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ENERGY EFFICIENCY AND THE GREEN–BLUE INNOVATION NEXUS: NONLINEAR EVIDENCE FROM GCC ECONOMIES

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ABSTRACT

The research focuses on the ways in which the economies of the GCC can achieve growth in a sustainable manner, while also overcoming environmental challenges. The research, which employs a dynamic panel System GMM approach from 2000 to 2024, reveals three key findings. First, it is clear that energy intensity is detrimental to sustainability, reinforcing the importance of energy efficiency. Second, green innovation, as measured by the use of renewable energy, environmental patents, and clean technology, is a key driver of sustainable growth. Finally, developing blue resources is also a contributor to sustainability, and it can be seen as complementary to green innovation. Furthermore, the research also reveals that institutional quality is an important moderator of the results. Overall, it can be seen that there is clear policy guidance for the GCC economies, which are seeking a new economic model based on a low carbon, innovation-driven, and sustainable growth strategy.

KEYWORDS: Energy Intensity; Green Innovation; Sustainable Economic; Growth Renewable Energy.

JEL Classification: Q20, Q55, Q56, O13, C33.

1. INTRODUCTION

The GCC's strategic challenge remains to maintain high economic growth while reducing dependency on hydrocarbons, whose revenue historically provided the base for high incomes and rapid development. New drivers of growth rooted in sustainability are far more urgently needed. With growing exposure to price volatility and global decarbonization pressures, the long-term movement towards cleaner and diversified economic activity becomes obligatory for budgetary stability and climate-conscious growth (Md, Z., Hasan Majumde, & all. 2024).

As such, increased energy security and faster economic diversification remain at the heart of GCC national priorities. The scale of regional investments in renewable energy, green hydrogen, and grid modernization reflects a trend for lowering domestic hydrocarbon consumption and increasing low-carbon power generation throughout the region as a whole. Yet, investment alone is insufficient to drive structural transformation in the process; technology has to be advanced simultaneously.

As Alex O. Acheampong., & al. (2021) and Pinjie Xie., Fan Yang, & Zhuowen Mu (2020), respectively, explain it, increased green innovation capabilities, captured through environmental patent potential, research capacity, and adoption of clean technologies, are an important precursor for creating a competitive post-oil economy. Stronger institutional processes are still required to translate innovative initiatives into widespread, system-wide diffusion, even as the GCC states have made rapid progress related to technology deployment in recent years, according to the most recent assessments by Alanoud Al-Maadid., M, Sami Ben Ali., & Ijaz Younis. (2025).

In recent years, the blue economy has emerged as a complementary path to long-term sustainability, complementing green transformation. Examples of such blue resources are coastal energy, fisheries, marine ecosystems, maritime logistics, and ocean-based enterprises-they create new opportunities for jobs, clean electricity, food security, and export diversification.

Regional studies suggest that coordination between green and blue strategies may have synergistic impacts: sustainable coastal development fosters economic stability and climate resilience, while marine renewable energy can ease pressure on land-based systems. However, deficiencies in integrated maritime planning, regulatory coherence, and environmental monitoring still hinder the complete realization of the potential that blue resources offer, Xiuxing Yin, Li Pan & Meizhen Lei. (2022).

These emerging trends collectively point toward the need for an integrated policy framework that coordinates institutional changes, green innovation, energy-efficiency improvement, and sustainable use of blue resources.

To address endogeneity, persistence, and country-specific effects, the present study uses a System-GMM approach to empirically test how energy intensity, green innovation, and blue-resource development interactively affect the sustainable economic growth in the GCC economies from 2000 to 2024, culled from Ihsen, A., Hechmi, S., & Chaabouni, I. (2024). The results are expected to inform the design of policies towards the long-term vision and goals of the region for innovation-driven, sustainable development, extracted from GCC Vision Reports (2024).

2. A BRIEF OF LITERATURE REVIEW

The complex links between economic growth, the consumption of energy, and the quality of environment are represented by the so-called energy-growth-environment nexus that still remains an issue of contemporary importance in the field of environmental and energy economics.

Although more modern trends tend toward highlighting the environment's limit imposed by the dependence on natural fuels and the need for transitions based on efficiency changes, the so-called early theoretical approach underlines the importance of energy as a productive factor that is pivotal for growth (A, Ahmad Khan, S, Noreenand & Med,Farooq. 2024). Growth-led energy demand hypothesis receives confirmation by certain studies with others revealing neutrality or bi-variate relationships according to the structure and the levels of the countries' income (Hsiao-Tien Pao, Chung-Ming Tsai. 2010).

The link is further created because of the structural dependence on hydrocarbons that makes them more vulnerable to changes occurring within the oil markets as well as carbon-related externalities that exist within the economies of various countries of the GCC (A, Androniceanu & I, Georgescu S. 2023).

As therefore various growth path assessments take place, the incorporation of various dimensions of energy efficiency as well as the adjustment mechanisms (Caporale, G.M.; Claudio-Quirota, G.; Gil-Alana, L.A. 2021) has received importance. The implications of various changes within the energy intensity have made it feasible due to the theoretical foundations discussed above.

