutional, regulatory, and educational barriers.

Moreover, diversification efforts are influenced by the economic concept of the "Dutch Disease," where a reliance on natural resources can stymie the development of other sectors. For Oman, this phenomenon is a potential challenge, as heavy reliance on hydrocarbons could limit the competitiveness of non-oil sectors and inflate wages, making diversification difficult (Van der Ploeg, 2011; Frankel, 2012). Given these complexities, economic diversification requires a coordinated policy approach, addressing both immediate needs for sectoral development and long-term strategies for labor, finance, and institutional reform (Cherif & Hasanov, 2016).

In their paper, Fatih et al., (2023) discusses the challenges of economic diversification in oil-dependent countries, emphasizing that structural and institutional factors significantly influence diversification efforts. While it does not specifically address Oman, it suggests that countries with better infrastructure, human capital, and research and development are more likely to achieve successful diversification. This implies that in the context of Oman, the quality of these structural factors could determine whether the country leads in diversification or follows the trends set by others in the energy transition

3.2 Transition to Clean Energy

The global shift toward clean energy involves replacing fossil fuels with renewable energy sources like solar, wind, and hydrogen to reduce carbon emissions and mitigate climate change. For hydrocarbon-dependent economies, this transition poses particular challenges as it fundamentally changes the economic and industrial landscape (IEA, 2020). Clean energy investment has become integral to the climate action strategies of many countries, supported by initiatives like the Paris Agreement, which aims to limit global warming to below 2 degrees Celsius (UNFCCC, 2015).

Oman's transition to clean energy is a multifaceted endeavor influenced by its geographical advantages, political-economic structures, and societal readiness. The country has significant potential for renewable energy, particularly solar and wind, due to its geographical composition. Oman has substantial potential for solar and wind energy, driven by environmental, economic, and social sustainability concerns. The emphasis is on solar and wind energies due to the country's geographical advantages (Zubairu et al., 2024). A simulation study on green hydrogen supply chains highlights the feasibility of leveraging solar energy for hydrogen production, aligning with Oman's Vision 2040 goals (Tian et al., 2024).

Despite these positive steps, challenges persist in implementing renewable energy in hydrocarbon-dependent economies. Studies have shown that reliance on hydrocarbons can lead to an inertia against energy transition, as established industries and energy infrastructures are often resistant to the shift to renewables (Krarti (2020). Furthermore, renewable energy projects require substantial investment and technological expertise, which may not be readily available in hydrocarbon-dependent countries, creating an economic burden and often necessitating foreign partnerships and financing (Reiche 2010). In addition, high installation and maintenance costs, along with a lack of awareness, are significant barriers to solar energy adoption among Omani consumers (Mishrif & Khan, 2024).

Nasiru et al., (2024). Concluded that, the transition to clean energy in Oman is slow, despite the potential for renewable energy sources such as solar, wind, biomass, and geothermal. The study emphasizes the need for a strategic focus on solar and wind energy due to Oman's geographical advantages. Key factors influencing this transition include policies and regulations, advanced technologies, subsidy regimes, grid connectivity, storage capacity, and land availability. Addressing these elements is crucial for accelerating the sustainable transition to renewable energy in Oman.

Recent research suggests that clean energy transition in the GCC, including Oman, could generate significant economic opportunities, particularly in the development of green hydrogen, which has potential as a future export commodity (IEA, 2021). The emergence of green hydrogen could offer a dual advantage: reducing domestic reliance on hydrocarbons and providing new revenue streams, contributing to diversification (IRENA, 2022). However, these projects require substantial upfront investment and technology transfer, presenting a significant barrier to resource-constrained countries (Bade et al., 2024).

3.3 Interlinkages between Economic Diversification and Energy Transition

Economic diversification and the clean energy transition are interconnected processes that mutually reinforce each other. Investing in renewable energy sources supports economic diversification by fostering new industries, driving innovation, and generating employment in fields such as solar, wind, and hydrogen energy production (IRENA, 2021). For instance, in the United Arab Emirates, renewable energy projects have become central to economic diversification, generating thousands of jobs and promoting growth in sectors such as manufacturing and construction (Hvidt, 2013).

A diversified economy, in turn, enhances a country's capacity to invest in renewable energy by reducing reliance on oil and gas revenues, thereby allowing for greater flexibility in long-term clean energy investments. Norway exemplifies this approach, having used hydrocarbon export revenues to establish a sovereign wealth fund that supports public investments in renewable energy and other sectors, successfully integrating diversification with energy transition goals (Baffes et al., 2015).

The clean energy sector also benefits from the spillover effects of economic diversification. Studies have shown that diverse economies are more resilient and adaptive to technological change, facilitating the integration of renewable energy technologies (Arezki, Ramey, & Sheng, 2017; IEA, 2021). Oman's Vision 2040 highlights this synergy, aiming to build a diversified economy that promotes renewable energy as a long-term growth sector (Oman Vision 2040, 2020). The relationship between diversification and energy transition creates a feedback loop: diversification fosters clean energy investment, and clean energy development contributes to further diversification, paving the way for sustainable growth (IMF, 2022).

