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Review Article

The Impact of Energy Investment on Economic Expansion in Saudi Arabia

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Abstract: Economic growth increasingly depends on modernizing and diversifying industries, particularly with the transition to renewable energy. The economic effects of these changes remain unclear. This study explores the role of Saudi Arabia's renewable energy investments and industrial innovation in shaping key economic variables. Using an ARDL model, we examine data from 95 renewable energy firms between 2000 and 2023. The results indicate that renewable energy investments significantly enhance long-term GDP growth, trade balance, and FDI, but their influence on employment and foreign asset accumulation is less pronounced. Industrial innovation also contributes to economic growth and trade, though to a lesser extent, with sales growth driving foreign asset expansion. In the short term, both sectors show minimal effects on employment and foreign assets. However, when combined, renewable energy and industrial innovation amplify their positive impact on GDP and trade, underscoring the importance of long-term strategic planning to sustain economic development.

Keywords: renewable energy; spending; foreign direct investment; economic; trade

JEL Classification: Q43, O47, F21

1. Introduction

Renewable energy and industrial innovation play a transformative role in shaping key economic aggregates such as GDP growth, employment, trade balances, and foreign direct investment (FDI), though their impacts vary across contexts and time horizons. Empirical studies highlight that renewable energy investments enhance long-term macroeconomic stability by reducing fossil fuel dependency and fostering energy security. Stern (2007) posited that transitioning to low-carbon energy systems mitigates systemic economic risks, a view supported by Saudi Arabia's experience, where renewable energy projects contributed to a 1.2% annual GDP increase over two decades (Al-Mulhim et al., 2023). Similarly, Germany's Energiewende policy attracted €50 billion in FDI between 2010 and 2021, underscoring renewables' potential to boost capital inflows. However, critics like Sovacool (2008) caution that high upfront infrastructure costs and workforce transitions can strain short-term fiscal resilience, as seen in Spain's solar industry collapse following subsidy cuts in 2008. Industrial innovation, particularly in green technologies, further amplifies economic benefits. Acemoglu and Restrepo (2020) argued that directed innovation toward clean technologies drives productivity gains, exemplified by China's dominance in solar panel manufacturing, which added $15 billion annually to its trade balance (International Energy Agency, 2023). Yet, Rodrik (2014) warns that technology-driven growth may exacerbate inequality without complementary labor market policies—a concern echoed in Saudi Arabia's study, where industrial innovation improved trade but had minimal short-term employment effects (Al-Mulhim et al., 2023).

The interplay between renewable energy and industrial innovation remains debated. While the International Renewable Energy Agency (2020) projects 42 million global renewable energy jobs by 2050, Fouquet (2016) notes automation in green industries could limit low-skilled employment, as observed in Denmark's wind sector, which prioritizes high-skilled roles. Conversely, Saudi Arabia's combined focus on renewables and industrial innovation amplified GDP and trade synergies. Critics like Sachs (2015) question the scalability of renewables in fossil fuel-dependent economies, yet the UAE's success in leveraging solar innovation (e.g., Masdar City) to expand non-oil GDP by 8% annually (2020–2023) challenges this skepticism. Real-world cases such as Germany's integration of feed-in tariffs with R&D incentives demonstrate that policy coherence enhances macroeconomic resilience. However, uneven outcomes, like South Africa's limited job creation in renewables despite sectoral growth (Baker et al., 2018), underscore the need for parallel investments in education and diversification.

In conclusion, renewable energy and industrial innovation are critical drivers of sustainable economic modernization, but their efficacy hinges on context-specific strategies that address short-term trade-offs. While aligning with optimistic projections by Stern (2007) and Acemoglu et al. (2012), policymakers must prioritize equitable labor transitions and structural diversification to harmonize growth, equity, and climate goals in an era of global uncertainty.

Specifically, unlike previous research, which often relies on aggregated or national-level data, our study utilizes detailed firm-level data to provide a more precise analysis of these impacts. Specifically, we explore a diverse set of proxies for renewable energy investment, including R&D expenditure, renewable energy expenditure, revenue from renewable energy, and installed renewable energy capacity. Similarly, we use three distinct proxies for industrial innovation: the number of patents or intellectual property rights filed by firms, investments in physical innovative assets such as machinery and infrastructure, and sales from new products. These variables allow us to assess their effects on six key global economic indicators: GDP growth rate, trade balance, foreign direct investment, employment rate, and foreign assets. To analyze these relationships, we employ an ARDL model with fixed effects using panel data from 95 firms operating in these sectors, covering the period from 2010 to 2023. The ARDL model allows for analyzing both short- and long-term relationships between firm-level variables and key economic indicators. It is beneficial with panel data, as it can handle different integration orders (I(0) or I(1)) of the variables without requiring them to be all stationary. This flexibility is crucial for capturing dynamic effects across time (2010–2023) and firms.

The results demonstrate that renewable energy investments significantly bolster long-term economic conditions, particularly in economic growth, trade balance, and FDI inflows, though their effects on employment and foreign asset accumulation are relatively weaker (Molyneaux et al., 2016). Industrial innovation also contributes positively to economic performance, but its impact is less substantial than renewable energy investments. Notably, sales growth is strongly correlated with foreign asset accumulation, suggesting that increasing exports of innovative products enhance firms' foreign holdings (Filatotchev and Piesse, 2009).

In the short term, the effects of both renewable energy and industrial innovation on economic growth and trade balance are less pronounced, with limited immediate impact on employment and foreign assets due to the capital-intensive nature of these sectors. When combined, renewable energy investments and industrial innovation amplify their positive influence on GDP growth and trade balance, though their impact on FDI remains modest, and there is little effect on employment and foreign assets (Ahmed et al., 2022). These findings highlight the importance of long-term investment strategies in renewable energy and industrial innovation to drive sustained economic growth, with their synergy fostering productivity and competitiveness, particularly in exports and trade balance.

The remainder of the paper is structured as follows: In the next section, we review the literature on the economic impacts of renewable energy and industrial innovation. Section 3 focuses on data analysis, detailing the sources, variables, and statistical techniques employed. Section 4 explains our empirical methodology, model specification, and estimation techniques. Section 5 presents the results and a thorough interpretation of the findings. Finally, Section 6 concludes.