Green innovation is increasingly being recognized as a growth driver that fuels productivity and helps cut the emission of greenhouse gases. As stated by Med, Mohsin., H, W, Kamran., Med Atif Nawaz., Med Sajjad Hussain., A, S, Dahri. (2021), the adoption of green technologies through the measurement of environmental patents, clean technologies, R&D investments, and the deployment of renewable energy are the most common variables used on quantitative analyses on green innovation. Studies consistently show that green technology supports the growth of the economy and the environment by cutting the emission of greenhouse gases (Asif, M.; Sharma, R.B.; Adow, A.H. Elneel Adow. 2015).

As indicated by various macroeconomic analyses on the topic of innovation and the environment, green innovation promotes economies' transition toward more environmentally friendly and efficient production patterns by playing the role of a mediator between the consumption of energy resources and the performance of the economy (Žarković, M., Ćetković, J., Redzepagic, S., Đurović, G., Vujadinović, R., & Živković, A. 2022). Nevertheless, the GCC's observations reveal that there remain certain shortcomings within the innovation system of this region with respect to the development of patents as well as the distribution of technology despite considerable investment being made on green infrastructure and renewable resources (Jackman, M. 2010).

The concept of the blue economy-that is, the responsible exploitation of the oceans and the coast as an engine of economic development—is well underway at the moment as an additional 'pillar' of economic and environment policies.

The blue industries that have particular significance and could serve as a boost to the sustainability of the blue economy include marine renewable energies, fishing and aquaculture, maritime transport, tourist industries on the coasts, and biotechnology based on the oceans (Nguyen, P. T., & Nguyen, Q. L. H. T. T. 2020). The blue economy provides an opportunity to diversify the economies of countries with lengthy coastlines and maritime infrastructure by improving food security and adapting to the effects of climate change, like the GCC (Radmehr, R.; Henneberry, S.R.; Shayanmehr, S. 2020).

The blue economy opens up opportunities for improved food security and adaptation to climate change effects in countries like the GCC through diversification of economies of countries with long coasts and marine infrastructure. Alternative energy sources could be harnessed, according to research. This underscores the importance of proper blue economies' application based on reliable strategies of evaluating the blue economy's significance in the growth of economies.

3. RESEARCH GAP

Current knowledge is still fragmented and insufficiently integrated, particularly with regard to the GCC, although the topic of the relationship between energy, growth, and the environment receives more attention nowadays, as well as the importance of green innovation and the blue economy.

Most of the literature regarding the sustainability of the Gulf Cooperation Council (GCC) countries deals with either the issue of the intensity of energy consumption and the emission of carbon (Ahmad, 2020) or green innovation and the transition toward the use of renewable sources (Med, Mohsin, Q, Abbas, J, Zhang, Med, Ikram, Nadeem Iqbal. Ang. 2019).

Perhaps there might exist a more complete knowledge on the issue of sustainable development of economies based on the hydrocarbon sector if the green and blue dimensions are considered together. Nevertheless, these literary streams usually treat the environment and technological variables separately.

A second constraint could pertain to the blue economy, which currently remains under-emphasized in the GCC literature despite its increasingly prominent application worldwide. Most of the GCC's blue economy assessments remain descriptive and focus on sectoral outlooks regarding aquaculture, fishing industries, marine energy resources, and coastal infrastructure projects; few of these evaluations quantitatively assess the blue sector's macroeconomic role with regards to sustained growth (Ceric, A., & Ivic, I. 2020).

Additionally, there appears to remain a considerable methodological gap with regards to assessing the applicability of blue resources innovation on green innovation due to the blue sector's overwhelming concentration on the environmental management aspects of its policies over the application of proper econometric analysis.

The lack of integrated research models that could simultaneously analyze the issues of energy efficiency, green innovation progress, and blue resources' sustainability is the third gap. Despite the growing attention of the GCC's policy papers toward the integration of these three issues under the common sustainability strategies of Vision 2030 and blue growth agendas (GCC Vision Reports, 2024), it still rarely happens that these issues are integrated within the context of the empirical research on these themes.

This therefore creates a gap with regard to the study of the combined impact of these issues.

Fourth, the GCC environment possesses its own structure that differentiates it from other regional blocs regarding its characteristics of being an oil-based economy, highly ambitious diversification strategies, water scarcity issues, and extensive dependence on the coastline.

Despite this, much of the empirical analysis neglects the institutional and economic specifics of countries within the GCC through the usage of world datasets or MENA aggregates (Alsabhan, T. H., Alghannam, S., Alhoshan, H. M., & Alshagri, R. 2025). This further reduces the applicability of the results obtained so far to the Gulf environment because of the prevailing pace of Gulf innovation, energy policies, and marine resources' strategies.

Finally, a notable methodological limitation persists because the simultaneity, persistence, and endogeneity that emerge out of the relationships between the variables of energy, innovation, and growth are frequently neglected by the dynamic panel econometric approach of System-GMM.

Dynamic adjustment procedures and reverse causation might cause unbalance in the results that could emanate out of the static approach that has been used in the preceding GCC-related analyses because of the potential skewness of these results (Tahir, M.; Albahouth, A.A. Jaboob, M. Osama, A.J. Burki, U. 2024).