Achieving a balance between diversification and energy transition, however, is challenging, as both objectives require substantial resources. While Saudi Arabia and the UAE have made strides in both areas, sustaining these agendas simultaneously presents challenges due to the high capital and resource allocations involved (IEA, 2021). Oman, with more limited resources than its GCC counterparts, must carefully allocate resources and potentially adopt targeted policies to balance diversification and clean energy efforts (Oxford Business Group, 2023).

In summary, the literature emphasizes the need for a dual approach that integrates economic diversification with clean energy transition. Aligning these goals is essential for hydrocarbon-dependent countries, like Oman, to build economic resilience in a low-carbon future. This review underscores the complexities and potential synergies in Oman's path to diversification and energy transition, providing valuable insights for policymakers on supporting both agendas effectively (Cherif & Hasanov, 2014; IEA, 2020; IRENA, 2021).

The interlinkages between economic diversification and energy transition are complex, requiring shifts in policy, infrastructure, and market dynamics. For countries reliant on fossil fuels, economic diversification is crucial as the global transition toward renewable energy threatens traditional revenue sources, necessitating a reorientation of economic structures to maintain stability and growth.

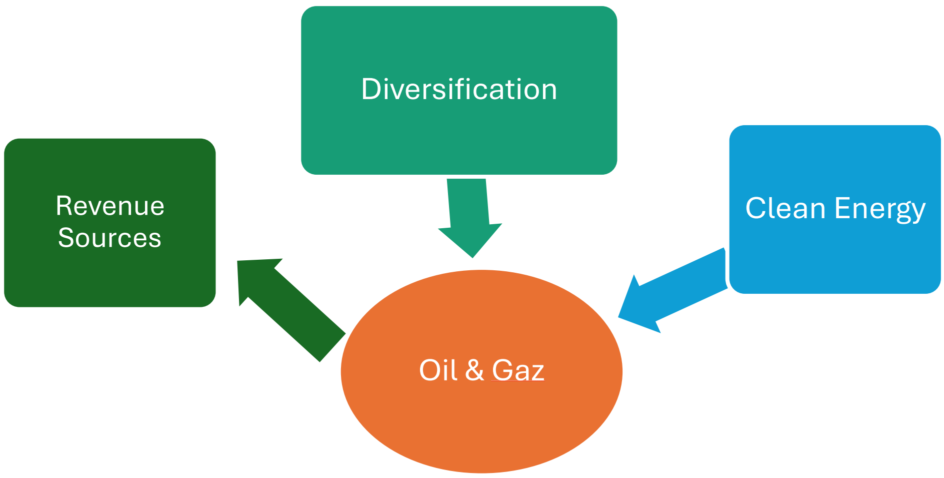
Economic diversification as a response to the energy transition presents distinct challenges and strategies. Resource-rich African countries, for instance, must leverage their mineral wealth for diversification while adapting to the global shift toward renewable energy, requiring strategic policy adaptations and regional collaboration to boost investment and value chains (Weldegiorgis, 2023). Similarly, oil-dependent countries need to diversify their economies to mitigate revenue volatility and carbon risks, with structural factors like infrastructure quality and human capital being pivotal for success (Fatih et al., 2023).

Diversification in the energy sector itself is a critical strategy. This includes increasing the share of renewable energy sources in the market and adopting integrated planning systems to minimize public costs (Gitelman et al., 2023). Arab oil-exporting countries are encouraged to implement diversification strategies that balance the energy transition speed with the strategic importance of the oil sector, while exploring alternative income sources (Fattouh & Sen, 2021).

Policy and structural reforms play a vital role. Kuwait, for example, focuses on enhancing productivity in non-energy sectors and reforming energy pricing to encourage diversified growth as part of its economic transformation strategy (IMF, 2016). Public-private partnerships and regional strategies are also essential for resource utilization and economic diversification in the context of energy transition (Weldegiorgis, 2023).

While the energy transition presents challenges, it also creates opportunities for economic diversification. Countries that integrate structural reforms and strategic planning effectively are more likely to achieve economic stability and resilience. However, the success of these efforts depends on the quality of infrastructure, institutional frameworks, and the ability to adapt to global energy dynamics (Chart 1).

Chart 1: Delicate Balance between Diversification and Transition to Clean Energy



4. MODEL, DATA, AND ECONOMETRIC STRATEGY

4.1 The Model

The aim of this study is to investigate the effect of Economic diversification, along with energy use and other control variables, on CO_2 emissions and environmental footprint in Oman, over the period, 1996 to 2023.

