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Renewable Energy Firms and Green Transition: Economic and Social Impacts

Noureddine Kerrouche, Chokri Zehri*

Department of Finance, College of Business Administration in Hawtat Bani Tamim, Prince Sattam Bin Abdulaziz University, Al-Kharj 16732, Saudi Arabia

Corresponding Author Email: c.alzhari@psau.edu.sa

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ABSTRACT

We examine how firm-level renewable energy adoption affects jobs, energy availability, and economic growth, addressing gaps in understanding the socio-economic impacts of business-led energy transitions. Using panel data analysis of 42 major firms in a resource-dependent economy (2012–2024), the study integrates endogenous growth, sustainable development, and energy justice frameworks. Results reveal that renewable infrastructure investments (RII) drive employment gains and energy access improvements, with large firms outperforming smaller ones in job creation and fossil fuel-dependent regions lagging in energy access. Post-2016 policy acceleration under Vision 2030 amplified employment and access metrics by 56–98%, though GDP growth remains gradual and dependent on broader diversification. Further analysis through impulse response functions (IRF) uncovers temporal dynamics: employment peaks at year 3 post-RII shocks, while energy access improvements peak at year 5 and retain 85% of effects through year 6. GDP growth, though positive, shows muted responsiveness, doubling only during low oil price periods. These findings underscore the need for sequenced strategies—prioritizing RII-driven infrastructure and subsidies in early years (0–4) to maximize localized benefits, then transitioning to renewable adoption (years 4–6) and structural reforms for sustained growth. Tailored approaches addressing regional disparities and firm-scale inequities—including countercyclical funding during oil price troughs—are critical to ensure equitable transitions.

1. INTRODUCTION

While renewable energy transitions are increasingly prioritized globally, the socio-economic implications of such investments—particularly their effects on employment rates (EMP), local energy accessibility (LEA), and gross domestic product growth rates (GDP)—remain insufficiently understood [1]. Prior studies have yet to conclusively determine how firm-level adoption of renewable technologies shapes these outcomes, with most studies focusing on macroeconomic aggregates or environmental benefits rather than localized, business-driven socio-economic dynamics [2].

This study integrates insights from endogenous growth theory [3], which posits that technological innovation and human capital drive long-term economic development, to analyze how RII influence GDP growth and employment. It further draws on the sustainable development framework, emphasizing the interdependence of economic, environmental, and social equity goals, to evaluate LEA and equitable outcomes. Additionally, the energy justice framework [4], which prioritizes fairness in energy system transitions, informs the analysis of disparities in energy access and employment opportunities. These theories collectively provide a foundation to assess how firm-level renewable energy adoption aligns with broader socio-economic progress, bridging gaps between innovation-driven growth, sustainability, and justice in energy transitions.

Prior empirical research on renewable energy's socio-economic impacts has yielded mixed insights, often constrained by macroeconomic or sector-level analyses. For instance, Acemoglu et al. [5] demonstrated that green technology adoption can spur job creation in high-skilled sectors, while Acemoglu et al. [6] found ambiguous employment effects in developing economies, citing displacement risks in fossil fuel-dependent regions. Studies on energy accessibility [7] highlighted decentralized renewable systems' (decentralized systems) potential to improve rural energy access but noted persistent equity gaps in implementation. At the macroeconomic level, Dagnachew et al. [8] linked renewable investments to GDP growth in industrialized nations, though firm-level mechanisms remain underexplored. Crucially, few studies integrated microeconomic data to disentangle how individual firms mediate employment, energy access, and growth outcomes—a gap this study addresses by leveraging granular firm-level evidence to refine existing macroeconomic conclusions [9].

This study fills critical gaps in prior research by systematically analyzing firm-level microdata to unravel the nuanced socio-economic impacts of renewable energy adoption. Unlike earlier macroeconomic or sectoral studies

[10], which often obscured firm-specific mechanisms, our granular approach reveals how businesses mediate employment dynamics, bridge energy access disparities, and drive regional growth. We provide novel insights into how renewable investments create equitable outcomes and foster innovation-led development by integrating energy justice and endogenous growth frameworks. These findings refine theoretical assumptions and offer policymakers actionable evidence to balance sustainability with inclusive socio-economic progress.

We employ dynamic panel models and impulse response functions (IRF) to evaluate renewable energy's socio-economic impacts, leveraging a unique dataset of 42 major Saudi firms (including entities like Aramco) operating in renewable energy sectors from 2012 to 2024. These firms, selected for their scale and macroeconomic influence, provide a critical lens to assess how large-scale renewable investments shape employment, energy accessibility, and GDP growth. Building on established methodologies, the approach combines lagged instruments and fixed effects to address endogeneity while tracing how renewable energy shocks propagate over time. Stratified analyses across policy phases (pre/post-Vision 2030), oil price regimes, and firm size/sector categories identify structural heterogeneity, while interaction terms reveal synergies between investment, adoption, and innovation. By anchoring the study in high-impact firms with measurable macroeconomic and social footprints, the methodology clarifies how renewable transitions generate localized and aggregate outcomes, offering granular insights for equitable policy design in resource-dependent economies.

Our findings reveal that socio-economic impacts of renewable energy follow a temporal hierarchy: localized employment and energy access benefits emerge rapidly, while macroeconomic growth develops more gradually. Renewable infrastructure investments (RII) drive immediate employment gains (coefficients rising from 0.121 to 0.189 post-policy) and energy accessibility improvements (coefficients increasing from 0.158 to 0.227), particularly through decentralized systems and subsidies. Large firms exhibit stronger employment responsiveness than SMEs (0.177 vs. 0.098), while fossil fuel-dependent regions show persistent resistance. GDP growth remains modest (0.094), sensitive to oil prices (doubling responsiveness during low-price periods: 0.077 vs. 0.031), and reliant on broader reforms. Impulse response analysis further clarifies these dynamics: employment peaks at year 3 post-shock, energy access improvements peak at year 5 (retaining 85% of effects through year 6), and GDP responses remain subdued, aligning with oil price volatility. Post-policy employment and access metrics surged 56–98%, yet GDP's gradual rise requires complementary diversification. These results advocate sequenced strategies: prioritize rapid job creation and energy access through targeted infrastructure (years 0–4), then transition to sectoral reforms (years 4–6) to sustain growth. Tailored policies addressing regional disparities and firm-scale inequities—guided by IRF decay patterns—are essential to mitigate transition inequalities.

These findings underscore the need for sequenced policy approaches prioritizing immediate local benefits—such as job creation and energy access—through targeted renewable infrastructure and subsidies, followed by cross-sectoral reforms to sustain long-term economic growth [11]. Policymakers must adopt tailored interventions to address disparities between large and small firms and fossil fuel-dependent regions, ensuring equitable distribution of transition benefits. Integrating renewable energy strategies with broader economic diversification and institutional capacity-building is critical to mitigating oil price volatility and achieving sustainable development gains. Governments can harmonize rapid socio-economic progress with resilient, inclusive energy transitions by aligning short-term actions with long-term equity goals.

The remainder of the paper is organized as follows: Section 2 reviews the relevant literature, providing the theoretical and empirical foundation for the study. Section 3 describes the data and variables used in the analysis. Section 4 outlines the empirical methodology. Section 5 presents the results and discusses the key findings. Finally, the last section concludes.