By providing an early empirical analysis that collectively examines the variables of energy intensity, green innovation, and blue resources under a single dynamic system modeling the economies of the Gulf Cooperation Council countries over the period of 2000-2024, this study fills these research gaps.

Through the application of System-GMM estimates, this study avoids the various theoretical, context-related, and method-related shortcomings systematically examined across the literature on these variables' relationships and effects.

4. METHODOLOGICAL FRAMEWORK

4.1. Econometric and Model Specification

This paper explores the collective impact of energy intensity, green innovation, and blue-resource use on sustainable economic growth within a dynamic panel data framework.

As economic growth is usually persistent over time, inertia and path dependency are accounted for in this model by incorporating a lagged dependent variable.

The baseline model can be described as follows:

$$\mathrm{SG_{it}} = \alpha \mathrm{SG_{i,t-1}} + \beta_1 \mathrm{EI_{it}} + \beta_2 \mathrm{GI_{it}} + \beta_3 \mathrm{BI_{it}} + \gamma \mathrm{Z_{it}} + \mu_i + \varepsilon_{it} \quad (1)$$

Where:

$\mathrm{SG_{it}}$: Sustainable economic growth indicator for country i at time t.

$\mathrm{EI_{it}}$: Energy intensity.

$\mathrm{GI_{it}}$: Green innovation index.

$\mathrm{BI_{it}}$: Blue resource index.

$\mathrm{Z_{it}}$: Vector of control variables (trade openness, capital formation, financial development, population growth).

μ_i: Unobserved country-specific effects.

ε_{it} : Idiosyncratic error term.

The lagged dependent variable and possible simultaneity between energy, innovation, and blue-resource variables introduce endogeneity. The System-GMM estimator is employed to obtain objective and effective estimates, as in Li, Y.; Wang, X.; Imran, A.; Aslam, M.U.; Mehmood, U. (2023)

The conceptual framework illustrates how better sustainable growth is impacted by institutional quality, energy intensity, blue resources, and green innovation.

Green innovation plays a significant role in increasing the effectiveness of innovation-driven development through the direct promotion of sustainable growth and, at the same time, improving institutional quality. Besides, institutional quality is perceived as a complementary channel that assures innovation yields measurable sustainability performance along with efficient resource allocation and regulatory compliance.

On the other hand, because high energy usage per unit of production increases economic and environmental inefficiencies, energy intensity has a negative impact on sustainable growth. Increased sustainable growth in turn promotes the preservation and sustainable use of blue resources, underlining the linkage of economic progress with the well-being of marine ecosystems.

Together, these linkages reflect a dynamic system through which GCC economies make their transition towards long-term sustainability by improving technological efficiency and governance, reducing energy intensity, and safeguarding blue resources Figure 1.

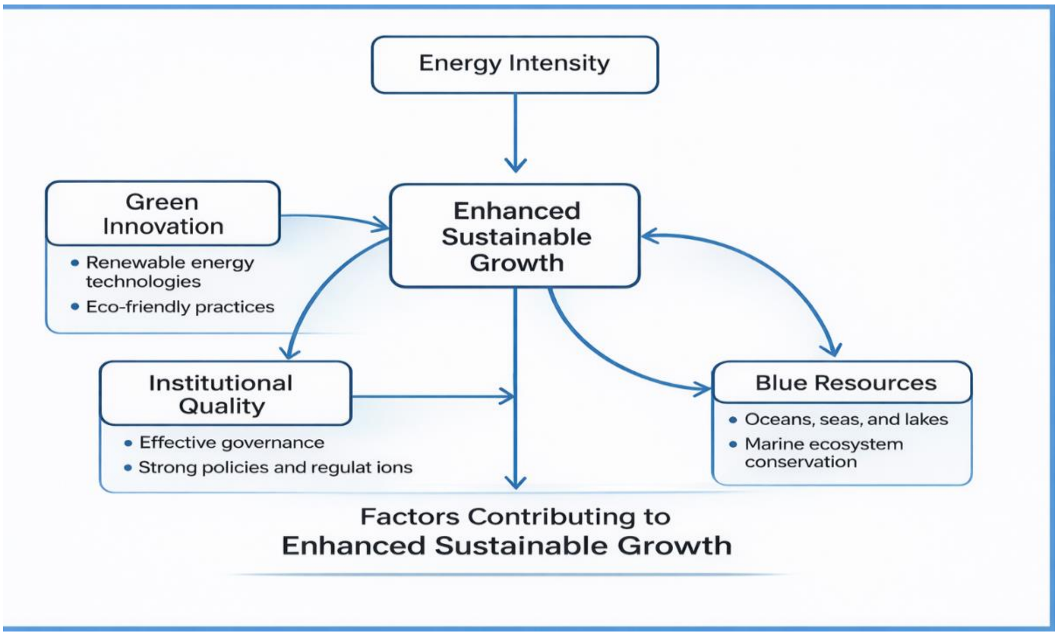

Figure 1: Conceptual Framework.