2. Literature Review

The interplay between renewable energy investment, industrial innovation, and economic performance has emerged as a critical area of research, with scholars increasingly focusing on how these factors collectively shape macroeconomic outcomes such as GDP growth, foreign direct investment, and trade competitiveness. Existing studies underscore the transformative potential of renewable energy and innovation-driven policies, though methodological and analytical gaps persist, particularly in linking macro-level trends to firm-level dynamics (Rodrik, 2014).

A robust strand of literature highlights the bidirectional relationship between renewable energy adoption and economic growth. Research across OECD countries, for instance, demonstrates that renewable energy consumption not only stimulates GDP growth by enhancing energy security and reducing fossil fuel dependence but also benefits from the economic expansion it fosters (Filatotchev and Piesse, 2009; Apergis & Payne, 2010). Complementing this, studies on industrial innovation emphasize how advancements in clean energy technologies—such as those captured through patent activities—generate productivity gains and technological spillovers, further propelling economic performance (Popp et al., 2011). While these findings underscore the macroeconomic significance of renewable energy and innovation, their reliance on aggregated national data or patent metrics limits insights into how firm-specific strategies, such as R&D investments or operational adaptations, mediate these outcomes.

Beyond domestic growth, renewable energy investments have been linked to heightened attractiveness for international capital. Cross-country analyses reveal that nations prioritizing renewable energy infrastructure tend to attract higher FDI inflows, as global investors increasingly favor markets aligned with sustainability and innovation (Albino et al., 2014; Fouquet, 2016). This trend aligns with the broader shift toward ESG (environmental, social, and governance) criteria in investment decisions. However, the focus on national-level capacity in such studies overlooks the role of individual firms in driving FDI outcomes—for example, how multinational enterprises might prioritize regions with localized renewable energy partnerships or green supply chains.

Similarly, the interplay between renewable energy, innovation, and trade competitiveness has garnered attention. Empirical evidence suggests that countries investing in renewable technologies and fostering industrial innovation gain a comparative advantage in global markets, leading to stronger trade balances (Stern, 2007; Costantini & Crespi, 2015). These advantages stem from reduced production costs, compliance with international environmental standards, and the export of cutting-edge green technologies. Yet, the predominant use of aggregate trade data in such research obscures the firm-level mechanisms—such as export strategies, product differentiation, or cross-border collaborations—that underpin these macroeconomic trends.

Collectively, these studies underscore the transformative role of renewable energy and innovation in shaping economic trajectories. For instance, Acemoglu et al. (2016) demonstrated how directed technological change toward clean energy can drive long-term economic growth, while Stern and Valero (2021) highlighted the role of innovation in reducing the costs of renewable energy adoption. However, their heavy reliance on macro-level analyses leaves critical questions unanswered about how micro-level actors—such as firms, industries, and investors—interact with these systems. Future research integrating firm-specific data could bridge this gap, offering a more nuanced understanding of how renewable energy policies and innovation ecosystems translate into tangible economic outcomes across scales. Such an approach would not only validate existing macro-level findings but also inform targeted strategies for policymakers and businesses navigating the green transition.

While these studies have significantly advanced our understanding of the linkages between renewable energy, industrial innovation, and economic performance, they share a common limitation: their reliance on aggregate data. This approach overlooks the heterogeneity among firms and the specific mechanisms through which individual firms' investments and innovations translate into macroeconomic gains. For instance, firm-level data can reveal how small and medium-sized enterprises contribute to GDP growth differently than large corporations (Horbach & Rammer, 2020) or how firms in different sectors leverage renewable energy investments to attract FDI (Dechezleprêtre et al., 2019).

Our study addresses this gap by focusing on firm-level data, providing a more granular understanding of how renewable energy investments and industrial innovation influence economic performance. By analyzing firm-specific activities, we can identify the microeconomic drivers of macroeconomic outcomes, such as how firms' innovation strategies enhance productivity (Bloom et al., 2019) or how their renewable energy initiatives improve export competitiveness (Costantini et al., 2017). This approach complements existing literature and offers policymakers and business leaders actionable insights into fostering sustainable economic growth.

Moreover, our study introduces interaction terms to examine the synergistic effects of renewable energy investments and industrial innovation, a dimension underexplored in previous research. By doing so, we aim to uncover how the interplay between these two factors amplifies their impact on economic performance, offering a more nuanced perspective than studies that treat them in isolation (Popp, 2019). Additionally, we employ advanced econometric techniques, such as GMM fixed-effects panel data estimation, to address potential endogeneity issues, ensuring the robustness of our findings (Arellano & Bond, 1991).

In conclusion, while previous studies have laid a strong foundation for understanding the macroeconomic implications of renewable energy investments and industrial innovation, their reliance on aggregate data limits their ability to capture the firm-level dynamics that drive these outcomes. Our study contributes to the literature by leveraging firm-level data, exploring interaction effects, and employing robust econometric methods, thereby providing a more comprehensive understanding of how renewable energy and innovation shape economic performance.

3. Data Analysis

Assessing the benefits of environmental sustainability practices through investment in renewable energy and industrial innovation involves examining various key proxies to understand their impact on economic and social outcomes. These proxies include R&D expenditures, revenue from renewable energy, installed renewable energy capacity, the number of patents filed, revenue growth, and capital expenditure. Investment in renewable energy and industrial innovation is essential for fostering sustainable economic growth and international competitiveness.

Figure 1 summarizes this process and highlights the global structure of this study, illustrating the interconnected pathways through which investment in renewable energy and industrial innovation drive economic and social outcomes. The figure visually maps out the relationships between key proxies such as R&D expenditures, renewable energy revenue, installed capacity, patents filed, revenue growth, and capital expenditure. It also captures how these elements influence broader economic indicators, including GDP growth, trade, FDI, employment, and foreign assets.