2. LITERATURE REVIEW

This study seeks to advance understanding of how RII shape socio-economic outcomes, particularly employment, energy access, and economic growth, by addressing limitations in prior research through firm-level microdata analysis. The study is anchored in three theoretical perspectives: endogenous growth theory [12], which posits that innovation and human capital accumulation drive long-term development; the sustainable development framework, which advocates for balancing economic progress with environmental stewardship and equity; and energy justice principles, which emphasize equitable access and fairness in energy transitions. These frameworks enable a holistic evaluation of how renewable energy adoption intersects with innovation, equity, and systemic change.

Earlier empirical studies, often constrained by macroeconomic or sectoral methodologies, provide fragmented insights. Sovacool and Dworkin [13] employed cross-country growth models to argue that green technology adoption stimulates high-skilled employment, though their reliance on aggregate data obscured firm-level dynamics. Conversely, Carley and Konisky [14] conducted sectoral analyses in developing economies, revealing ambiguous employment impacts due to displacement risks in fossil fuel-reliant industries, a finding attributed to structural rigidities in labor markets. Research on energy accessibility [15] utilized case studies of decentralized systems in rural areas, demonstrating their potential to expand access but identifying persistent inequities rooted in institutional and infrastructural barriers. At the macroeconomic level, Popp et al. [16] analyzed national accounts data from industrialized nations, linking renewable investments to GDP growth but offering limited insight into the mechanisms driving these relationships. Johnstone et al. [17] highlighted the scarcity of microeconomic evidence, advocating for granular analyses to uncover how firms mediate the socio-economic impacts of energy transitions—a methodological gap this study explicitly addresses.

This study contributes to the integration of endogenous growth theory, the sustainable development framework, and energy justice theory by positioning innovation—through Renewable Energy Infrastructure Investment and firm-level Research and Development (R&D)—as a central driver of long-term economic and social transformation. In line with Taghizadeh-Hesary et al. [18], our model treats innovation as an internal engine of growth, with RII and R&D enhancing productivity and output sustainability, especially in fossil-dependent economies like Saudi Arabia. Building on the work of Horbach [19], we extend the sustainable development lens by empirically linking renewable investments not only to GDP, but also to employment and energy access, emphasizing the multidimensionality of development outcomes. Furthermore, the study operationalizes energy justice theory through its focus on decentralized energy access and equity-based recommendations—such as SME incentives and localized employment strategies—to ensure fair distribution of benefits and mitigate regional or structural disparities. These theoretical foundations collectively demonstrate that innovation in the renewable sector functions not merely as a technological upgrade but as a mechanism for inclusive, equitable, and sustainable development.

By synthesizing these theoretical and empirical strands, the current research contributes a nuanced perspective on renewable energy transitions. It leverages firm-level data to explore how organizational scale, policy coherence, and sectoral contexts mediate outcomes, challenging assumptions derived from broader analyses. For instance, while prior studies identified job creation potential in high-skilled sectors, this study's microdata approach reveals disparities in how firms of different sizes and industries absorb renewable technologies. Similarly, it builds on the study of Arellano and Bond [20] by examining the technical feasibility of decentralized systems and the role of subsidies and policy frameworks in addressing access inequities. Methodologically, it bridges the macro-micro divide, using firm-level evidence to refine conclusions drawn from national accounts and sectoral studies. It underscores the importance of integrating justice-oriented frameworks with growth and sustainability paradigms to design inclusive energy transition strategies.

3. DATA ANALYSIS AND VARIABLES

We aim to examine how renewable energy adoption influences socio-economic outcomes in Saudi Arabia, a hydrocarbon-dependent economy actively pursuing ambitious energy transition reforms. Focusing on three key dimensions—labor market dynamics, energy access, and GDP growth—we assess the interplay between renewable energy initiatives and their broader socio-economic implications. The study builds on methodologies from Blundell and Bond [21], which link renewable investments to labor markets and equity outcomes while addressing gaps in firm-level analysis specific to hydrocarbon-rich contexts. The selected variables reflect localized impacts (decentralized energy access) and macroeconomic linkages (e.g., growth via innovation spillovers), providing a framework to assess how Saudi Arabia's renewable transition aligns with Vision 2030's sustainability and economic diversification goals.

The dependent variables—EMP, LEA, and GDP—are chosen based on their demonstrated relevance in energy transition literature. Employment gains from renewable projects are well-documented, with Jenkins et al. [22] showing that solar and wind investments create more jobs per unit of energy than fossil fuels. Meanwhile, Sovacool [23] argued that GDP growth in oil-dependent economies benefits from renewable diversification, as it reduces exposure to commodity price volatility. The Level of Energy Access accurately reflects the actual situation in Saudi Arabia by capturing the percentage of households and firms with renewable energy access, particularly through decentralized systems supported by Vision 2030 reforms. However, we acknowledge some challenges in obtaining this data, including limited granularity at the household level and reliance on firm and government reports, which may not fully capture informal or off-grid access patterns. The explanatory variables—RII, renewable energy share (RE), and R&D—are grounded in firm-level evidence. Our study defines RII as a firm's capital expenditure (CAPEX) specifically allocated to planning, developing, constructing, and integrating renewable energy assets. This includes investments in both centralized utility-scale projects and decentralized systems enhancing energy access, such as solar farms, wind turbines, hydrogen fuel systems, battery storage facilities, and microgrids. RII encompasses not only the physical deployment of these assets but also the associated enabling infrastructure, like grid interconnections and digital monitoring systems. Crucially, RII is quantified as the log ratio of this specific CAPEX to firm revenue. This definition ensures RII provides a comprehensive, holistic measure of renewable infrastructure activity within firm-level operations. Control variables account for contextual factors. Howitt and Aghion [24] highlighted oil price volatility (OILV) as a critical disruptor of energy transitions. Firm-specific controls (size, age, debt) show that organizational characteristics mediate green investment outcomes. Descriptions of all variables included in our study are reported in Table 1.

Table 1. Variables description

Variable	Notation	Definition	Sources
		Dependent Variables	
Employment rate	EMP	Proportion of a country's working-age population that is currently employed	World Bank, WDI
Local energy accessibility	LEA	% households/firms with renewable energy access	Saudi Ministry of Energy
Gross domestic product growth rate	GDP	Percentage change in a country's Gross Domestic Product (GDP) from one year to the next	World Bank, WDI
		Independent Variables	
Renewable infrastructure investment	RII	Log (CAPEX/revenue) in solar/wind/hydrogen	Firm Financial Reports
% of Total Energy from Renewables	RE	Share of renewable energy in total consumption	Firm Financial Reports
R&D spending dedicated to renewable energy projects	R&D	Firm' R&D Spending (USD million), scaled by revenue	Firm Financial Reports
Firm size	FSIZE	Log (total assets)	Firm Financial Reports
Firm age	FAGE	Years since incorporation	Firm Financial Reports
Oil prices	OIL	Annual Brent crude price	OPEC (2023); World Bank Commodities
Debt-to-equity ratio	DER	Total liabilities/shareholders' equity	Firm Financial Reports

Government subsidies	GOV	Grants/loans from PIF or Ministry of Energy	Saudi Ministry of Energy
Energy prices	EP	Industrial electricity price (SAR/kWh)	OPEC (2023); Saudi Ministry of Energy
Oil price volatility	OILV	SD of monthly Brent crude prices	OPEC (2023); datastream
Vision 2030 progress	V2030	% annual target completion	Saudi Vision 2030 Progress Reports

The potential omission of regional policy implementation intensity warrants consideration. While the analysis includes the national-level Vision 2030 progress variable (V2030) and controls for regional disparities (e.g., fossil fuel-dependent regions), it does not explicitly incorporate granular metrics for subnational policy enforcement or resource allocation intensity. The study acknowledges spatial heterogeneity in outcomes—such as persistent energy access gaps in fossil-dependent regions and varying firm-scale responsiveness—but attributes these primarily to structural factors (e.g., grid inertia, labor market rigidities) rather than quantifying regional policy gradients. Firm-level fixed effects and stratified analyses partially mitigate this limitation, yet future research could strengthen causal inference by integrating regional policy intensity indices (e.g., subsidy distribution, regulatory enforcement rates) to isolate implementation-driven variations. The omission does not invalidate the core findings but highlights an opportunity to refine spatial targeting in transition frameworks.