The following model are used to examine this interconnected relationship:

$$\text{Ln } \mathbf{CO_2} = \alpha_0 + \alpha_1 \text{Ln DIV}_{it} + \alpha_2 \text{Ln PCy}_{it} + \alpha_3 \text{Ln ENRGU}_{it} + \alpha_4 \text{ Ln URn}_{it} + \alpha_5 \text{GOEF}_{it} + \alpha_6 \text{FDEX}_{it} + \varepsilon_{it}$$

The equation represents the natural logarithm of carbon dioxide emissions (Ln CO_2) as a function of several independent variables. These include the Economic diversification index(DIV) which is directly represented by the export diversification index, which reflects the extent to which each country's export structure differs from global patterns, the natural logarithm of real GDP per capita (Ln $RGDP_C$), which reflects the impact of economic growth on emissions, and energy use per capita (Ln ENGY), showing how energy consumption influences emissions. The natural logarithm of the percentage of the urban population (Ln URB) captures the effect of urbanization, while government effectiveness ($GVEF_{it}$) measures the role of government policy towards energy. Additionally, the Financial Development Index (FDEX) reflects the impact of the financial sector's development on emissions. The coefficients ($\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ and α_6 represent the expected changes in CO_2 emissions for each variable, and the error term (ϵ) accounts for factors not included in the model.

4.2. Data, Variable Description & Expected Sign of Parameters

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1. α_1Ln DIV_{it} (Economic diversification (DIV)) is directly represented by the export diversification index, which reflects the extent to which each country's export structure differs from global patterns. This index takes values between 0 (high level of diversification) and 1 (low level of diversification), where a low diversification score indicates a high level of economic diversification, and vice versa. The data was obtained from the United Nations Conference on Trade and Development (UNCTAD) website (UNCTAD, 2023). Therefore, α_1 is likely to be positive, $\alpha_1 > 0$
2. Ln PCy_{it} (Per Capita GDP): The coefficient α1 represents the effect of per capita GDP on carbon emissions. Typically, as a country's per capita GDP increases, it indicates higher economic development. In this context, a positive relationship is often observed, meaning that as the economy grows, carbon emissions tend to increase due to increased industrialization, energy consumption, and transportation. Therefore, α_2 is likely to be positive, $\alpha_2 > 0$
3. $ENRGU_{it}$ (Energy Use): The coefficient α_3 represents the effect of energy use per capita on carbon emissions. Higher energy use is generally associated with higher carbon emissions, as most energy sources involve the combustion of fossil fuels. Hence, α_3 is also likely to be positive. $\alpha_3 > 0$
4. URn_{it} (Urban Population Percentage): The coefficient $\alpha_4$signifies the impact of the percentage of urban population on carbon emissions. Urbanization often leads to increased energy consumption and emissions due to factors like increased transportation and energy demand. Thus, α_4 is likely to be positive. $\alpha_4 > 0$.
5. $GOEF_{it}$ (Government Effectiveness): Effective governance can lead to better environmental regulations, which may reduce emissions (negative effect). However, if government is not effective, it could also increase emissions (positive effect). The direction of α_5 will depend on how government effectiveness impacts the economy and environmental policies. ($\alpha_5 < 0$ or $\alpha_5 > 0$)
6. $FDEX_{it}$ (Financial Development Variable): A developed financial sector can promote green investments and sustainable practices, potentially reducing emissions (negative effect). Conversely, if financial development leads to increased industrial activity, it might raise emissions (positive effect). Like other variables, the direction of α_6 will depend on specific circumstances. ($\alpha_6 < 0$ or $\alpha_6 > 0$). Here is proxied by domestic credit to private sector as a percentage of GDP.
7. ε_{it} (Error Term): The error term εit captures unexplained variation in carbon emissions that is not accounted for by the independent variables in the model. It encompasses other factors and random variability.

The following table provides a detailed description of the variables used in the study and their respective data sources.

Table 1. Variables' description and data sources

Variable	**Définition**	**Codes**	**Source**
Dépendent variable	CO_2 émissions (metric tons per capita	CO_2	WDI, 2023
Independent variables	Real GDP at constant 2010 prices	PCy_{it}	WDI, 2023
	Energy use (kg of oil equivalent per capita	$ENRGU_{it}$	WDI, 2023
	Gouvernent Effectiveness	$GOEF_{it}$	WGI, 2023
	Urban Population	$URPN_{it}$	WDI, 2023
	Économic Diversification	DIV_{it}	UNCTAD, 2023
	Financial Développent Index	$FDEX_{it}$	WDI, 2022

Source: World Bank "World Development Indicators (WDI, 2023)" World Development Governance Indicators (WGI, 2023) and UNCTAD, 2023