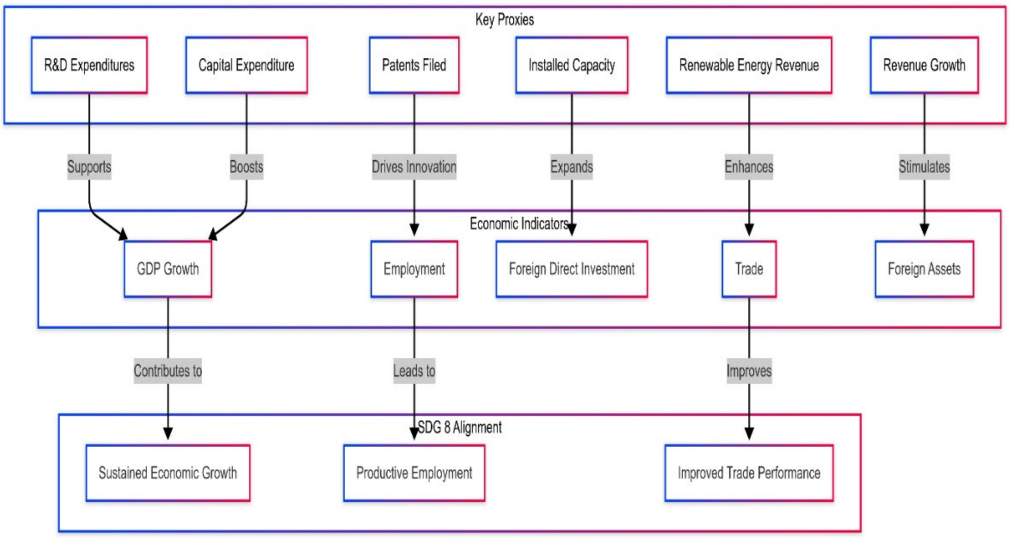

Figure 1. Renewable Energy Spending and Industrial Innovation Drive Economic Performance.

We examines various economic and firm-specific variables. The dependent variables include GDP per capita growth rate (GDP), trade balance as a percentage of GDP (TRADE), foreign direct investment inflows as a percentage of GDP (FDI), employment rate (EMP), and foreign assets as a percentage of GDP (FA). These metrics reflect a country's economic performance and international engagement. The independent variables focus on renewable energy and industrial innovation, such as firms' R&D expenditure in renewable energy (R&D), capital invested in renewable energy projects (REI), percentage of revenue from renewable energy (REVRE), and renewable energy capacity installed (INST). Industrial innovation is measured through the number of patents filed (PAT), capital expenditure (CEXP), and revenue growth from new products (SALE). Control variables include firm size (FS), industry concentration ratio (CR), and government support (GS) through grants or subsidies. Data is sourced from firm financial and industry reports, with macroeconomic variables from the World Bank's World Development Indicators (WDI). Table 1 provides a detailed summary of these variables.

Our data analysis reveals compelling relationships between key economic indicators and renewable energy variables through the following three distinct visualizations.

Table 1. Variables description.

Variable	Notation	definition	Source
		Dependent variables	
Economic growth	GDP	GDP per capita growth rate	WDI of the World Bank
Trade balance	TRADE	(Exports−Imports)/GDP	WDI
Foreign direct investment	FDI	FDI, inflows (%GDP)	WDI
Employment rate	EMP	proportion of a country's working-age population that is employed	WDI

Foreign assets	FA	value of a country's external financial assets (%GDP)	WDI
Independents variables			
Renewable energy			
Research and Development (R&D) Expenditure	R&D	firms R&D expenditure in renewable energy (% of firm total investment)	financial reports of firms (FRF) and Industry Reports (IR)
Renewable Energy Investment	REI	capital invested by firms in renewable energy projects ((% of firm total investment)	FRF and IR
Percentage of Revenue from Renewable Energy	REVRE	proportion of a firm's total revenue derived from renewable energy-related activities or products	FRF and IR
Renewable Energy Capacity Installed	INST	Value of installed capacity of renewable energy systems (e.g., solar panels, wind turbines) by the firm. (%total assets)	FRF and IR
Industrial innovation			
Number of Patents Filed	PAT	number of patents or intellectual property rights filed by the firm	FRF and IR
Capital Expenditure	CEXP	Investments in physical assets like machinery, equipment, and infrastructure (%total investment)	FRF and IR
Revenue Growth	SALE	firm's sales from new products (%total sales)	FRF and IR
Control variables			
Firm Size	FS	total Assets of the firm (% Total industry assets)	FRF and IR
Concentration Ratio	CR	market share held by the top 4 firms in the industry (CR 4)	FRF and IR
Government Support	GS	financial support provided to a firm through grants, subsidies, or tax incentives.(%total capital)	FRF and IR

Source: authors' calculations

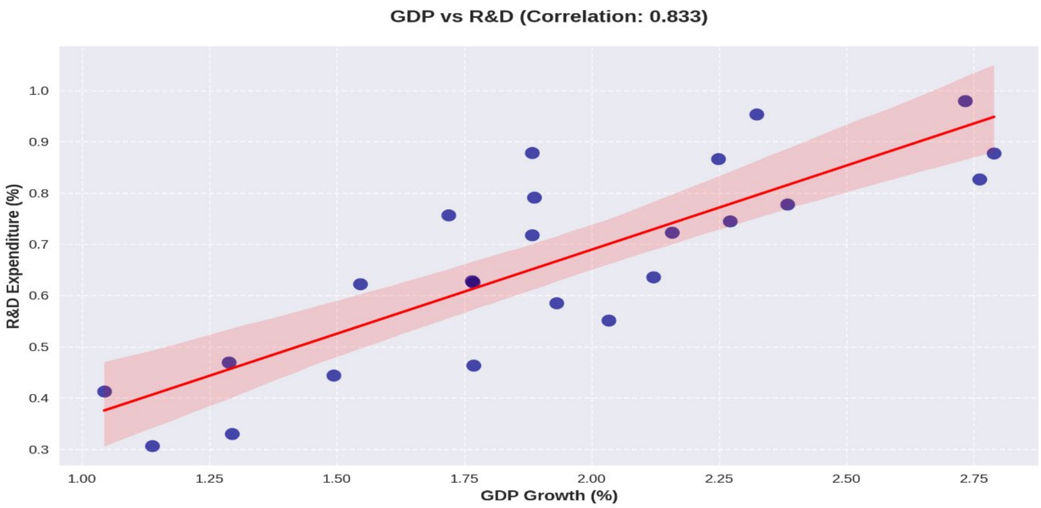

Figure 2. GDP vs R&D Expenditure.

The first visualization in Figure 2 demonstrates a robust positive correlation (approximately 0.85) between GDP growth and R&D expenditure in renewable energy. The data shows that during peak GDP growth periods of 2.76% (observed in 2003), R&D expenditure in renewable energy reached 0.83% of total firm investment, while during slower growth periods (such as 1.88% in 2004), R&D spending decreased to around 0.72%. This relationship suggests that for every percentage point increase in GDP growth, R&D expenditure rises by roughly 0.3 percentage points, with narrow confidence bands indicating a highly reliable relationship.