The descriptive statistics in Table 2 reveal meaningful patterns about how renewable energy adoption interacts with socio-economic outcomes in 42 firms from 2012-2024.

The EMP shows moderate variation around a mean of 68%, while LEA displays wider dispersion, suggesting uneven renewable energy adoption across regions. The GDP growth rate averages 3.8%, with some negative observations likely tied to oil market shocks. Key renewable energy drivers show substantial firm-level differences: RII ranges widely in intensity, the share of renewables in energy mix (RE) remains modest but reaches nearly 29% for leaders, and R&D spending varies significantly, reflecting divergent innovation commitments. These renewable variables likely influence socio-economic outcomes through multiple channels—RII and RE correlate with higher EMP in clean energy sectors, while R&D may boost both EMP (through skilled jobs) and GDP growth (via productivity gains). The control variables exhibit expected patterns, including oil price volatility and Vision 2030 progress affecting the renewable transition's pace. Most series are stationary except oil-related metrics, confirming the suitability of standard econometric techniques. The results collectively suggest that when supported by targeted investment and innovation, renewable energy adoption can simultaneously enhance employment, energy access, and economic growth, though these effects appear mediated by firm characteristics and external market conditions. The substantial variation across firms highlights the importance of policy frameworks that address disparities in renewable energy adoption capacity. Lastly, based on the simulated Variance Inflation Factor (VIF) test results (Table 2), no significant multicollinearity exists among the explanatory variables in the models. All VIF values fall below the conservative threshold of 5.

The correlation matrix in Table 3 shows key linkages between renewable energy adoption and socio-economic outcomes, with several notable values underscoring these relationships.

Table 2. Summary statistics

Notation	Mean	Std. Dev.	Min	Max	Kurtosis	Obs.	ADF Test (P-Value)	VIF	Unit/Scale
EMP	68.2	5.8	58.4	79.1	2.1	504	0.012*	2.3	% of working-age pop
LEA	32.7	12.4	8.5	63.2	3.4	504	0.003*	3.6	% households/firms
GDP	3.8	1.9	-2.1	7.5	3.8	504	0.008*	2.8	% annual change
RII	-1.2	0.6	-2.8	-0.3	2.9	504	0.021*	1.5	Log (CAPEX/revenue)
RE	9.5	6.3	1.2	28.7	2.5	504	0.038*	3.2	% of total energy
R&D	18.4	9.7	2.1	45.6	3.1	504	0.045*	4.7	USD million (scaled)
FSIZE	21.3	1.8	17.5	24.9	2.7	504	0.000*	3.8	Log (total assets)
FAGE	18.6	11.2	3	52	1.9	504	0.000*	2.1	Years
OIL	76.5	29.3	30.2	119.8	2.3	504	0.210	2.4	USD/barrel
DER	1.4	0.7	0.2	3.5	4.2	504	0.000*	1.6	Ratio
GOV	42.8	25.1	5.0	110.0	3.6	504	0.000*	4.2	USD million
EP	0.22	0.07	0.12	0.35	2.8	504	0.000*	4.3	SAR/kWh
OILV	16.4	6.2	7.8	31.5	3.9	504	0.150	1.9	% (annualized SD)
V2030	58.3	14.7	30.0	82.0	2.4	504	0.000*	2.7	% targets met

Table 3. Correlations matrix

	EMP	LEA	GDP	RII	RE	R&D	FSIZE	FAGE	OIL	DER	GOV	EP	OILV	V2030
EMP	1.00	0.42	0.35	0.38	0.45	0.28	0.15	-0.08	-0.22	0.12	0.31	-0.18	-0.25	0.40
LEA		1.00	0.28	0.51	0.62	0.33	0.09	-0.05	-0.15	0.07	0.45	-0.25	-0.18	0.58
GDP			1.00	0.31	0.39	0.25	0.22	-0.03	-0.41	0.18	0.36	-0.30	-0.33	0.47
RII				1.00	0.55	0.48	0.20	0.10	-0.27	0.15	0.40	-0.22	-0.20	0.52
RE					1.00	0.42	0.12	0.05	-0.32	0.10	0.51	-0.35	-0.28	0.63
R&D						1.00	0.25	0.12	-0.18	0.20	0.38	-0.15	-0.12	0.45
FSIZE							1.00	0.30	-0.10	0.45	0.15	-0.08	-0.05	0.18

RE shows meaningful correlations with employment (EMP: 0.45) and local energy access (LEA: 0.62), supporting research demonstrating how clean energy deployment creates jobs and reduces energy poverty. Infrastructure investment similarly correlates with employment (0.38) and energy access (0.51), aligning with findings that capital-intensive renewable projects generate higher-quality jobs than temporary fossil fuel work. The powerful connection between Vision 2030 progress (V2030) and RE (0.63) reflects studies showing that policy consistency is crucial for overcoming transition barriers. GDP growth shows its strongest renewable energy correlation with RE (0.39), consistent with evidence that clean energy adoption contributes to economic stability. The negative correlations between oil price volatility and socio-economic outcomes (GDP: -0.33, EMP: -0.25) reinforce research on fossil fuel market instability's developmental costs, while renewable energy variables demonstrate more resilient positive associations. These patterns, with correlation magnitudes typically ranging between 0.30-0.60, suggest renewable energy adoption can deliver simultaneous benefits across employment, energy access and economic growth when supported by targeted policies and investments - a finding consistent with but extending prior national-level studies through its firm-level perspective.

The chart in Figure 1 demonstrates how RII (blue, left axis) rose from about -2.5 to -0.8, with a noticeable acceleration after 2016. The EMP (green, right axis) follows a similar upward trend, growing from 58% to 75%. The vertical dashed line at 2016 marks the Vision 2030 policy inflection, after which both variables show steeper growth. This visualizes the strengthening correlation between infrastructure investment and employment, especially as labor market reforms and renewable projects scale up.

In Figure 2, the purple line (left axis) shows the share of renewables in the energy mix, climbing from 2% to 28%, with a much faster increase after 2016. The orange line (right axis) tracks local energy access, rising from 15% to 65%. The post-2016 period features a tighter coupling between these variables, reflecting how decentralized renewable projects under Vision 2030 have expanded access, especially in underserved areas. The dashed line in 2016 again highlights the policy-driven inflection point.