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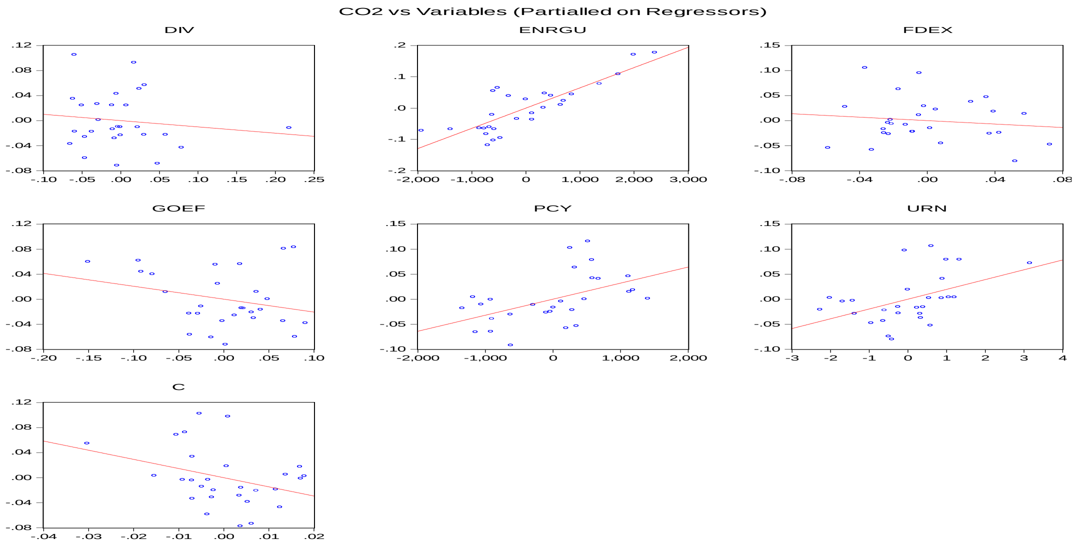
4.3 Initial Check

The scatter plots (Figure 1) depict the partial relationships between CO emissions and each independent variable in the model. Energy Use (ENRGU) shows a clear positive relationship with CO2 emissions, suggesting it is a key driver. Per Capita Income (PCY) and Urbanization Rate (URN) also exhibit slight positive trends, though the relationships appear weaker. Diversification (DIV) and Government Effectiveness (GOEF) indicate negative trends, but the scatter of data points suggests these effects may be weak or inconsistent.

The overall patterns indicate that while energy use is a significant factor influencing CO_2 emissions, other variables such as financial development, diversification, and government effectiveness exhibit weak or minimal effects. Further exploration may be needed to fully capture the dynamics between these variables and CO_2 emissions, potentially by including interaction terms or additional factors to refine the model, See Figure 2 below:

Figure 1: Partial relationships between CO_2 emissions and other independent variables



4.4 Econometric Strategy

The core econometric methodologies at our disposal include the Fully Modified Ordinary Least Squares (FMOLS), Robust Least Squares, the Johansen Cointegration Test, the Error Correction Model (ECM), Canonical Cointegrating Regression (CCR), and various Cointegration Tests. These methodologies are well-suited for examining the long-term relationships, short-term dynamics, and causal linkages between CO2 emissions and other variables in Oman.

Specifically, the FMOLS technique corrects for both endogeneity and serial correlation in the regressors, providing unbiased and efficient estimates of long-run relationships. Robust Least Squares estimation is employed to address potential issues of heteroscedasticity and outliers that could otherwise distort standard regression results, thereby ensuring the robustness of our findings.

The Johansen Cointegration Test is crucial for determining the existence and number of cointegrating relationships among the variables. This test allows for a system-based approach rather than a single-equation method, providing a richer understanding of the interdependencies among the variables under study.

To capture the short-term dynamics and speed of adjustment toward long-run equilibrium, we employ the Error Correction Model (ECM). The ECM not only quantifies the short-run deviations but also measures how quickly any disequilibrium in the long-run relationship is corrected over time.

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The Canonical Cointegrating Regression (CCR) approach serves as an alternative to FMOLS, offering another method to estimate long-run relationships by correcting for endogeneity and serial correlation. CCR complements the FMOLS results and reinforces the robustness of our findings.

Additionally, we apply supplementary Cointegration Tests, such as the Pedroni and Kao tests (if dealing with panel data), to validate the robustness of our long-run relationships across different testing frameworks.

Together, these econometric techniques provide a comprehensive framework for investigating both the equilibrium relationship and the adjustment mechanisms between CO2 emissions and macroeconomic factors in Oman. By employing a multi-method approach, we aim to enhance the reliability, consistency, and depth of our empirical results, ensuring that policy recommendations are based on solid statistical foundations.

5. FINDINGS AND DISCUSSION

5.1 Summary Statistics

As shown in Table 2, the descriptive statistics show moderate variability for CO_2, DIV, ENRGU, FDEX, GOEF, PCY, and URN. PCY has the highest variability, with a mean of 18774.5 and a significant negative skew, suggesting more high-end values. Most variables exhibit symmetric distributions, with skewness close to zero and kurtosis indicating generally flat distributions. The Jarque-Bera tests suggest that all variables are approximately normally distributed, except PCY, which shows a slight deviation from normality with a p-value of 0.059.