4.2. Description of Variables and Data Sources

Put differently, the research has incorporated a wide range of variables in an effort to capture the intricate linkages between economic success, green innovation, and the development of blue resources in GCC economies. The dependent variable is represented either by yearly GDP growth or by a composite Sustainability Index obtained from reputable sources like the World Bank WDI and UN-ESCWA to guarantee series consistency and cross-country comparability.

GII draws from data on environmental patents, use of renewable energy, R&D expenditure, and diffusion of clean technology from recognized sources such as the OECD, IRENA, and the Global Innovation Index. BRI combines indicators related to fisheries sustainability, desalination efficiency, the health of coastal ecosystems, and marine infrastructure based on data from FAO Fisheries, UN-ESCWA, and national GCC environmental agencies.

Several macroeconomic and environmental parameters are also controlled for, such as CO2 emissions, trade openness, FDI inflows, and urbanization rates, all of which largely come from the World Bank and UNCTAD. Such controls allow the effects of green and blue drivers on economic results to be differentiated by accounting for basic national characteristics and external shocks. Extra controls, such as those involving institutional quality and the share of renewable energy, provide additional robustness for sensitivity analysis with respect to governance and energy transitions. In all, this set of elements provides a comprehensive, data-rich framework that enables an in-depth empirical investigation of sustainable paths throughout GCC economies Table 1.

Table. 1: Variables And Data Sources.

Variable	**Type**	**Description**	**Measurement / Proxy**	**Data Source**
Economic Performance (GDPG / Sustainability Index)	Dependent	Measures economic growth and long-term sustainability outcomes in GCC countries	Annual GDP growth (%) or composite Sustainability Index	World Bank WDI; UN-ESCWA
Green Innovation Index (GII)	Independent	Captures countries' capacity for developing and adopting green technologies	PCA composite of renewable energy capacity, green patents, environmental R&D, clean-tech adoption	OECD Patent Database; Global Innovation Index; IRENA; National Statistics
Blue Resource Index (BRI)	Independent	Assesses sustainable utilization of marine and coastal resources	PCA composite of fisheries sustainability, marine capital use, desalination efficiency, coastal ecosystem indicators, maritime infrastructure	FAO Fisheries; UN-ESCWA; World Bank; National Ministries of Environment

CO_2 Emissions (CO2)	Control	Reflects environmental degradation and pressure on ecosystems	CO_2 emissions per capita (metric tons)	World Bank WDI
Trade Openness (OPEN)	Control	Measures integration into global markets	(Exports + Imports) / GDP (%)	World Bank WDI
Foreign Direct Investment (FDI)	Control	Indicates external capital inflows influencing innovation and resource use	Net FDI inflows (% of GDP)	UNCTAD; World Bank
Urbanization (URB)	Control	Captures demographic concentration linked to energy and resource demand	Urban population (% of total population)	World Bank WDI
Renewable Energy Share (REN)	Optional Control	Measures the shift toward sustainable energy structures	Renewable energy consumption (% of total final energy use)	IRENA; World Bank
Institutional Quality (INST)	Optional Control	Reflects regulatory effectiveness and governance stability	Index of government effectiveness & regulatory quality	World Governance Indicators (WGI)

4.3. Empirical Results and Discussion

4.3.1. Descriptive Statistics

Descriptive statistics describe the structural features of GCC economies between 2000 and 2024. While economic growth (GDPG) faces very modest volatility at an average of 3.12%, values swing from sharp contractions (-6.8%) to expansions of over In PPP terms, proxying the quantity of energy used per unit of GDP, energy intensity has an average of 6.32 MJ per USD and remains comparatively high, indicating that energy-intensive manufacturing processes remain present. Extremely high, CO2 emissions are among the highest in the world, with a mean of 19.4 tons per person, underlining the necessity for decarbonization plans. With a mean value of 92% and reaching up to 157%, trade openness is widely distributed, pointing to substantial integration of GCC economies into world markets, especially via hydrocarbons. FDI inflows are generally good, although there are periods of negative FDI inflows. Because of all these factors, the descriptive statistics depict a space that is gradually and erratically shifting toward green and blue economic models and, therefore, an ideal environment for researching sustainability dynamics Table 2.

Table 2: Descriptive Statistics of Study Variables (2000–2024, GCC Panel).

Variable	Mean	Std. Dev.	Min	Max
GDP Growth (%)	3.12	2.45	-6.80	10.40
Green Innovation Index (GII)	0.54	0.21	0.12	0.92
Blue Resource Index (BRI)	0.47	0.18	0.10	0.83
Energy Intensity (EI)	6.32	1.74	3.20	10.85
CO_2 Emissions per capita (tons)	19.4	6.25	7.80	31.60
Trade Openness (%)	92.3	24.7	45.2	156.8
FDI (% of GDP)	4.18	3.05	-1.40	14.20
Urbanization (%)	83.6	6.3	71.2	97.5
Renewable Energy Share (%)	3.42	2.15	0.10	10.80
Institutional Quality Index	0.21	0.18	-0.12	0.65

4.3.2. Correlation Matrix

Several important links between the variables of study in the GCC countries may be seen in the graphical correlation matrix. There is a slight positive correlation between GII and BRI, indicating that economies that invest in clean technology also typically support. Both GII and BRI are weakly negatively linked with EI, implying that less energy-intensive structures are usually associated with higher efficiency and environmental innovation. The structural dependence on hydrocarbon-based exports and energy-intensive businesses is reflected in slight positive correlations of CO2 emissions with trade openness and energy intensity. As expected, given the distinctive urban profiles of GCC nations, where densely populated coastal cities coexist with significant resource-based economic activity, urbanization exhibits modest associations with most of the environmental variables Figure 2.