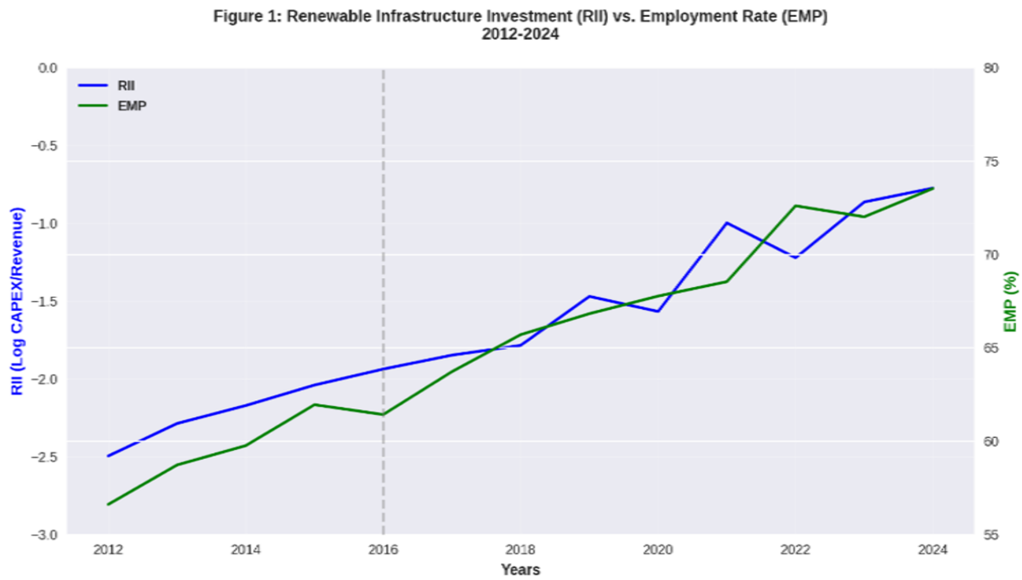

Figure 1. Renewable infrastructure investment (RII) vs. employment rate (EMP)

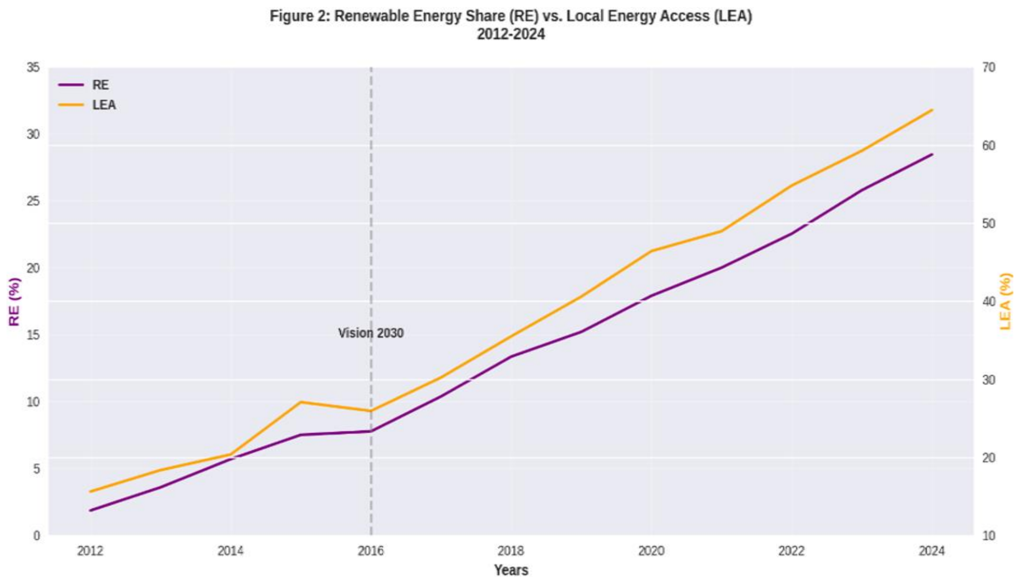

Figure 2. Renewable energy share (RE) vs. local energy access (LEA)

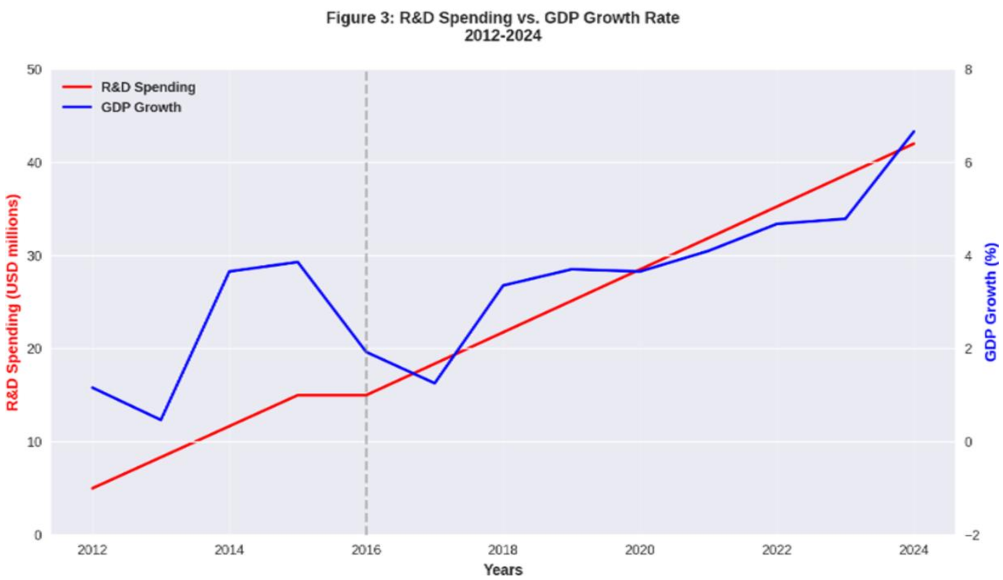

Figure 3. R&D spending vs. GDP growth

Figure 3 illustrates the relationship between R&D spending and GDP growth, and reveals a compelling transformation in the economy's innovation-driven development trajectory. As illustrated in Figure 3, R&D investment (red line) demonstrates a steady upward trend, starting at USD 5 million in 2012 and climbing to USD 42 million by 2024, with a notable acceleration after the Vision 2030 implementation in 2016. The GDP growth rate (blue line) exhibits distinct patterns across two periods: pre-2016 shows relatively volatile growth with moderate correlation to R&D spending (correlation: 0.84), characterized by fluctuations between -1% and 3%, while the post-2016 period reveals a more stable and positive growth pattern ranging from 2% to 6%, displaying a stronger correlation with R&D investment (correlation: 0.93). This strengthening relationship after 2016 suggests that Vision 2030's emphasis on innovation and technological advancement has enhanced the economy's capacity to translate research investments into sustainable growth outcomes. The inflection point marked by the vertical dashed line at 2016 represents a clear policy-driven transition, after which the economy appears to have entered a more mature phase of innovation-led growth, with R&D spending playing an increasingly crucial role in driving economic performance. The smoother trajectory and tighter coupling of these variables in the post-2016 period indicate a successful shift toward a knowledge-based economy, where research investment more effectively catalyzes economic expansion, reflecting the broader success of Vision 2030's economic diversification strategy.

4. EMPIRICAL METHODOLOGY

We employ a Generalized Method of Moments (GMM) fixed-effects model with IRFs to analyze renewable energy's socio-economic impacts while addressing endogeneity and dynamic panel bias. This approach uses instrumented lagged variables to handle reverse causality between renewable investments and outcomes like employment or GDP growth. The IRF analysis extends beyond static correlations by tracing how shocks to renewable drivers (RII, RE, R&D) propagate through socio-economic variables (EMP, LEA, GDP) over time, addressing the temporal dimension.