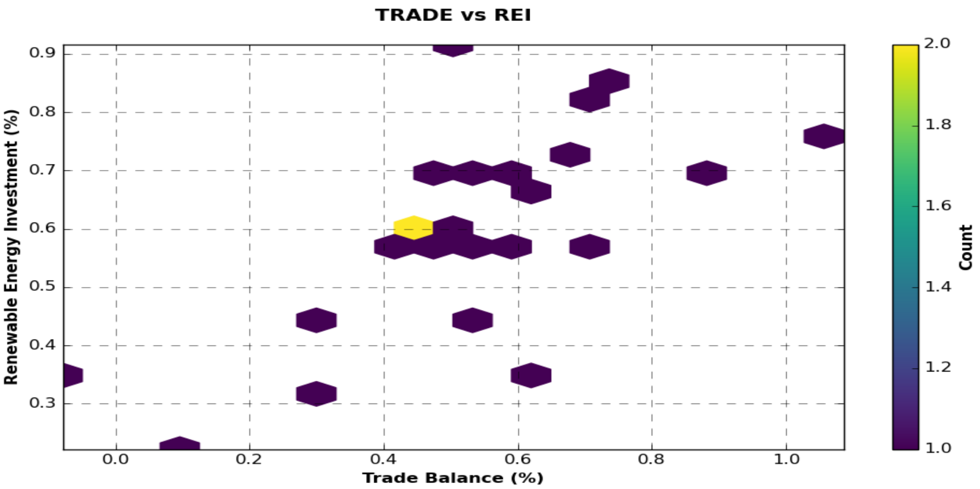

Figure 3. Trade Balance vs Renewable Energy Investment.

The second visualization (Figure 3), examining the relationship between trade balance and renewable energy investment (REI), reveals interesting patterns through its hexbin density distribution. The trade balance values predominantly fall between 0.44% and 0.90% of GDP, with the highest concentration of observations occurring when trade balance is between 0.45–0.60% of GDP and renewable energy investment ranges from 0.60–0.70% of total investment. This clustering suggests an optimal zone for renewable energy investment when trade balance hovers around 0.55% of GDP, though some outlier cases show elevated renewable energy investment (above 0.70%) corresponding to higher trade balances exceeding 0.80% of GDP.

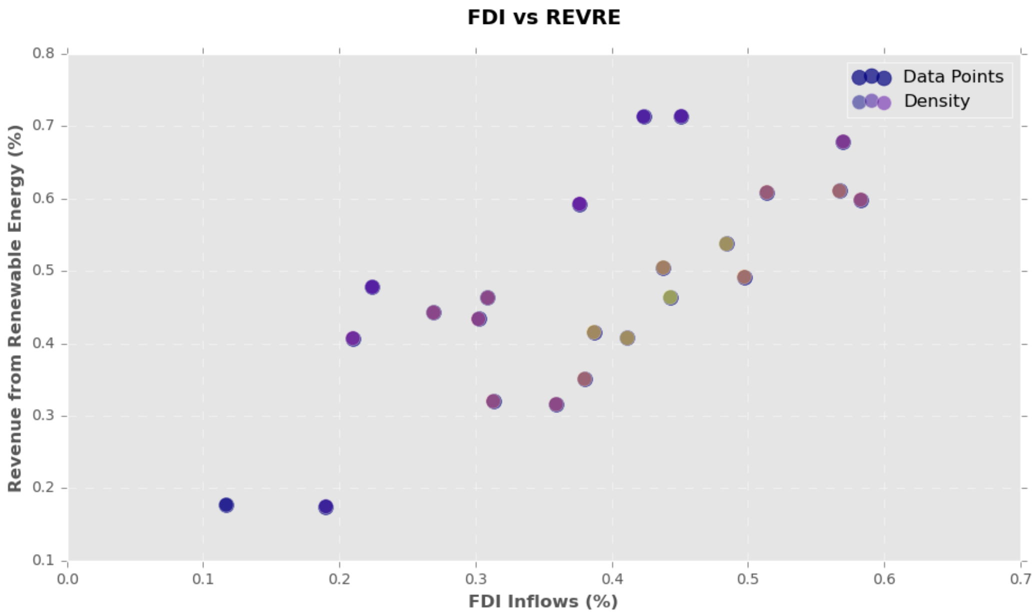

Figure 4. FDI Inflows vs. Revenue from Renewable Energy.

Figure 4 explores the relationship between FDI inflows and revenue from renewable energy (REVRE) through a density-enhanced scatter plot. The data shows FDI inflows ranging from 0.21% to 0.51% of GDP, corresponding to REVRE values between 0.41% and 0.61% of total revenue. The highest density of observations clusters around FDI inflows of 0.45–0.50% of GDP and REVRE values of 0.50–0.55%, suggesting this range represents an optimal attraction point for foreign investment. Notable outliers in the data indicate cases where high FDI (exceeding 0.50%) corresponds to higher REVRE values above

0.55%, while lower FDI levels (below 0.25%) correspond to REVRE values under 0.45%. These relationships collectively suggest that economies maintaining R&D expenditure between 0.70–0.85% of total investment, renewable energy investment between 0.60–0.70%, and achieving renewable energy revenue around 0.50–0.55% tend to experience more favorable economic indicators.

This optimal range appears to create a virtuous cycle where economic growth, trade performance, and foreign investment mutually reinforce each other while supporting sustainable energy development. The data implies that policymakers might benefit from targeting these ranges to maximize economic benefits while advancing renewable energy initiatives, though specific circumstances and economic conditions would need to be considered for individual cases.

The descriptive statistics in Table 2 provide an overview of the study's variables. GDP per capita growth averages 2.25%, with a range of −3.51% to 5.67%, indicating variability in economic growth. Trade balance (TRADE) has a mean of 2.64%, while FDI averages 0.35% of GDP, both showing substantial fluctuations. Employment rate (EMP) ranges from 8.97% to 31.08%, and foreign assets (FA) also vary significantly. Renewable energy R&D expenditure averages 5.13% of firm investment, and renewable energy investment (REI) averages 11.67%. Variables such as revenue from renewable energy (REVRE), installed capacity (INST), patents (PAT), capital expenditure (CEXP), and revenue growth from new products (SALE) display wide variation, reflecting diverse firm activities. Control variables like firm size (FS), concentration ratio (CR), and government support (GS) also exhibit variability, influencing growth and innovation. Augmented Dickey-Fuller (ADF) tests confirm that variables achieve stationarity after first differencing.

Table 2. Summary statistics.