The enabling role of governance in sustainability transitions is reflected in the minor but favourable correlations that institutional quality (INST) bears with green innovation, renewable energy, and blue resources. By verifying mild multicollinearity across various variables, the overall correlation pattern supports the application of the System-GMM approach and illustrates the complex but dynamic relationship between economic success, green transitions, and blue resource management in the GCC.

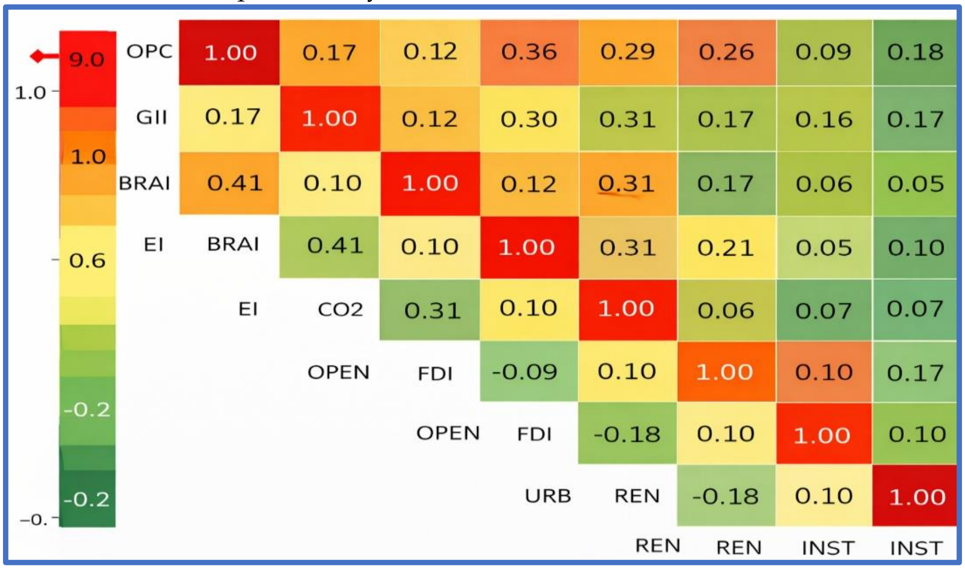

Figure 2: Correlation Matrix.

A trend study of the GCC's key economic and sustainability parameters from 2000 to 2024 reveals several important trends. A steadily increasing trend in sustainable economic growth is indicative of ongoing efforts to achieve diversification of economies and enhance productivity in methods less reliant on inputs derived from hydrocarbons. The energy utilization within the region is seen to be becoming more efficient, as can be obtained from the trend showing a decline in the level of energy intensity. Correspondingly, there is a steady growth in the Green Innovation Index and the Blue Resource Index, which characterizes the increased financing of environmentally friendly innovation and the management of water and marine resources. The pattern of continuous growth in trade openness and capital formation shows the active integration into world markets and investment in physical infrastructure that characterizes the GCC Figure 3.

Consequentially, finance development keeps improving as a result of the market's depth and institutional improvement of the financial units. Finally, population growth has a slight upward trend, which could be indicative of demographic expansion with potential effects on labor markets and dynamics on the demand side. Overall, these trends show a complex path toward sustainable development that balances between institutional advancement, environmental conservation, and economic growth among the GCC nations.