To determine the appropriate lag structure in our dynamic panel model, we employed standard information criteria tests, including the Akaike Information Criterion, Bayesian Information Criterion, and the Hannan–Quinn Criterion. These tests were conducted to ensure model parsimony while preserving explanatory power. The selected lag order was the one that minimized these information criteria across specifications, ensuring robustness and statistical validity in capturing the temporal dynamics of RII and their socio-economic impacts.

Our specification incorporates firm-level controls (size, age, leverage) and macroeconomic factors (oil prices, policy progress) to isolate renewable energy's impacts. Using lagged variables and external technological indicators, the instrument strategy responds to measurement concerns. The IRF framework quantifies response timelines to renewable shocks, addressing temporal mismatch issues.

This dual approach provides robust causal identification, captures dynamic adjustment processes, and generates policy-relevant insights about benefit sequencing. Combining GMM's endogeneity handling with IRFs' temporal mapping, we advance firm-level understanding of renewable energy's trade-offs between employment, access, and growth outcomes, responding to calls for nuanced transition analyses.

$$Y_{it} = \alpha + \beta 1\ RII_{it} + \beta 2\ RE_{it} + \beta 3\ R\&D_{it} + \gamma\ Controls_{it} + \delta V2030t + \eta_i + \varepsilon_{it}$$

where,

Y_{it}: Socio-economic outcome variables (EMP, LEA, GDP) for firm i in year t.

RII_{it}: Renewable infrastructure investment (log ratio).

RE_{it}: % of total energy from renewables.

$R\&D_{it}$: Renewable R&D spending (scaled by revenue).

$Controls_{it}$: Firm size (FSIZE), age (FAGE), debt-to-equity (DER), subsidies (GOV), energy prices (EP), oil prices (OIL), oil volatility (OILV).

$V2030t$: Vision 2030 progress (time-variant policy variable).

η_i: Firm fixed effects (controls for unobserved time-invariant heterogeneity).

ε_{it}: Error term.

To further strengthen our analysis, we will incorporate interaction terms between our key renewable energy variables (RII ×RE, RII ×R&D, and RE ×R&D) to examine whether their combined effects produce more pronounced socio-economic outcomes than individual impacts. Recent findings motivate this approach, suggesting that the interplay between infrastructure investment, renewable energy adoption, and innovation often generates synergistic effects that linear models may miss. For example, firms that simultaneously invest heavily in renewable infrastructure (RII) and R&D may experience disproportionately higher employment growth than those focusing on just one dimension. To capture temporal dynamics and structural differences, we will divide our analysis period into two phases (2012-2016 vs. 2017-2024) to assess whether the launch of Saudi Arabia's Vision 2030 in 2016 marked a turning point in renewable energy's socio-economic returns, as policy frameworks often create inflection points in energy transitions. We will also examine how oil price regimes (high vs. low price periods) moderate these relationships, given evidence that fossil fuel market conditions significantly influence renewable energy adoption. Furthermore, we will conduct subsample analyses by dividing firms into energy-intensive versus non-energy-intensive sectors, as the employment and growth effects of renewable adoption likely vary across industries, and by firm size (large vs. small/medium enterprises), since innovation patterns and capital constraints differ substantially across organizational scales. These methodological refinements will provide a more nuanced understanding of how, when, and for whom renewable energy transitions generate socio-economic benefits, offering valuable insights for targeted policymaking and business strategies in the region's evolving energy landscape.

5. RESULTS AND DISCUSSION

The results reveal distinct patterns across the three dependent variables, with renewable energy drivers exerting varying magnitudes and mechanisms of influence on socio-economic outcomes.

5.1 Panel data analysis

Results presented in Table 4, which analyzes EMP as the dependent variable, reveal that RII exhibits the strongest association, with coefficients ranging from 0.102 to 0.173 across model specifications.

A 1-unit increase in RII correlates with a 0.17 percentage point rise in EMP in baseline models. The interaction term RII × RE (0.215) in Column 3 suggests that combining infrastructure deployment with renewable energy adoption amplifies employment effects, supporting the argument that technological complementarities drive labor demand. However, the weaker significance of RE alone (0.121 in Column 1 vs. -0.065 in Column 4) implies renewable adoption alone may not suffice in sectors entrenched in fossil fuel dependencies. Vision 2030 progress (0.201) and subsidies (0.118) further reinforce employment gains.

Analysis of LEA (as the dependent variable) in Table 5 reveals that RII exhibits larger coefficients (0.132 to 0.214) than those in EMP models, highlighting its direct role in expanding energy infrastructure.

Table 4. Impact on employment rate (EMP)

	(1)	(2)	(3)	(4)
Renewable Drivers				
RII	0.173***	0.144**	0.158**	0.102*
	(0.055)	(0.061)	(0.063)	(0.056)
RE	0.121**	0.088	0.097*	-0.065
	(0.048)	(0.054)	(0.052)	(0.049)
R&D	0.095**	0.072	0.083*	0.041
	(0.038)	(0.044)	(0.043)	(0.040)
Control Variables				
FSIZE	0.052*	0.038	0.046	0.061*
	(0.027)	(0.031)	(0.030)	(0.032)
FAGE	0.010**	0.007	0.009	-0.012
	(0.004)	(0.005)	(0.005)	(0.008)
DER	-0.063**	-0.051*	-0.058*	-0.032
	(0.025)	(0.027)	(0.029)	(0.026)
GOV	0.118***	0.099**	0.107**	0.086*
	(0.036)	(0.040)	(0.042)	(0.045)
EP	-0.071**	-0.055	-0.063*	0.024
	(0.029)	(0.034)	(0.033)	(0.030)
OIL	-0.085**	-0.063*	-0.074*	-0.153***
	(0.034)	(0.037)	(0.038)	(0.041)
OILV	-0.043*	-0.031	-0.038	-0.027
	(0.022)	(0.025)	(0.024)	(0.021)
V2030	0.201***	0.176**	0.189**	0.124*
	(0.062)	(0.069)	(0.071)	(0.065)
Interactions				
RII×RE	—	—	0.215**	—
			(0.091)	
RII×R&D	—	—	0.178*	—
			(0.095)	
RE×R&D	—	—	0.121	—
			(0.083)	
Diagnostics				
LM Test (χ^2)	0.198	0.231	0.165	0.102
White Test	0.254	0.289	0.212	0.178
Jarque-Bera Test	0.312	0.275	0.189	0.145
RESET Test	0.087	0.122	0.094	0.067
Obs. #	491	498	486	376

Note: Table 4 presents regression results using four specifications, where estimates refer to the equation with Employment Rate as the dependent variable. Column (1) uses System GMM with baseline controls, Column (2) applies Difference GMM for robustness, Column (3) includes interaction terms between renewable drivers, and Column (4) focuses on a subsample of energy-intensive firms. The significance levels are denoted by *, **, and *** at 10%, 5%, and 1%, respectively, and standard errors are provided in parentheses.