Table 2. Summary of statistics for the model variables

Series	CO_2	DIV	ENRGU	FDEX	GOEF	PCY	URN
Mean	0.8174	0.567	5431.15	0.357	0.326	18774.5	77.332
Median	0.8615	0.612	5698.00	0.351	0.321	19458.71	74.892
Maximum	1.1025	0.805	9250.77	0.422	0.498	21458.39	87.556
Minimum	0.4509	0.262	2803.88	0.299	0.081	13337.60	71.509
Std. Dev.	0.2107	0.171	1848.56	0.037	0.103	2132.009	5.962
Skewness	-0.422	-0.361	0.163	0.297	-0.247	-1.079	0.530
Kurtosis	1.8059	1.752	2.053	1.918	2.507	3.405	1.693
Jarque-Bera	2.495	2.427	1.171	1.779	0.568	5.631	3.302
Probability	0.287	0.297	0.556	0.410	0.752	0.059	0.191
Sum	22.887	15.89	152072.3	10.00	9.129	525686.0	2165.30
Sum Sq. Dev.	1.198	0.789	9226	0.038	0.286	1.23E+08	959.80
Observations	28	28	28	28	28	28	28

5.2 : Check for Outliers

The box plots in figure 2, illustrate the distribution of various economic or environmental variables**.** CO2 and DIV show fairly symmetric distributions with medians around 0.6 and 0.3, respectively, and no outliers. ENRGU (median ~6,000) and FDEX (median ~0.34) are also symmetrical, with FDEX showing tighter clustering. GOEF (median ~10,000) is slightly skewed but lacks outliers, while PCY (median ~18,000) shows a few outliers below the lower quartile, indicating some extreme values. URN (median ~76) exhibits wider variability without outliers. Overall, most variables are symmetrically distributed, with only PCY displaying notable outliers. The spread differs, with FDEX being tightly clustered and URN and ENRGU showing broader ranges.

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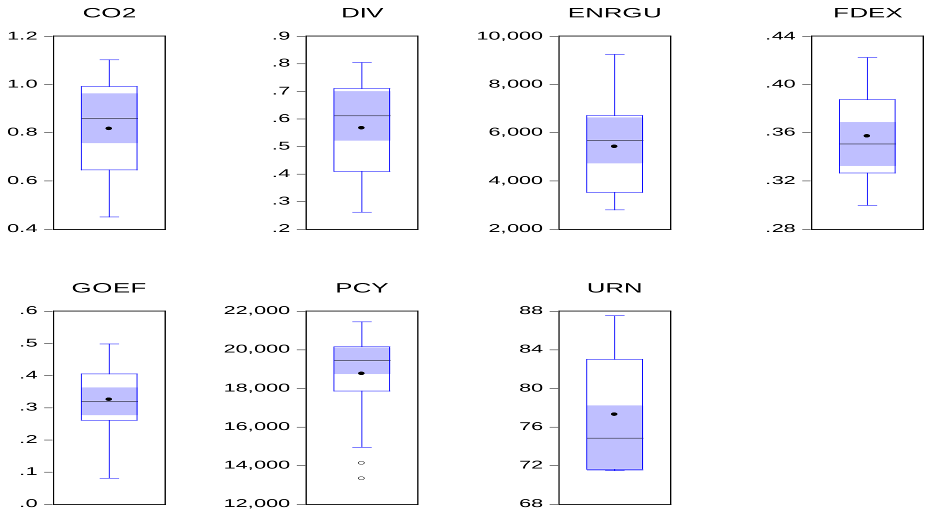
Figure 2: The box plots for Model variables



5.3 Unit Root Results

The Augmented Dickey-Fuller (ADF) test results indicate that most variables, including CO_2, EnRgU, GoEF, FDEX, and DIV, are non-stationary at level (I(0)) but become stationary at the first difference (I(1)). However, PCy and Urn remain non-stationary at the first difference and only become stationary at the second difference (I(2)). This suggests that the majority of variables have a unit root at level but achieve stationarity after first differencing, while PCy and Urn require an additional level of differencing to become stationary. Ensuring stationarity is crucial for subsequent time series modeling, such as cointegration analysis or error correction models, see Table 3.

Table 3: Panel Root Test Results

Variable	Level ADF Test Statistic	Level Critical Value (5%)	Level P-Value	Conclusion	First Difference ADF Test Statistic	First Difference Critical Value (5%)	First Difference P-Value	Conclusion
CO_2	-2.590	-3.0131	0.0950	I(0)	-6.5836	-2.9865	0.0000	I(1)
PCy	-0.888	-3.0312	0.7919	I(0)	0.379	-3.0312	0.9807	I(2)
EnRgU	-0.533	-2.9812	0.8853	I(0)	-4.0324	-2.9865	0.0013	I(1)
Urn	-0.755	-2.9812	0.8321	I(0)	-1.5777	-2.9812	0.4948	I(2)
GoEF	-2.149	-2.9764	0.2251	I(0)	-5.3748	-2.9812	0.0000	I(1)
FDEX	-0.955	-3.0420	0.7694	I(0)	-3.3282	-3.0312	0.0136	I(1)
DIV	-0.546	-2.9812	0.883	I(0)	-7.9387	-2.9812	0.0000	I(1)

5.4. The Johansen Cointegration test

The Johansen cointegration test results displayed in Table 4, suggest the presence of long-term equilibrium relationships among the variables in the model. The trace statistics exceed the critical values for the first four hypothesized Cointegrating equations, with significant p-values below 0.05, leading to the rejection of the null hypothesis of no cointegration. This implies that there are at least four Cointegrating relationships at the 5% significance level. For the remaining hypotheses (at most 4, 5, and 6), the trace statistics are less than the critical values, and the p-values are above 0.05, indicating that no further cointegration relationships exist beyond the fourth. Thus, the trace test indicates the presence of four cointegrating equations, highlighting that the variables maintain a stable long-term equilibrium relationship.