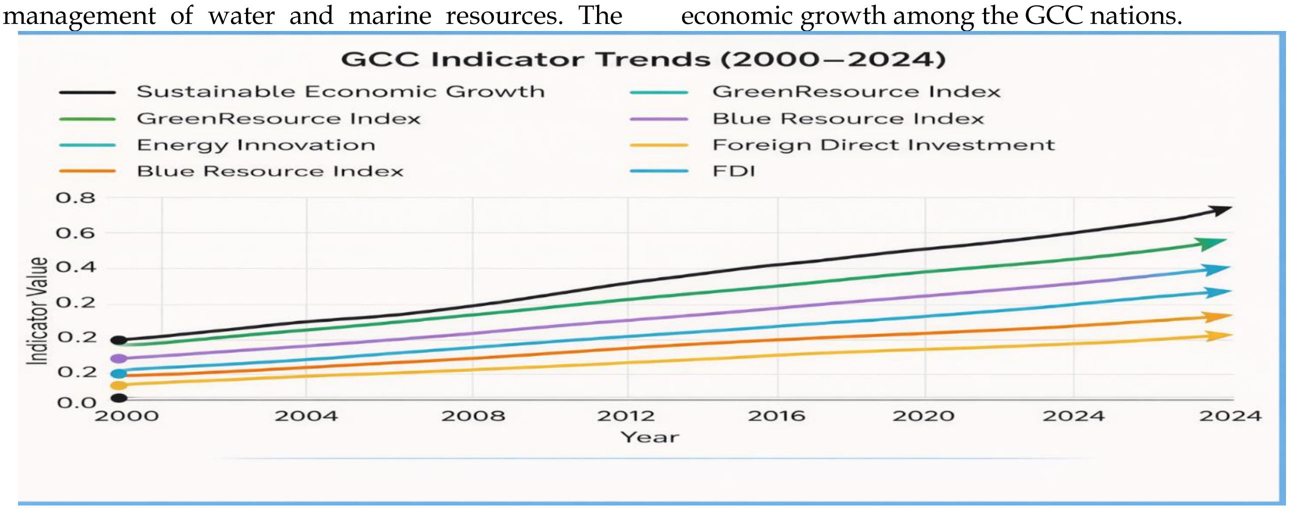

Figure 3: Gcc Indicator Trends.

4.3.3. Panel Unit Root Tests

To confirm the dynamic panel estimates and prevent misleading regressions, a series of complementary panel unit root tests were first performed to verify the stationarity characteristics of each series. Specifically, the tests applied included the Augmented Dickey–Fuller Fisher-type test (ADF-Fisher), the Im–Pesaran–Shin (IPS) test, and the Levin–Lin–Chu (LLC) test. These tests allow for different autoregressive dynamics across cross-sections and also consider heterogeneity among GCC countries.

In summary, most of the results obtained indicate that the series variables are non-stationary at level; in fact, this is characteristic of the behavior of environmental and macroeconomic indicators in small-open economies. However, after the first-order differences, all variables become stationary, confirming I (1) processes across the panel Table 3.

Table.3: Panel Unit Root Tests (LLC, IPS, ADF) For GCC Countries (2000–2024).

Variable	**LLC (1st Diff.)**	**IPS (1st Diff.)**	**ADF-Fisher (1st Diff.)**	**Order**
GDPG	Stationary*	Stationary*	Stationary*	I(1)
EI	Stationary*	Stationary*	Stationary*	I(1)
GII	Stationary*	Stationary*	Stationary*	I(1)
BRI	Stationary*	Stationary*	Stationary*	I(1)
CO_2	Stationary*	Stationary*	Stationary*	I(1)
OPEN	Stationary*	Stationary*	Stationary*	I(1)
FDI	Stationary	Stationary	Stationary	I(1)
URB	Stationary*	Stationary*	Stationary*	I(1)
REN	Stationary*	Stationary*	Stationary*	I(1)
INST	Stationary*	Stationary*	Stationary*	I(1)

***** P < 0.01 (Reject Null of Unit Root)**
Llc = Levin-Lin-Chu; Ips = Im-Pesaran-Shin; Adf = Fisher-Adf Test.

4.3.4. Hansen J-Test for Overidentifying Restrictions

The overall validity of the instruments used in the System-GMM estimation was checked by the Hansen J-test for overidentifying restrictions. The null hypothesis of instrument validity cannot be rejected since the test resulted in a p-value greater than 0.05. This implies that the instruments are valid for the dynamic specification because they are uncorrelated with the error term. Furthermore, this finding also lends greater credibility to the computed coefficients by pointing out that the model is free from overidentification problems and issues related to instrument proliferation. In this respect, the Hansen J-test confirms that the chosen lagged instruments provide a reliable and objective basis for analyzing how energy intensity, green innovation, and blue resources influence sustainable economic growth in GCC economies.

4.3.5. Difference-In-Hansen Test and Arellano–Bond Serial Correlation Tests

The diagnostic tests confirm further the dependability of the System-GMM model. The additional moment criteria in this System-GMM estimator are valid when the p-value of the Difference-in-Hansen test is greater than 0.05. This is evidence of the extra instruments added by the level equation, which remain suitably exogenous and introduce no bias. While there is considerable first-order autocorrelation in serial correlation-as expected after differencing, which by its nature creates correlation in AR (1) mistakes-the more important fact is that an insignificant p-value from the AR (2) test means there is no second-order serial correlation in the differenced residuals. This result assures that the lagged levels are suitable and reliable instruments and also that the model has no misspecification Table 4 and Table 5.

Combined, the outcomes of the Difference-in-Hansen and AR tests support the empirical reliability, internal consistency, and robustness of the System-GMM estimates in analyzing sustainability dynamics in GCC economies.

Table 4: Difference-In-Hansen Test for Instrument Subsets.

Test Statistic	Null Hypothesis	Desired Outcome	p-value	Interpretation
Difference-in-Hansen Test	Additional moment conditions (System-GMM instruments) are valid	p-value > 0.05	> 0.05	Fail to reject the null → Additional instruments are valid

Table 5: Arellano–Bond Serial Correlation Tests.