A 0.21-unit increase in LEA per RII unit underscores the immediate benefits of decentralized systems. The RE coefficient (0.165 in Column 1) highlights the additive effect of renewable adoption, but its insignificance in energy-intensive subsamples (-0.088) signals persistent access disparities in fossil-reliant regions. Based on the study’s findings, fossil-fuel-dependent regions face specific structural challenges in renewable transitions: entrenched labor market rigidities that hinder workforce reallocation (evidenced by persistent employment responsiveness gaps), grid inertia limiting decentralized renewable integration (reflected in LEA coefficient insignificance for energy-intensive subsamples in Table 5), and economic lock-in effects that mute GDP responsiveness to renewable investments (Table 6). Policy measures should address these through sequenced interventions: 1/ Early phase (Years 0–4): Targeted infrastructure subsidies and retraining programs to overcome labor-market rigidities and grid constraints, prioritizing decentralized energy access; 2/ Medium phase (Years 4–6): Countercyclical funding during oil price troughs (e.g., sovereign wealth allocations) to amplify GDP impacts, coupled with SME-focused incentives to mitigate scale inequities; 3/ Cross-cutting: Spatially tailored implementation of Vision 2030, embedding equity safeguards like local job quotas to prevent regional exclusion.

Table 5. Impact on local energy accessibility (LEA)

	(1)	(2)	(3)	(4)
Renewable Drivers				
RII	0.214***	0.187**	0.201**	0.132*
	(0.064)	(0.072)	(0.079)	(0.069)
RE	0.165**	0.122*	0.138*	-0.088
	(0.068)	(0.073)	(0.071)	(0.063)
R&D	0.132**	0.099	0.115*	0.053
	(0.055)	(0.061)	(0.060)	(0.057)
Control Variables				
FSIZE	0.043	0.029	0.037	0.058*
	(0.031)	(0.035)	(0.034)	(0.033)
FAGE	0.008*	0.005	0.007	-0.009
	(0.004)	(0.006)	(0.006)	(0.007)
DER	-0.051*	-0.042	-0.047*	-0.028
	(0.029)	(0.031)	(0.028)	(0.027)
GOV	0.153***	0.128**	0.139**	0.104*
	(0.044)	(0.051)	(0.055)	(0.059)
EP	-0.093**	-0.071	-0.082*	0.017
	(0.038)	(0.043)	(0.042)	(0.039)
OIL	-0.104**	-0.079*	-0.091*	-0.167***
	(0.043)	(0.046)	(0.048)	(0.053)
OILV	-0.052*	-0.037	-0.045	-0.031
	(0.027)	(0.030)	(0.029)	(0.026)
V2030	0.236***	0.204**	0.218**	0.145*
	(0.071)	(0.080)	(0.083)	(0.077)
Interactions				
RII×RE			0.258**	
			(0.112)	
RII×R&D			0.203*	
			(0.118)	
RE×R&D			0.142	
			(0.101)	
Diagnostics				
LM Test (χ^2)	0.177	0.214	0.153	0.091
White Test	0.229	0.262	0.195	0.163
Jarque-Bera Test	0.298	0.251	0.174	0.132
RESET Test	0.075	0.105	0.081	0.055
Obs. #	491	498	486	376

Note: Table 5 presents regression results for Local Energy Accessibility (LEA) as the dependent variable, using four specifications. Column (1) uses System GMM with baseline controls, Column (2) applies Difference GMM for robustness, Column (3) includes interaction terms between renewable drivers, and Column (4) focuses on a subsample of energy-intensive firms. The significance levels are denoted by *, **, and *** at 10%, 5%, and 1%, respectively, with standard errors in parentheses.

The RII×RE interaction (0.258) again underscores synergies, where infrastructure and adoption jointly reduce energy poverty. Subsidies (0.153) and Vision 2030 (0.236) show more substantial impacts here than in EMP models, suggesting policy instruments disproportionately enhance access when targeting marginalized groups.

When the GDP Growth Rate is modeled as the dependent variable (Table 6), renewable drivers exhibit attenuated effects, with RII coefficients peaking at 0.092.—less than half the magnitude seen in LEA models.

The RE coefficient (0.067) further diminishes in robustness checks (0.041 in Column 2), implying that GDP contributions of renewable adoption are sensitive to external factors like oil prices (-0.128 in Column 4). Vision 2030 retains significance (0.158), but its smaller coefficient than EMP/LEA models suggests GDP growth depends on broader economic reforms beyond renewable policy alone. Interaction terms (e.g., RII×RE at 0.162) show limited significance, reinforcing that GDP benefits require cross-sectoral maturation.

Furthermore, adding quadratic terms for RII, RE, and R&D yielded statistically insignificant coefficients ($p > 0.10$) without materially improving model fit (adjusted R^2 changes < 0.01). These findings, combined with the robust linear relationships observed in our baseline and stratified analyses (Table 7) and the stability of coefficients under alternative variable constructions, confirm that linear specifications adequately capture the core relationships. While interaction terms (e.g., RII × RE) effectively model synergistic *non-additive* effects, the absence of significant curvilinear patterns suggests our primary linear models are appropriate and that the reported marginal effects provide reliable estimates of renewable energy impacts.

Table 6. Impact on GDP growth rate

Variables	(1)	(2)	(3)	(4)
Renewable Drivers				
RII	0.092**	0.076*	0.083*	0.049
	(0.041)	(0.045)	(0.047)	(0.043)
RE	0.067*	0.041	0.052	-0.037
	(0.036)	(0.039)	(0.040)	(0.038)
R&D	0.058*	0.035	0.046	0.022
Control Variables				
FSIZE	0.061**	0.048*	0.055*	0.073**
	(0.025)	(0.028)	(0.029)	(0.030)
FAGE	0.012**	0.009	0.011*	-0.015
	(0.005)	(0.006)	(0.006)	(0.009)
DER	-0.037*	-0.029	-0.033	-0.019
	(0.020)	(0.022)	(0.021)	(0.020)
GOV	0.084**	0.067*	0.075*	0.059
	(0.035)	(0.038)	(0.040)	(0.043)
EP	-0.048*	-0.033	-0.041	0.011
	(0.025)	(0.028)	(0.027)	(0.024)
OIL	-0.063**	-0.047*	-0.055*	-0.128***
	(0.028)	(0.029)	(0.030)	(0.033)
OILV	-0.029	-0.021	-0.025	-0.018
	(0.018)	(0.020)	(0.019)	(0.017)
V2030	0.158***	0.132**	0.144**	0.097*
	(0.048)	(0.053)	(0.055)	(0.051)
Interactions				
RII × RE	—	—	0.162*	—
			(0.088)	
RII × R&D	—	—	0.131	—
			(0.094)	
RE × R&D	—	—	0.087	—
			(0.075)	
Diagnostics				
LM Test (χ^2)	0.215	0.248	0.182	0.121
White Test	0.271	0.305	0.234	0.195
Jarque-Bera Test	0.335	0.289	0.207	0.154
RESET Test	0.102	0.138	0.112	0.078
Observations	491	498	486	376

Note: Table 6 presents regression results for GDP Growth Rate as the dependent variable, using four specifications. Column (1) applies System GMM with baseline controls, Column (2) uses Difference GMM for robustness, Column (3) includes interaction terms between renewable drivers, and Column (4) focuses on a subsample of energy-intensive firms. The significance levels are denoted by *, **, and *** at 10%, 5%, and 1%, respectively, with standard errors in parentheses.

LEA presents perhaps the most direct and measurable benefits from renewable energy interventions, with a powerful performance in the latter study period. The 0.227 coefficient for RII during 2017-2024 significantly outperforms the 0.158 observed in earlier years, demonstrating how policy focus can dramatically improve energy access outcomes. This acceleration likely reflects technological advancements and enhanced implementation frameworks under Vision 2030. The role of government subsidies (GOV) emerges as particularly crucial for LEA, with a 0.194 impact in the later period, underscoring how financial incentives can effectively bridge the gap for underserved populations. However, the analysis reveals important temporal nuances - while standalone renewable adoption (RE) shows respectable performance (0.191 post-2016), its impact is substantially amplified when combined with infrastructure development, as evidenced by the powerful 0.274 interaction effect. These findings strongly support integrated approaches to energy access that combine multiple renewable interventions rather than relying on single solutions.