Table 4: Johansen cointegration test Output

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None *	0.947551	207.8066	125.6154	0.0000
At most 1 *	0.827568	131.1609	95.75366	0.0000
At most 2 *	0.697441	85.45928	69.81889	0.0017
At most 3 *	0.678929	54.37682	47.85613	0.0108
At most 4	0.402324	24.83844	29.79707	0.1673
At most 5	0.283505	11.45608	15.49471	0.1849
At most 6	0.101685	2.788092	3.841466	0.0950

Trace test indicates 4 cointegrating eqn(s) at the 0.05 level
* denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

5.5 The Vector Error Correction (VEC)

The Vector Error Correction Model (VECM) results shown in Table 5, indicate a significant long-term relationship between economic diversification (DIV) and the other variables—energy use (ENRGU), governance effectiveness (GOEF), and per capita income (PCY). Specifically, energy use positively affects diversification, while governance effectiveness and per capita income show negative long-term impacts, all with statistical significance.

In terms of short-term adjustments, economic diversification has a significant error correction coefficient of -0.716, indicating that approximately 71.6% of the disequilibrium is corrected each period, implying a relatively fast adjustment towards equilibrium. In contrast, energy use, governance effectiveness, and per capita income show insignificant error correction terms, suggesting that these variables do not significantly adjust to restore equilibrium after deviations in the short run.

Table 5: Vector Error Correction Estimates

Cointegrating Eq:	CointEq1
DIV(-1)	1.000000
ENRGU(-1)	2.46E-05
	(6.4E-06)
	[3.82811]
GOEF(-1)	-0.785763
	(0.11518)
	[-6.82217]
PCY(-1)	-3.13E-05
	(5.6E-06)
	[-5.57617]
C	0.144412

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Error Correction:	D(DIV)	D(ENRGU)	D(GOEF)	D(PCY)
CointEq1	-0.716341	-4463.020	0.018242	2608.457
	(0.30997)	(2648.89)	(0.32433)	(2021.80)
	[-2.31099]	[-1.68487]	[0.05624]	[1.29017]

5.6 Robustness tests results

The robustness tests in the analysis provide insights into the estimated coefficients using four different estimation techniques: FMOLS, DOLS, STWR, and CCR. The results reveal that Energy Use (ENRGU) and Per Capita Income (PCY) consistently show positive and significant impacts on the dependent variable across several methods, underscoring their strong influence on the model. Although the levels of significance vary, both variables maintain robust relationships, indicating their importance. Urbanization Rate (URN) also demonstrates a positive and significant relationship with the dependent variable in the FMOLS and STWR methods, indicating a notable positive effect in these models. In contrast, Diversification (DIV), Financial Development (FDEX), and Government Effectiveness (GOEF) do not show statistical significance across the different estimation methods, suggesting weak or inconclusive effects on the dependent variable.

The R-squared and Adjusted R-squared values are generally high across all models, indicating that a significant portion of the variability in the dependent variable is well-explained by the model, see Table 6.

Table 6: Robustness tests results

	FMOLS		***DOLS***		**STWR**		***CCR***	
	Coeff	*t*-Stats	*Coeff*	*t*-Stats	Coeff	*z*-Stats	*Coeff*	*t*-Stats
DIV	-0.13101	-0.86249	-0.1102	0.1927	-0.100271	- 0.60500	-0.1654 **	-0.672
ENRGU	6.78E-05	7.75679*	0.0000	1.1600	6.47E-05	6.83420	0.0000	6.903
FDEX	-0.15909	-0.60241	-0.17169	0.2834	-0.171696	0.60458	-0.088	-0.291
GOEF	-0.22066	-1.48223	-0.28564	0.194	-0.206030	1.27563	-0.291 **	1.421
PCY	3.87E-05	3.35052*	0.0000	1.480	3.20E-05	2.67566	0.0000	2.68***
URN	0.01905	2.50864*	0.01607	0.010	0.019552	2.39808 **	0.0162	1.421
C								
R-squared		0.948300		0.95742		0.957427		0.945
Adjusted *R*-squared		0.935991		0.94526		0.945264		0.928
S.E. of regression		0.051063		0.04928		0.049289		0.053
Durbin-Watson stat		2.053210		2.05101		2.957427		1.129
Mean dependent var		0.830981		48.5786		0.817408		0.830
S.D. dependent var		0.201829		78.7125		0.210676		0.201
Sum squared resid		0.054756		0.95742		0.051018		0.058

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

5.7 Diagnostic tests

5.7.1 Normality Test

The histogram of residuals shown in figure 3 below, indicates an approximately normal distribution, with most residuals centred around zero. The mean is near zero, suggesting no bias. The Jarque-Bera test (p-value = 0.467)