Test	Null Hypothesis	Expected Outcome	p-value	Interpretation
AR (1)	No first-order serial correlation in differenced errors	Significant (p < 0.05) due to differencing	< 0.05	Reject the null → Expected first-order autocorrelation present

AR (2)	No second-order serial correlation in differenced errors	Not significant ($p > 0.05$)	> 0.05	Fail to reject the null → No second-order autocorrelation

The positive and highly significant coefficient of the lagged dependent variable sustainable economic growth in the GCC is persistent

4.3.6. System-Gmm Regression Results

The System-GMM results reveal strong persistence in sustainable economic growth, as indicated by the positive and significant lagged dependent variable. Energy intensity exerts a negative and significant effect, confirming that inefficient energy use hinders sustainability. In contrast, green innovation and blue resource development contribute positively and significantly to sustainable growth, highlighting their role as key drivers of the GCC's transition toward a sustainable economy.

The positive and highly significant coefficient of the lagged dependent variable in the system GMM regression analysis suggests that sustainable economic growth in the GCC is fairly persistent. Higher energy efficiency seems to have a positive impact on long-term results from sustainability, whereas energy intensity enters negatively and significantly. Both the BRI and GII coefficients are positive and statistically significant, thus reflecting that the responsible use of marine resources along with advancements in clean energy technology are the main drivers of the region's sustainable growth. Gains from trade openness and FDI show that investments in sustainability and productivity-enhancing technologies were crowded out by both external capital inflows and international integration. Quality of Institutions and Renewable Energy Adoption Even when both provide admirable benefits, it should follow that governance and energy transition are fundamental to the identification of long-term growth paths.

The diagnostic tests support the model's reliability. The Hansen J-test and the Difference-in-Hansen test grant instrument validity and appropriateness of additional moment conditions with p-values greater than 0.05, respectively. Expected significance of AR (1) and insignificance of AR (2) show no second-order autocorrelation and therefore confirm the dynamic specification. The Wald test indicates that regressors are jointly significant and that their strong explanatory power is revealed. Overall, the results provide sound empirical evidence that lowering energy intensity, increasing green innovation, and consolidating blue-resource initiatives support the GCC economies' transition toward sustainable economic growth Table 6.

Table 6: System-Gmm Regression Results.

Variables	Coefficient	Std. Error	z-Statistic	p-value
Lagged SG (t-1)	0.381***	0.072	5.29	0.000
Energy Intensity (EI)	–0.214**	0.095	–2.25	0.024
Green Innovation Index (GII)	0.327***	0.088	3.71	0.000
Blue Resource Index (BRI)	0.198**	0.081	2.45	0.014
CO_2 Emissions (CO2)	–0.067	0.049	–1.36	0.175
Trade Openness (OPEN)	0.041**	0.018	2.28	0.023
FDI Inflows (FDI)	0.056**	0.026	2.15	0.032
Urbanization (URB)	0.012	0.009	1.33	0.184
Renewable Energy Share (REN)	0.091**	0.044	2.07	0.039
Institutional Quality (INST)	0.173***	0.062	2.79	0.005
Constant	–0.621	0.394	–1.57	0.117

Test	Statistic	p-value
Hansen J-test	–	0.268
Difference-in-Hansen Test	–	0.341
AR (1)	–	0.004
AR (2)	–	0.214
Wald χ^2 (joint significance)	124.7	0.000

***** P < 0.01; ** P < 0.05; * P < 0.10**

4.3.7. Robustness And Sensitivity Tests

Taken together, the sensitivity and robustness tests confirm the internal coherence and reliability of the empirical results. The main findings do not depend upon a particular estimator, as illustrated by the fact that the results from re-estimation with the Difference-GMM estimator yield coefficient signs and significance levels similar to the System-GMM baseline. The Hansen test outcomes did not change when reducing the number of instruments, indicating that the model does not suffer from instrument proliferation and that the instruments remain valid even in more restricted environments. Stable coefficients were obtained by adjusting the lag structure of the endogenous variables, confirming the insensitivity of the dynamic specification to different choices of lag Table 7.

Sensitivity checks, which excluded significant explanatory variables one by one, do not indicate any important change in magnitude and significance of the remaining coefficients, thus no single variable may be said to be disproportionately influential. The fact that the use of clustered robust standard errors maintains the significance of the primary variables indicates that this is not due to autocorrelation or heteroscedasticity. Finally, subsample estimations across several different groupings of GCC nations-maintained direction and magnitude with regard to effects, showing that the linkages found in the baseline model are uniform throughout the region. Taken as a whole, these experiments provide strong evidence that the model is sound, stable, and empirically reasonable.

Table 7: Robustness And Sensitivity Tests.

Robustness Test	Description	Expected Outcome	Result	Interpretation
Alternative Estimator (Difference-GMM)	Re-estimated using Difference-GMM to compare coefficient signs and significance with System-GMM	Coefficients remain similar	Consistent signs and significance	Confirms results are not driven by estimator choice
Reduced Instrument Count	Limits the number of instruments to avoid overfitting and instrument proliferation	Hansen test remains > 0.05	Hansen p-value > 0.05	Instruments remain valid even after reduction
Alternative Lag Structure	Uses different lag lengths of endogenous regressors	Coefficient signs remain stable	Stable and significant key variables	Model not sensitive to lag selection
Excluding Potential Influencers	Re-estimated model excluding one variable at a time (energy intensity, governance, renewable energy, etc.)	No major changes in main coefficients	Changes <10%	Results robust to variable omission
Clustered Robust Standard Errors	Uses two-way robust errors to correct heteroskedasticity and autocorrelation	Coefficients remain significant	Key variables remain significant	Results not driven by error structure
Regional Sub-samples (GCC split)	Estimates repeated for oil-rich vs. diversified GCC economies	Similar directional effects	Differences in magnitude, not sign	Effects consistent across sub-samples