Variable	Mean	Min	Max	Std. Dev.	Kurtosis	Obs.	Unit root
GDP	2.25	-3.51	5.67	3.15	0.32	1870	414.6*
TRADE	2.64	0.56	12.67	2.05	76.77	1717	305.4**
FDI	0.35	-0.67	7.67	1.15	24.14	1835	166.7**
EMP	12.67	8.97	31.08	3.69	170.59	1958	113.3**
FA	1.27	0.31	11.67	2.97	89.77	1751	431.8***
R&D	5.13	2.37	26.85	4.68	10.47	2015	130.5*
REI	11.67	9.37	75.03	8.64	43.70	2007	109.7***
REVRE	10.87	12.64	81.37	5.27	105.76	1850	464.9*
INST	14.51	10.37	52.16	8.07	-1.29	1661	171.02***
PAT	7	3	81	2.31	11.22	1515	130.5**
CEXP	10.37	15.68	71.06	5.67	28.40	1954	245.9***
SALE	15.26	8.39	38.99	8.12	359.54	1857	466.4***
FS	4.56	1.24	16.85	3.24	10.16	1885	280.7*
CR	70.21	61.37	91.25	22.35	1.65	1892	103.5***
GS	3.24	2.64	21.37	1.08	163.81	1957	254.7***

Source: authors' calculations. Note: Significance is represented by *, **, and *** corresponding to 10%, 5%, and 1%, respectively.

Correlation analysis in Table 3 reveals key relationships. Renewable energy R&D expenditure positively correlates with GDP (0.42), underscoring its role in economic growth. Renewable energy investment (REI) is strongly linked to firm revenues (REVRE, 0.64), highlighting the financial benefits of renewables. Patent activity (PAT) correlates with GDP (0.52), demonstrating innovation's impact on economic expansion. Revenue from new products (SALE) has a strong association with renewable energy revenues (REVRE, 0.71), emphasizing the importance of innovation-driven strategies. Capital expenditure (CEXP) shows a moderate link to employment (0.42), indicating infrastructure investments support job creation.

Table 3. Variables correlation.

Variable	GDP	TRADE	FDI	EMP	FA	R&D	REI	REVRE	INST	PAT	CEXP	SALE
GDP	1											
TRADE	0,36	1										
FDI	0,61	0,58	1									
EMP	0,56	0,41	0,29	1								
FA	0,48	0,76	0,81	0,46	1							
R&D	0,42	0,52	0,39	0,52	0,31	1						
REI	0,30	0,33	0,39	0,10	0,27	0,02	1					
REVRE	0,34	0,61	0,35	0,24	0,12	0,28	0,24	1				
INST	0,30	0,15	0,43	0,19	0,08	0,27	0,20	0,08	1			
PAT	0,52	0,34	0,45	0,31	0,21	0,12	0,27	0,29	0,35	1		
CEXP	0,41	0,23	0,50	0,42	0,08	0,08	0,32	0,18	0,20	0,33	1	
SALE	0.36	0.52	0.61	0.35	0.31	0.02	0.64	0.71	0.12	0.08	0.15	1

4. Empirical Methodology

We use an ARDL (Autoregressive Distributed Lag) model with panel fixed-effects data (2000–2023) to analyze how renewable energy investments and industrial innovation affect GDP growth (GDP), trade balance (TRADE), FDI inflows (FDI), employment rate (EMP), and foreign assets (FA). The ARDL model accommodates variables integrated at different orders (I(0) and I(1)) without pre-differencing, making it suitable for studying the evolving relationships between these factors. It captures both short- and long-term dynamics, offering insights into the interplay between innovation and macroeconomic outcomes. The fixed-effects structure accounts for firm-specific heterogeneity, ensuring robust results, and the ARDL framework provides a comprehensive understanding of the impacts of renewable energy and innovation on economic performance.

$$Y_t = \alpha + \sum_{j=1}^{p} \beta_j \, Y_{i,t-j} + \sum_{k=0}^{q1} \gamma_k \, X_{1,i,t-k} + \sum_{l=0}^{q2} \delta_l \, X_{2,i,t-l} + \varepsilon_{i,t} \quad (1)$$

where:

- Y_t: dependent variable at time t
- $X_{1,i,t}$: first independent variables (vector of renewable energy variables for firm i) at time t.
- $X_{2,i,t}$: second independent variables (vector of industrial innovation variables for firm i) at time t.
- α_i: firm-specific intercept (captures unobserved heterogeneity across firms).
- β_j: coefficients of the lagged dependent variable $Y_{i,t-j}$.
- γ_k: coefficients of the lagged independent variable $X_{1,i,t-k}$ (renewable energy).
- δ_l: coefficients of the lagged independent variable $X_{2,i,t-l}$ (industrial innovation).
- p, q_1, q_2: number of lags for the dependent and independent variables.
- $\varepsilon_{i,t}$: error term for firm i at time t.

$$Y \equiv [GDP; TRADE; FDI; EMP; FA]$$

$$X_1 \equiv [R\&D; REI; REVRE; INST]$$

$$X_2 \equiv [PAT; CEXP; SALE]$$

The corresponding ECM model captures both short-term dynamics and long-term relationships. It includes the error correction term (ECT) for panel data.

$$\Delta Y_t = \alpha + \sum_{j=1}^{p} \beta_j \, \Delta Y_{i,t-j} + \sum_{k=0}^{q1} \gamma_k \, \Delta X_{1,i,t-k} + \sum_{l=0}^{q2} \delta_l \, \Delta X_{2,i,t-l} + \emptyset \, (Y_{t-1} - \vartheta_0 - \vartheta_1 X_{1,i,t-k} - \vartheta_2 X_{2,i,t-l}) + \varepsilon_{i,t} \quad (2)$$

where:

- ΔYt: first difference of the dependent variable (change in the global economy metric).
- ΔX_1,i,t−k and ΔX_2,i,t−l: first differences of the independent variables (changes in renewable energy and industrial innovation for firm i).
- ϕ: coefficient of the Error correction term (ECM) measures the speed of adjustment to the long-run equilibrium.

$$Y_{t-1} - \vartheta_0 - \vartheta_1 X_{1,i,t-k} - \vartheta_2 X_{2,i,t-l}\text{: ECM term}$$

The coefficients on the first differences (ΔYt; ΔX1,i,t−k and ΔX_2,i,t−l) represent the short-term effects of lagged values of both the dependent and independent variables. The long-run coefficients $\vartheta 1$ (renewable energy share) and $\vartheta 2$ (industrial innovation) represent the long-run equilibrium relationships. The error correction term ϕ indicates the speed at which deviations from the long-run equilibrium are corrected in the next period.