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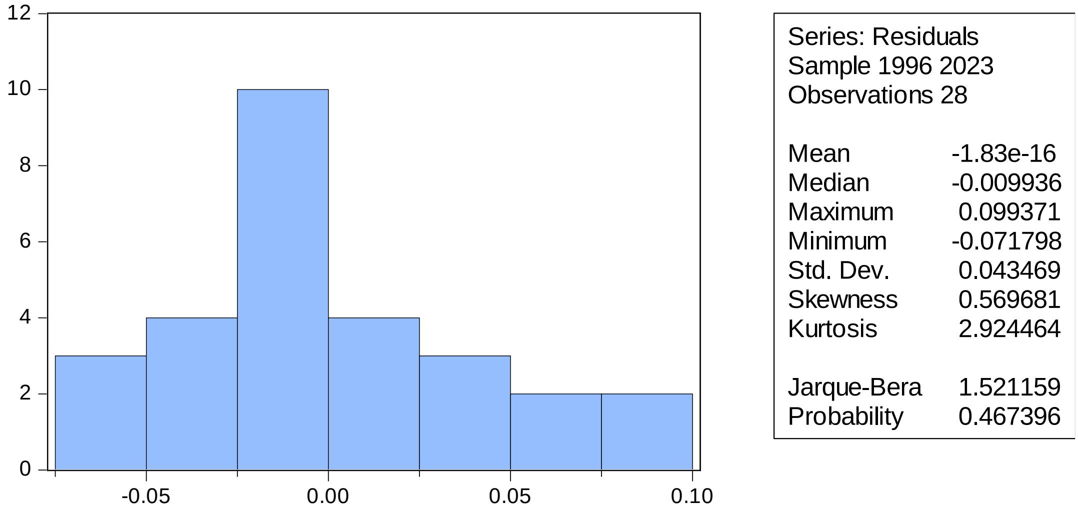
supports normality, and skewness (0.57) and kurtosis (2.92) are close to expected values for a normal distribution. Overall, the residuals meet normality assumptions, supporting model validity

Figure 3: normal distribution



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5.7.2 AECH Heteroscedasticity Test

The Breusch-Pagan-Godfrey heteroskedasticity test is used to determine if heteroskedasticity exists in the residuals of a regression model. Heteroskedasticity indicates that the variance of residuals varies at different levels of an independent variable, which can lead to inefficient estimates and unreliable statistical conclusions if unaddressed.

Table 7 display the results of the test. The F-statistic and its p-value suggest that we cannot reject the null hypothesis of constant variance, indicating no significant evidence of heteroskedasticity. Similarly, the Obs*R-squared statistic, which is based on the regression of squared residuals on explanatory variables, also has a p-value above the threshold, meaning we fail to reject the null hypothesis of homoskedasticity. Lastly, the Scaled Explained Sum of Squares also has a high p-value, further supporting the absence of significant heteroskedasticity in the residuals.

Table 7: Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	1.724584	Prob. F(6,21)	0.1646
Obs*R-squared	9.242526	Prob. Chi-Square(6)	0.1604
Scaled explained SS	5.002569	Prob. Chi-Square(6)	0.5435

5.8 Stability Test

5.8.1 N-step Forecast Test

Figure 5 of recursive residuals and N-step probability bounds indicates that the model is generally stable over the sample period. The residuals fluctuate around zero and remain well within the 95% confidence bounds (represented by the dashed red lines), suggesting no significant structural breaks or instability.

Since there are no instances where the recursive residuals exceed the confidence bounds, the model appears to have consistent parameters throughout the observed period. This indicates that the model specification is reliable and that the relationships it captures remain stable over time.