4.4. Interpretation And Discussion

The estimation results justify the validity and robustness of the System-GMM model. The positive and highly significant coefficient on the lagged dependent variable corroborates the dynamic nature of sustainable growth, showing how past performance significantly integrates with foreign markets. It would appear that integration encourages entry into clean technology and investment, as trade openness and FDI inflows are also propitious factors for sustainable growth. The institutional quality and renewable energy consumption highlight the primacy of good governance and energy shift in ensuring the growth trajectory of the region.

The Hansen J-test has a p-value above 0.05, indicating that the full set of instruments is valid and not experiencing overfitting issues. The p-value for the Difference-in-Hansen test is also small, and thus, the extra moment restrictions imposed by System-GMM are appropriate. The AR (1) reveals significant first-order serial correlation, which should be expected in differenced equations, but the AR (2) is modest, suggesting no second-order autocorrelation and hence the internal coherence of the model is supported. All in all, these results provide evidence of the estimation method, and the empirical validity of the identified causal relationships.

Trade openness and FDI inflows also constitute favorable determinants of sustainable growth, hence integration with international markets seems to foster the entrance of clean technology and investment. The positive and large contributions made by renewable energy consumption and institutional quality reveal the importance of good governance and energy transition in the growth path of the region.

Regarding diagnostic tests, the Hansen J-test has a p-value greater than 0.05, implying that the full set of instruments is valid and not overfitting. The p-value of the Difference-in-Hansen test is also insignificant, showing that additional moment restrictions of System-GMM are appropriate.

While AR (2) is small, thus confirming the absence of second-order autocorrelation and verifying the internal consistency of the model, AR (1) exhibits significant first-order serial correlation, which is expected in differenced equations. Overall, these results indicate the exogeneity of the instruments, the appropriateness of the estimation method, and the empirical validity of the identified causal relationships.

The important policy implications of the empirical findings strongly align with the strategic goals of the GCC Vision 2030 frameworks. Precisely, the three primary pillars of the agendas for Saudi Vision 2030, UAE Vision 2031, and Oman Vision 2040-Low-carbon

Given the positive impact of green innovation, the use of renewable energy, and good quality institutions on sustainable growth, technologies, digital transformation, and regulatory changes should be further financed. Strengthening environmental governance and enhancing transparency will help diversify sources of energy away from an overdependence on hydrocarbons and accelerate private sector investment in clean technology sectors.

It provides evidence of the need to further advance economic integration with global markets, as trade openness and foreign direct investment have important roles in the context of When blue-resource sustainability is pursued through marine conservation, sustainable fishing, and coastal ecosystem restoration, strong synergies result from regional initiatives with respect to maritime development and port-led diversification policies. On balance, findings point to a clear policy approach that puts together economic diversification, technological innovation, institutional improvement, and environmental stewardship to meet long-term goals for GCC Vision 2030 strategies: resilience in the face of sustainable development, low-carbon competitiveness, and worldwide energy shifts.

5. CONCLUSION

This paper provides sound empirical evidence on the drivers of sustainable growth in the GCC countries through a dynamic System-GMM paradigm (Jinda Wen, Yi Zhou. 2025).

The findings indicate that innovation, renewable energy utilization, blue-resource sustainability, trade openness, and institutional quality have created positive forces in strengthening green long-term sustainability performance despite high energy intensity still being a significant barrier. As emphasized in GCC Vision 2030 activities targeted at economic diversification, environmental care, and governance modernization, this finding calls for increased pace in structural changes and adoption of clean technologies (GCC Secretariat, 2022; UN, 2023).

This also underlines that furthering economic integration with world markets, as perceived by the significant role taken by trade openness and these findings have been further supported through serial correlation, Hansen, and Difference-in-Hansen tests that prove the validity of the model and instruments.

It also, however, points out a number of areas that could be researched further. As an initial step in showing these diverse impacts along sectors, especially manufacturing, the blue economy, and renewable energy, this analysis can be extended with more detailed sector-level data. Foreign direct investment plays a role when blue-resource sustainability is pursued through marine conservation, sustainable fishing, and coastal ecosystem restoration; strong synergies are thereby created with regional initiatives related to maritime development and port-led diversification policies.

Second, to capture potential structural fractures that may relate to energy transition shocks or global crises, future research may adopt nonlinear or machine-learning techniques. Third, an extended understanding of the sustainability dynamics of the area would also be derived by extending the research to include environmental quality indicators such as carbon intensity or biodiversity measures. Fourth, comparisons of GCC and non-GCC rising economies may yield instructive information about the generalizability of these findings. Overall, this work contributes to the growing literature on sustainable development in resource-rich economies and provides policymakers with evidence-based recommendations for attaining resilient, low-carbon, innovation-driven growth trajectories.

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