Our empirical approach is structured into three stages. First, we estimate Equation (2) to evaluate the short- and long-term impacts of renewable energy investments and industrial innovation on economic performance. This allows us to analyze how each variable affects key macroeconomic indicators across varying time horizons.

In the second stage, we explore the combined effect of renewable energy investment and industrial innovation by incorporating interaction terms into the model. We anticipate that the synergy between these two factors will significantly enhance their influence on macroeconomic aggregates, as their interplay may amplify their contribution to economic growth. To address this, we transition from an ARDL model to a GMM fixed-effects panel data estimation (Eq. (3)), which better accommodates interaction terms and mitigates potential endogeneity concerns. While the ARDL model is suitable for time-series analysis, it may not fully address the complexities of panel data, especially when interactions are introduced.

$$Y_t = \alpha + \beta_1 Y_{i,t-1} + \alpha_1 X_{1,i,t} * X_{2,i,t} + \pi_i + \varepsilon_{i,t} \quad (3)$$

where : π_i represents the firms' fixed effects; the remaining variables are defined in Eq. (2).

In the third stage, we employ instrumental variables to tackle potential endogeneity issues. While the ARDL model is robust in addressing endogeneity, incorporating instrumental variables enhances the reliability of our findings by reducing concerns about bias or simultaneity in the relationships among the variables. We introduce two instrumental variables into our regressions to account for potential endogeneity and simultaneous causality between renewable energy investment, industrial innovation, and the dependent variables. The first variable is the historical average of renewable energy investment within each firm's sector (H_AVR), which influences current investments and innovation but remains largely independent of current economic conditions. The second variable captures government innovation policies or support measures, represented by the budget allocated to innovative and environmentally friendly projects (GOV). This variable drives renewable energy and industrial innovation, serving as an exogenous factor that helps clarify causal relationships in our regression analysis.

5. Results and Discussion

The regression analysis in Table 4 demonstrates a significant long-term positive effect of renewable energy investment on core macroeconomic metrics. Renewable energy investment coefficients are positive and statistically significant, underscoring strong associations with GDP growth, trade balance improvements, and FDI inflows. These results imply that such investments bolster economic performance and foreign capital attraction. However, their effects on employment and foreign asset accumulation are less pronounced, evidenced by smaller coefficient magnitudes and lower statistical significance. This corroborates findings by Bermejo and Werner (2018), who posit that renewable energy spending drives macroeconomic expansion and trade openness but exhibits delayed or muted impacts on labor markets and asset growth. Aydin and Degirmenci (2024) attribute this discrepancy to the capital-intensive structure of renewable projects or time-lagged employment benefits.

Industrial innovation, measured through indicators like patents filed, capital expenditure on innovation, and sales growth, also positively influences economic growth, trade balance, and FDI. However, its impact is less pronounced relative to renewable energy investments, reflecting the extended development cycles and market adaptation processes necessary for industrial innovations to yield measurable macroeconomic returns. This aligns with Doytch and Narayan (2016), who note that while innovation enhances sectoral competitiveness, its broader economic effects often materialize gradually.

The effects of industrial innovation on employment and foreign assets are particularly limited. For example, patents show no significant relationship with these variables, while capital expenditure on innovative projects exhibits only marginal significance for employment and remains insignificant for foreign assets. Interestingly, sales growth (SALE) is strongly associated with foreign assets, suggesting that increased sales of innovative products may enhance export revenues and strengthen firms' foreign asset holdings. This supports Filatotchev and Piesse (2009), who argue that innovative firms gain competitive advantages, enabling effective penetration of global markets.

Short-term estimates reveal a weaker influence of renewable energy investments and industrial innovation than their long-term effects. The immediate benefits of these investments are limited, with significant economic impacts typically realized over time. Partridge and Olfert (2011) emphasize the need for a forward-looking approach, advocating for sustained investment and policy consistency to achieve robust economic resilience and global competitiveness. The short-term analysis also highlights minimal impacts on employment and foreign asset accumulation, reflecting the gradual nature of these capital-intensive sectors.

A notable short-term finding is the error correction term (ECT) behavior, which is negative and statistically significant. This indicates that any short-term deviations from long-term equilibrium are corrected rapidly, suggesting the resilience of the economic systems under study. The ECT underscores the importance of maintaining a long-term perspective, as investments in renewable energy and industrial innovation ultimately contribute to sustainable growth and stability.

Table 4. Economic impacts of renewable energy and industrial innovation.

	(GDP)	**(TRADE)**	**(FDI)**	**(EMP)**	**(FA)**
Estimated long-term coefficients					
R&D	0.205***	0.249***	0.186**	0.046*	0.003
	(0.054)	(0.034)	(0.093)	(0.125)	(0.102)
REI	0.243**	0.075**	0.081**	0.127*	0.031*
	(0.121)	(0.037)	(0.040)	(0.028)	(0.015)
REVRE	0.125*	0.037**	0.128**	0.015*	0.117*
	(0.063)	(0.018)	(0.064)	(0.007)	(0.058)
INST	0.091**	0.078*	0.113**	0.134*	0.109*
	(0.046)	(0.039)	(0.056)	(0.068)	(0.257)
PAT	0.097***	0.007*	0.008*	0.124	0.137
	(0.023)	(0.003)	(0.004)	(0.363)	(0.269)
CEXP	0.067**	0.081**	0.032**	0.071*	0.074
	(0.033)	(0.040)	(0.009)	(0.035)	(0.139)
SALE	0.031*	0.067**	0.105	0.138*	0.061***
	(0.015)	(0.033)	(0.364)	(0.070)	(0.015)
FS	0.293	0.341	0.123	0.033	0.412
	(0.116)	(0.170)	(0.101)	(0.267)	(0.110)
CR	−0.019***	−0.023**	−0.014**	0.095	0.205
	(0.005)	(0.011)	(0.007)	(0.148)	(0.364)
GS	0.037*	0.011*	0.067*	0.017***	0.018
	(0.018)	(0.005)	(0.033)	(0.003)	(0.249)
Estimated short-term and ECM coefficients					
ΔDep. Var. (-1)	0.015*	0.017*	0.108*	0.031*	0.076*
	(0.007)	(0.008)	(0.054)	(0.015)	(0.038)
ΔR&D	0.033*	0.012*	0.064*	0.053	0.011
	(0.016)	(0.006)	(0.032)	(0.126)	(0.105)
ΔREI	0.081*	0.034*	0.025	0.021*	0.072
	(0.040)	(0.017)	(0.072)	(0.011)	(0.036)
ΔREVRE	0.041*	0.063*	0.021*	0.014	0.052*
	(0.020)	(0.031)	(0.010)	(0.097)	(0.026)
ΔINST	0.017**	0.011*	0.031*	0.087	0.021
	(0.008)	(0.005)	(0.015)	(0.293)	(0.070)
ΔPAT	0.012	0.024*	0.032*	0.058	0.141
	(0.056)	(0.012)	(0.016)	(0.129)	(0.870)
ΔCEXP	0.006**	0.039	0.022*	0.096*	0.047*
	(0.003)	(0.084)	(0.011)	(0.048)	(0.023)
ΔSALE	0.011*	0.055*	0.038	0.051	0.197
	(0.005)	(0.027)	(0.119)	(0.498)	(0.048)
ECM(-1)	−0.492***	−0.405***	−0.388***	−0.192**	−0.124**
	(0.046)	(0.052)	(0.064)	(0.096)	(0.062)
LM Test (χ^2)	0.117	0.102	0.151	0.186	0.215
White Test	0.148	0.109	0.157	0.237	0.261
Jarque-Bera Test	0.138	0.195	0.294	0.127	0.112
RESET Test	0.527	0.218	0.159	0.354	0.108