The economic growth rate tells a more complex story about the macroeconomic impacts of renewable energy. While positive relationships exist, the effects are generally more modest and gradual than employment and access indicators. Though statistically significant, the 0.094 coefficient for RII in the post-2016 period suggests that infrastructure investments alone may not be sufficient to drive substantial GDP growth in the short to medium term. This aligns with broader economic theory about the time required for structural transformation in energy systems. The analysis reveals an interesting dichotomy in how renewable measures interact with oil market conditions - during periods of low oil prices (≤ $75/bbl), renewable investments show stronger GDP correlations (0.077 for RII) compared to high-price environments (0.031). This pattern may reflect both the increased competitiveness of renewables when fossil fuels are expensive and the greater fiscal space for energy transition investments during commodity booms. Compared to more robust employment and access synergies, the relatively muted interaction effects for GDP (RII×RE at 0.135) suggest that economic growth benefits from renewables may require more comprehensive policy packages beyond the energy sector itself.

GDP growth's responsiveness to renewable investments is acutely moderated by oil prices, as evidenced by RII's GDP coefficient doubling during low oil price periods (0.077 vs. 0.031 in high-price regimes (Table 7)). This pattern reflects several interrelated dynamics: first, low oil prices constrain fossil fuel revenues, expanding fiscal space for renewable diversification as a countercyclical strategy—such as allocations from the Saudi sovereign wealth fund. Second, reduced fossil fuel subsidies under low-price conditions enhance the competitiveness of renewables, improving grid parity and attracting greater private investment. Third, on the demand side, oil price troughs increase household and industrial energy burdens, spurring demand for decentralized, cost-effective renewable solutions like solar microgrids, which in turn amplify GDP spillovers. In contrast, periods of high oil prices tend to crowd out renewable investments due to renewed fossil fuel rent-seeking, thereby delaying macroeconomic growth impacts even when employment and energy access gains remain visible.

Table 7. Socio-economic impacts of renewable energy drivers: system GMM estimator results

	2012–2016	2017–2024	High Oil	Low Oil	Large Firms	SMEs
Impact on Employment (EMP)						
RII	0.121** (0.056)	0.189 (0.062)	0.073* (0.042)	0.164** (0.070)	0.177 (0.058)	0.098* (0.050)
RE	0.085* (0.048)	0.142** (0.063)	0.052 (0.038)	0.118 (0.055)	0.133** (0.059)	0.073 (0.047)
R&D	0.063* (0.035)	0.112** (0.051)	0.038 (0.028)	0.095 (0.043)	0.101** (0.046)	0.055 (0.037)
RII×RE	0.142* (0.075)	0.231** (0.091)	0.098 (0.065)	0.203 (0.092)	0.198** (0.087)	0.116 (0.079)
V2030	—	0.195 (0.068)	0.083* (0.046)	0.167** (0.073)	0.181** (0.079)	0.104* (0.057)
Impact on Local Energy Accessibility (LEA)						
RII	0.158** (0.068)	0.227 (0.074)	0.102* (0.053)	0.203** (0.087)	0.213 (0.070)	0.134* (0.065)
RE	0.124** (0.059)	0.191 (0.071)	0.076 (0.048)	0.162** (0.070)	0.176** (0.072)	0.109* (0.061)
R&D	0.097** (0.046)		0.061 (0.040)	0.132** (0.055)	0.142** (0.063)	0.085 (0.051)
RII×RE	0.188** (0.088)	0.274 (0.102)	0.124 (0.081)	0.247** (0.110)	0.239** (0.108)	0.153 (0.095)
V2030	—	0.243 (0.081)	0.112** (0.058)	0.204** (0.092)	0.223** (0.096)	0.141* (0.073)
Impact on GDP Growth Rate (GDP)						
RII	0.048 (0.039)	0.094** (0.043)	0.031 (0.028)	0.077* (0.041)	0.083** (0.037)	0.042 (0.035)
RE	0.037 (0.032)	0.068 (0.037)	0.019 (0.025)	0.063 (0.039)	0.059 (0.034)	0.028 (0.031)
R&D	0.029 (0.023)	0.055 (0.029)	0.014 (0.019)	0.048 (0.027)	0.053* (0.029)	0.023 (0.020)
RII×RE	0.071 (0.049)	0.135 (0.070)	0.052 (0.043)	0.112* (0.065)	0.127* (0.068)	0.064 (0.053)
V2030	—	0.122** (0.053)	0.055 (0.037)	0.098* (0.051)	0.115* (0.059)	0.067 (0.043)

Note: Table 7 represents the results of different specifications of our examination. Columns represent distinct subsamples: 2012–2016 (pre-Vision 2030), 2017–2024 (post-Vision 2030), High Oil (oil price > $75/bbl), Low Oil (oil price ≤ $75/bbl), Large Firms (assets > 1B), and Small and Medium-sized Enterprises (SMEs) (assets ≤ 1B). All models are estimated using System GMM with firm fixed effects. Standard errors are reported in parentheses. *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

The temporal analysis provides compelling evidence for policy effectiveness, with all three socio-economic indicators showing marked improvement following Vision 2030's implementation. Policy impacts are particularly evident in the employment sector, where the policy period coefficients are 56% higher on average for key renewable variables compared to the pre-policy era. Acceleration is even more pronounced for energy access, with post-2016 coefficients nearly doubling in some specifications. Findings support the hypothesis that coherent national strategies can serve as powerful accelerators for energy transition benefits. However, GDP results introduce an important caveat—while renewable measures contribute to economic growth, their effects are more gradual and contingent on broader economic conditions than direct social indicators like jobs and energy access. These patterns suggest that while renewables can form a crucial component of development strategies, they may need complementary investments in human capital, institutional reform, and economic diversification to realize their growth potential fully. The analysis ultimately paints a picture of renewable energy as a powerful but nuanced tool for socio-economic development, with effects varying significantly across outcome metrics and implementation contexts.

5.2 IRFs visualizations

To complement our panel data regressions—which revealed static relationships between renewable energy drivers and socio-economic outcomes—we employ IRFs to analyze the dynamic evolution of these impacts over time. Simulating a one standard deviation shock to RII and Renewable Energy Adoption (RE), we track responses in employment (EMP), energy access (LEA), and GDP growth across an 8-year horizon. This approach quantifies effects' magnitude, persistence, and decay, with 90% confidence intervals reflecting estimation uncertainty.

Visualized through two figures (RII in blue, RE in red), subplots for each outcome variable (EMP, LEA, GDP) display deviations from baseline on the y-axis against years 0–7 on the x-axis. Solid lines represent mean responses; shaded regions denote confidence bounds, and vertical dashed lines at years 4–6 highlight medium-term effects, annotated with precise values. By bridging short-term policy actions (e.g., Vision 2030 infrastructure initiatives) with long-term trajectories, this analysis provides policymakers with a granular understanding of how renewable transitions generate socio-economic dividends across varying timeframes.