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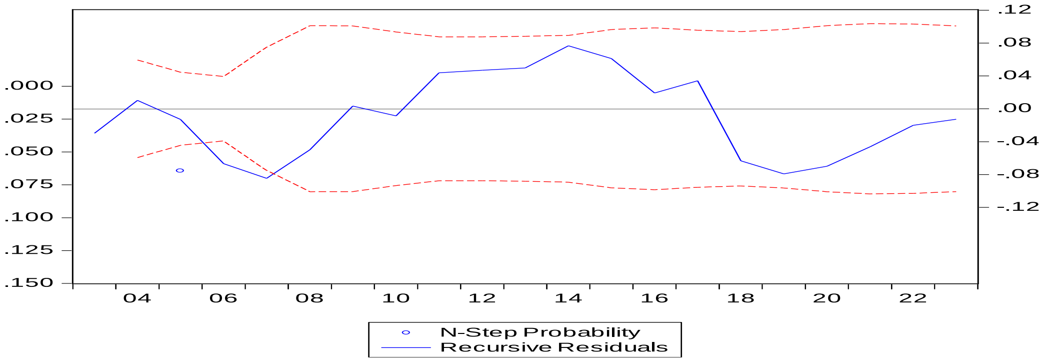
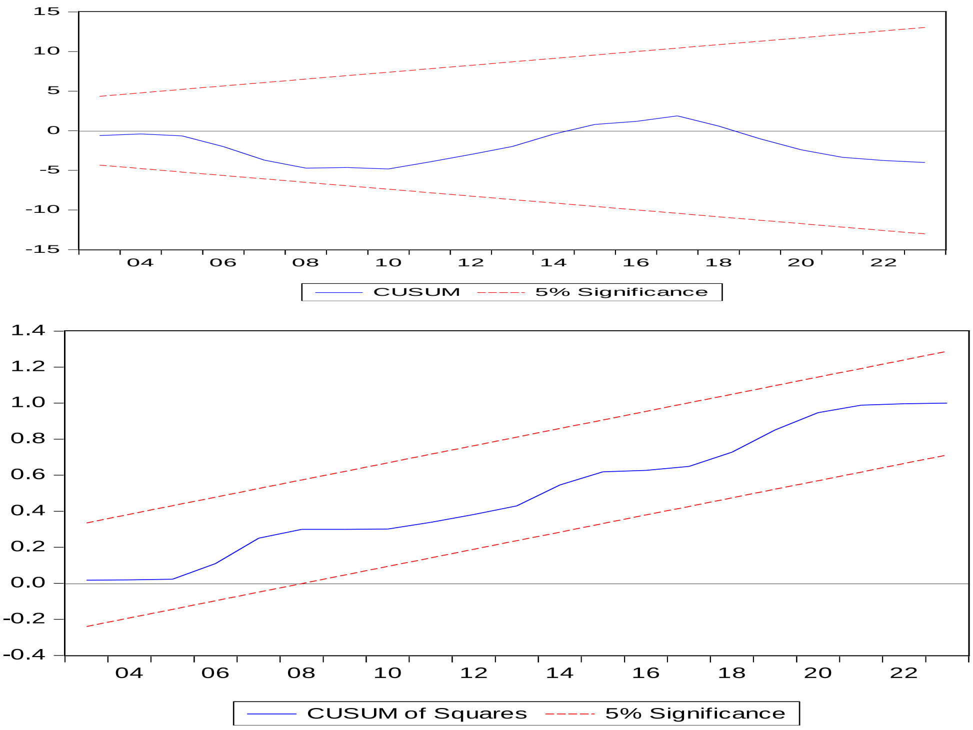
Figure 4: N-step Forecast Test



5.8.2 The CUSUM and CUSUMSQ

The CUSUM and CUSUMSQ tests were employed to assess the stability of the model's parameters over time. These tests, monitoring the cumulative sum of residuals (CUSUM) and squared residuals (CUSUMSQ), help detect structural breaks in econometric models (Brown, Durbin, & Evans, 1975). If the plotted values remain within the 5% significance bounds, the model is considered stable; if they cross, parameter instability is suggested (Gujarati & Porter, 2009). Studies like Jordaan and Eita (2007) confirm the utility of these tests in identifying structural shifts. As shown in Figure 6, The CUSUM plot indicates model stability, as the cumulative sum of residuals stays within the 5% significance boundaries, showing no significant structural changes. In contrast, the CUSUM of Squares plot suggests increasing variability, though it remains within acceptable limits. Together, these plots imply that the model is generally stable but may have some increasing variance over time that should be monitored (See figure 5)

Figure 5: Results of CUSUM and CUSUM square tests



2. Conclusion and Policy Recommendation

The current study intends to investigate the relationship between economic diversification and other variables on environmental degradation in Oman over the period 1996-2023. Employing a range of econometric techniques including CCR, FMOLS, DOLS, VEC and The Johansen cointegration test. The key relationships identified include

CO_2 emissions, economic diversification, energy use, financial development, governance, per capita income, and urbanization.

The Johansen cointegration analysis indicates the presence of long-term equilibrium relationships among the variables. The VECM analysis demonstrates a significant long-term relationship between economic diversification and other variables. Energy use has a positive impact on diversification, while governance and per capita income have negative effects. The adjustment process toward equilibrium is fast for diversification.

Robustness checks confirm the positive impact of energy use and per capita income, whereas diversification, financial development, and governance are not statistically significant. Diagnostic tests confirm that residuals are normally distributed, there is no evidence of heteroskedasticity, and the model remains stable over time, though increasing variability should be monitored.

The findings of this study provide significant insights into the relationship between economic diversification and environmental degradation in Oman. The results emphasize that energy use is a key factor positively influencing environmental degradation, whereas governance and per capita income exert mixed effects. Long-term equilibrium relationships exist among the variables, implying that strategic policy interventions in these areas can positively impact environmental outcomes.

However, the study reveals that the role of economic diversification in facilitating energy transition is currently limited. Despite efforts towards diversification, the results show that it has not had a statistically significant impact on reducing environmental degradation or transitioning towards cleaner energy. This indicates that economic diversification in Oman may still be largely dependent on activities that are linked to conventional energy use, rather than fostering a shift towards greener industries. For economic diversification to contribute more effectively to energy transition, it is crucial for policymakers to promote sectors that are less carbon-intensive and encourage investment in renewable energy initiatives.

To reduce environmental degradation, policymakers should focus on enhancing energy efficiency and implementing robust governance frameworks that support sustainable economic growth. Encouraging innovation and promoting investments in clean energy sectors could enhance the role of diversification in supporting the energy transition. Future studies could expand on these findings by exploring similar relationships in different contexts to offer a more comprehensive view of effective development strategies for Oman.

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