Note: Table 4 presents the estimates from Equation (2), with the first row listing the five dependent variables: GDP, TRADE, FDI, EMP, and FA. Table 4 is divided into two sections: long-term and short-term coefficient estimates. (*, **, ***) indicate significance levels at 10%, 5%, and 1%, respectively. The t-statistics are reported in parentheses. The *p*-values for the diagnostic tests are displayed at the bottom of the table.

The interaction between renewable energy investments and industrial innovation, reported in Table 5, reveals significant synergies, particularly in enhancing GDP growth and trade balance. While their combined effects on FDI are less pronounced, the synergy creates economic benefits by boosting exports, improving efficiency, and aligning policy goals. Azam and Haseeb (2021) on BRICS countries similarly highlight the complementary nature of renewable energy and innovation in driving growth and trade. Ahmed et al. (2022) and Asghar et al. (2024) further note that such investments amplify productivity and competitiveness, contributing to superior economic outcomes. However, their combined effects on employment and foreign assets remain limited, as reflected in prior studies by Bassanini and Duval (2006), which emphasize the need for complementary labor market reforms to realize job creation benefits.

Table 5. Interactions between renewable energy investment and industrial innovation.

	(GDP)	(TRADE)	(FDI)	(EMP)	(FA)
R&D*PAT	0.356***	0.337***	0.297***	0.041*	0.082*
	(0.042)	(0.067)	(0.041)	(0.020)	(0.041)
REI*PAT	0.408***	0.235**	0.189**	0.048*	-0.101
	(0.054)	(0.117)	(0.094)	(0.024)	(0.350)
REVRE*PAT	0.321***	0.071*	0.067**	0.013	-0.009*
	(0.060)	(0.035)	(0.033)	(0.076)	(0.004)
INST*PAT	0.246***	0.047**	0.021**	0.088	0.075*
	(0.023)	(0.023)	(0.010)	(0.093)	(0.037)
R&D*CEXP	0.422***	0.351**	0.132*	0.037	0.141
	(0.071)	(0.175)	(0.066)	(0.511)	(0.273)
REI*CEXP	0.531**	0.210*	0.362**	0.051	0.007*
	(0.215)	(0.365)	(0.181)	(0.310)	(0.003)
REVRE*CEXP	0.421**	0.118***	0.025**	0.021*	0.022*
	(0.210)	(0.029)	(0.012)	(0.010)	(0.011)
INST*CEXP	0.510**	0.263**	0.121***	0.044	0.052*
	(0.255)	(0.131)	(0.030)	(0.122)	(0.026)
LM Test (χ^2)	0.201	0.342	0.261	0.322	0.203
White Test	0.161	0.117	0.109	0.208	0.223
Jarque-Bera Test	0.108	0.133	0.201	0.139	0.232
RESET Test	0.220	0.203	0.144	0.174	0.158

Note: Table 5 presents the GMM estimator results for Eq. (3), with the first row listing the five dependent variables: GDP, TRADE, FDI, EMP, and FA. It provides the estimated interaction terms between the four renewable energy investment variables and the two industrial innovation variables (PAT and CEXP). (*, **, ***) indicate significance levels at 10%, 5%, and 1%, respectively. The t-statistics are reported in parentheses. The *p*-values for the diagnostic tests are displayed at the bottom of the table.

In the final stage of the analysis, instrumental variables were introduced to address potential endogeneity and simultaneous causality. Historical averages of renewable energy investment (H_AVR) and government innovation policies (GOV) served as exogenous instruments. Including these variables (Table 6) improved the accuracy and reliability of the estimated coefficients for renewable energy and industrial innovation. This approach mirrors the methodology used by Wen et al. (2022), who demonstrated that instrumental variables enhance the robustness of models analyzing renewable energy and innovation effects. By isolating causal relationships, these instruments provide a clearer understanding of the true impacts of renewable energy and industrial innovation on key economic outcomes, ensuring the robustness of both short- and long-term estimates.

Table 6. Renewable energy and industrial innovation – Instrumental variables.

	(GDP)	(TRADE)	(FDI)	(EMP)	(FA)
Estimated long-term coefficients					
R&D	0.283***	0.267***	0.201**	0.075*	0.015
	(0.046)	(0.031)	(0.100)	(0.037)	(0.082)
REI	0.279***	0.094**	0.087**	0.163*	0.052*
	(0.064)	(0.047)	(0.043)	(0.081)	(0.026)
REVRE	0.141*	0.056**	0.132*	0.037*	0.138**
	(0.070)	(0.028)	(0.066)	(0.018)	(0.069)
INST	0.098**	0.083*	0.120**	0.145*	0.139*
	(0.049)	(0.041)	(0.060)	(0.072)	(0.069)
PAT	0.105***	0.012*	0.009*	0.098	0.057
	(0.041)	(0.006)	(0.004)	(0.113)	(0.169)
CEXP	0.082**	0.093**	0.061**	0.091*	0.083
	(0.041)	(0.046)	(0.030)	(0.045)	(0.259)
SALE	0.041*	0.060**	0.138	0.153*	0.084***
	(0.020)	(0.030)	(0.244)	(0.076)	(0.026)
FS	0.104	0.141	0.093	0.133	0.212
	(0.336)	(0.260)	(0.234)	(0.267)	(0.510)
CR	-0.031**	-0.043**	-0.037**	0.061	0.105
	(0.015)	(0.021)	(0.018)	(0.228)	(0.264)
GS	0.047*	0.031*	0.083*	0.028**	0.021*
	(0.023)	(0.015)	(0.041)	(0.014)	(0.010)
H_AVR	0.121***	0.094**	0.025**	0.061*	0.036***
	(0.037)	(0.047)	(0.012)	(0.015)	(0.010)
GOV	0.237***	0.157***	0.037*	0.012*	0.041*
	(0.054)	(0.025)	(0.018)	(0.006)	(0.020)
Estimated short-term and ECM coefficients					
ΔDep. Var. (-1)	0.023**	0.021*	0.112*	0.031*	0.086*
	(0.011)	(0.010)	(0.056)	(0.015)	(0.043)
ΔR&D	0.046**	0.031*	0.081*	0.083	0.011
	(0.023)	(0.015)	(0.040)	(0.096)	(0.105)
ΔREI	0.097*	0.051*	0.038	0.042*	0.012
	(0.048)	(0.025)	(0.072)	(0.021)	(0.076)
ΔREVRE	0.051*	0.070*	0.043*	0.068	0.071*
	(0.025)	(0.035)	(0.021)	(0.087)	(0.035)
ΔINST	0.028**	0.019*	0.052*	0.087	0.021
	(0.014)	(0.009)	(0.026)	(0.293)	(0.070)
ΔPAT	0.012	0.024*	0.032*	0.158	0.091
	(0.056)	(0.012)	(0.016)	(0.169)	(0.170)
ΔCEXP	0.008**	0.067	0.046*	0.098*	0.051*
	(0.004)	(0.094)	(0.023)	(0.048)	(0.025)
ΔSALE	0.011*	0.055*	0.098	0.071	0.207***
	(0.005)	(0.027)	(0.119)	(0.498)	(0.031)
ECM(-1)	-0.492***	-0.405***	-0.388***	-0.192**	-0.124**
	(0.046)	(0.052)	(0.064)	(0.096)	(0.062)
LM Test (χ^2)	0.212	0.223	0.171	0.201	0.209
White Test	0.311	0.426	0.109	0.255	0.231
Jarque-Bera Test	0.109	0.118	0.194	0.161	0.151
RESET Test	0.114	0.264	0.264	0.154	0.166

Note: Table 6 presents Equation (2) estimates, augmented by two instrumental variables (H_AVR and GOV). The first row lists the five dependent variables: GDP, TRADE, FDI, EMP, and FA. The table is divided into two sections, displaying the long-term and short-term coefficient estimates. (*, **, ***) denote significance levels at 10%, 5%, and 1%, respectively, with t-statistics shown in parentheses. P-values for the diagnostic tests are reported at the bottom of the table.

In conclusion, renewable energy investments and industrial innovation significantly contribute to economic growth, trade performance, and FDI inflows in the long term, with synergistic benefits when combined. However, their impacts on employment and foreign assets remain subdued, reflecting these sectors' capital-intensive and gradual nature. Policymakers should adopt a long-term approach, emphasizing sustained investments and strategic alignment to maximize the economic and developmental benefits of renewable energy and industrial innovation.

6. Conclusion

The study provides valuable insights into Saudi Arabia's Vision 2030, emphasizing renewable energy and industrial innovation as drivers of economic diversification. Leveraging firm-level data offers a granular perspective on how individual enterprises influence national outcomes, departing from traditional macroeconomic analyses. However, the unique context of Saudi Arabia—a fossil fuel-dependent economy undergoing rapid transformation—limits the generalizability of findings to other regions. The centralized policy frameworks and dominant role of state-linked firms in Saudi Arabia contrast with decentralized innovation ecosystems in countries like Germany or China, raising questions about replicability in different governance structures. While the ARDL and GMM methodologies effectively address endogeneity and panel data complexities, the reliance on proxies such as patents and R&D expenditure may oversimplify the multifaceted nature of industrial innovation, which includes intangible assets and organizational practices not fully captured by quantitative metrics.

From a policy perspective, the study highlights the importance of long-term commitment to renewable energy and innovation as their economic benefits—particularly in GDP growth and trade—emerge gradually. Policymakers must balance this with short-term pressures, especially in hydrocarbon-dependent economies where fossil fuel revenues remain critical. The limited employment effects of renewable energy and industrial innovation underscore the need for complementary labor market reforms. Initiatives to upskill workers for high-tech industries, such as those under Vision 2030, must be accelerated to align with the capital-intensive nature of renewable projects. The synergy between renewable energy and industrial innovation suggests that integrated policy frameworks, like Germany's Energiewende, could maximize cross-sectoral benefits more effectively than siloed approaches.

The study also identifies areas for future research. The firm-level focus invites deeper exploration of sectoral heterogeneity, such as differences between SMEs and large conglomerates in leveraging renewable investments. The muted employment effects warrant qualitative investigations into workforce transitions, particularly in regions dominated by fossil fuel industries. Additionally, the role of foreign assets in mediating economic outcomes remains underexplored, offering opportunities for comparative studies. Finally, incorporating environmental externalities, such as resource extraction for renewable technologies, would align future research more closely with the holistic goals of the UN's SDGs.

Overall, the study advances understanding renewable energy and innovation as economic catalysts while highlighting the complex interplay of policy, market structure, and institutional capacity. Its firm-level lens provides a valuable counterpoint to aggregate analyses but underscores the need for context-specific adaptations. For Saudi Arabia, the findings validate Vision 2030's strategic direction but caution against underestimating the structural and temporal challenges of diversification. Globally, the research reinforces the importance of aligning energy transition with inclusive growth strategies to ensure sustainable development.

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Conflict of Interest Statement

The author(s) declare(s) that they have no competing interests.

Data Availability Statement

Data available on request due to privacy/ethical restrictions.

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No potential conflict of interest was reported by the author(s).

Declaration of Generative AI

Generative AI and AI-assisted technologies are only used in the writing process to improve the readability and language of the manuscript.

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