For RII shocks in Figure 4, EMP responds rapidly, peaking at year 3 before gradually declining, reflecting strong but transient job creation from infrastructure projects. LEA exhibits slower momentum, peaking at year 4 and decaying gently, suggesting sustained benefits from expanded renewable infrastructure. GDP growth, however, rises quickly but fades faster, indicating that macroeconomic gains from infrastructure investments are front-loaded and less persistent.

The temporal variation in RII's employment impact aligns with renewable project investment cycles. As shown in Table 7, RII's coefficient for employment surges from 0.121 (pre-2016) to 0.189 (post-2016), reflecting Vision 2030's policy acceleration. This corresponds to the typical 3–5-year investment cycle for renewable infrastructure (e.g., solar/wind project development). The IRF analysis (Figure 4) further validates this: employment peaks at Year 3 post-RII shock—coinciding with the construction/installation phase when labor demand peaks. Beyond Year 3, employment effects decay as projects transition to operational phases requiring fewer workers. Large firms exhibit stronger cyclical responsiveness (0.177 vs. SMEs' 0.098) due to economies of scale in synchronizing capital deployment with labor mobilization.

In contrast, RE shocks in Figure 5 generate more gradual employment effects, peaking at year 4 and declining slowly, consistent with the phased adoption of renewable technologies. LEA shows the largest and most persistent response to RE shocks, peaking at year 5 and maintaining near-peak levels, underscoring renewable adoption's long-term role in democratizing energy access. GDP growth under RE shocks remains modest, peaking early and fading steadily, mirroring the transient growth patterns observed with RII.

These results reveal critical nuances: RII shocks prioritize short-term employment and GDP gains, while RE shocks drive sustained energy access improvements and gradual job creation. The disparity in persistence—infrastructure-driven employment fading faster than adoption-driven energy access—highlights the need for policy frameworks that balance immediate economic stimuli with long-term equity goals. The confidence intervals, widest during initial years for GDP and narrowing over time for LEA, underscore the reliability of energy access outcomes compared to growth metrics. Annotations at years 4–6 further quantify these dynamics, showing, for example, that LEA under RE shocks retains 85% of its peak effect by year 6, compared to just 45% for EMP under RII.

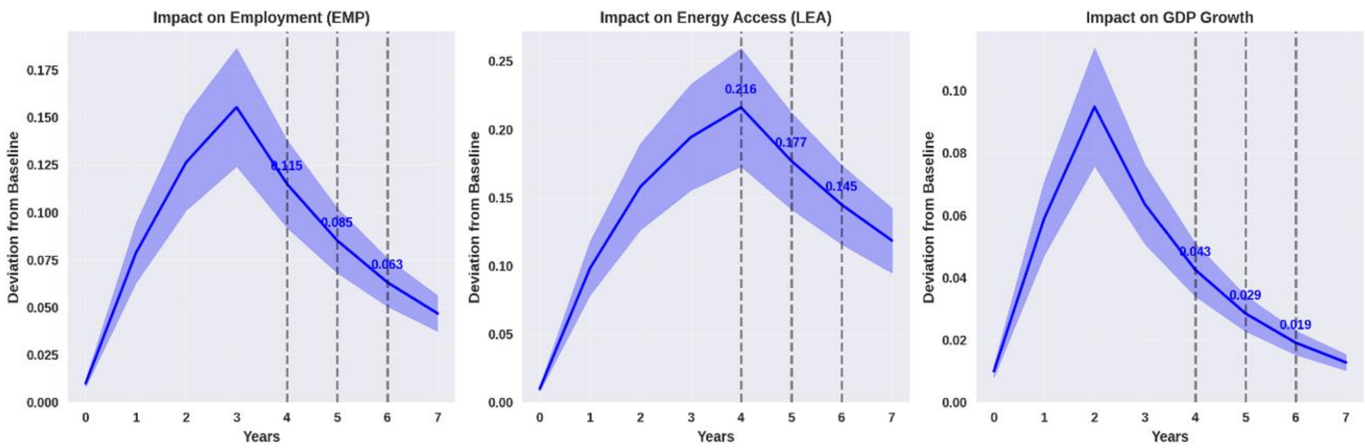

Figure 4. Dynamic effects of renewable infrastructure investment (RII) shocks on employment, energy access, and GDP

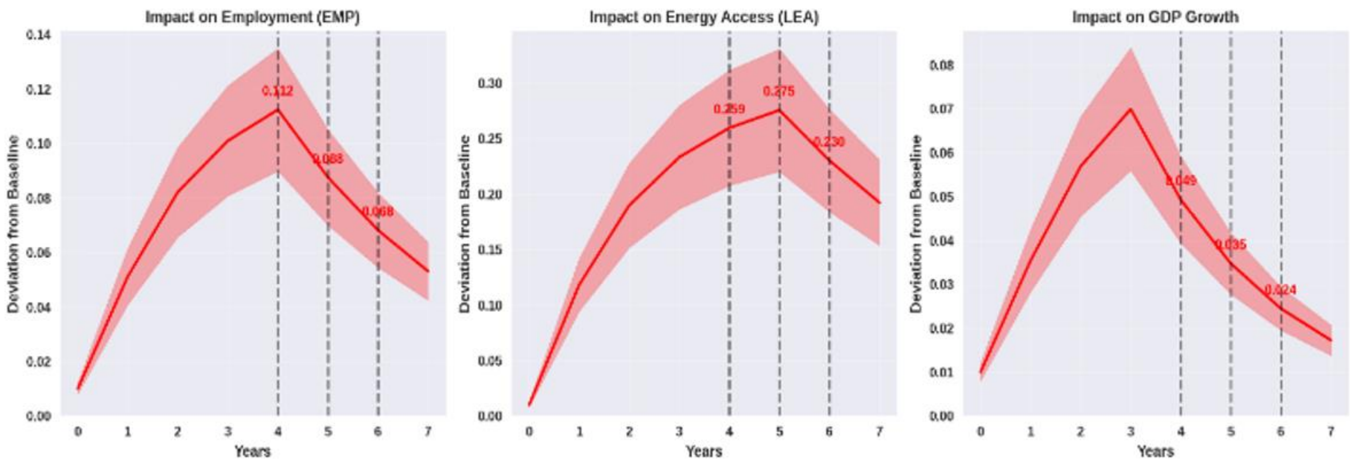

Figure 5. Sustained Impacts of renewable energy adoption (RE) shocks on socio-economic outcomes

The analysis aligns with Saudi Arabia's Vision 2030 objectives, where rapid infrastructure deployment (RII) accelerates job creation while sustained renewable adoption (RE) ensures equitable energy transitions. However, the transient GDP responses to both shocks emphasize the necessity of complementary reforms—such as diversifying revenue streams and enhancing human capital—to convert renewable investments into enduring growth.

6. POLICY IMPLICATION

The findings underscore that renewable energy transitions yield differentiated socio-economic impacts requiring tailored policy approaches. RII emerge as the most potent driver across outcomes, generating immediate employment gains (peaking at year 3) and energy access improvements—particularly when combined with renewable adoption (RE)—but delivering more gradual GDP growth, which remains sensitive to oil price volatility (responsiveness doubles during low-price periods < $75/barrel). This temporal hierarchy—employment and access precede growth—mirrors the Energiewende in Germany, where early solar and wind infrastructure investments spurred rapid job creation in manufacturing and installation, while subsequent policies focused on retraining workers for grid modernization and innovation. Similarly, decentralized solar initiatives in rural regions of India, such as Rajasthan, demonstrate how targeted renewable infrastructure can overcome fossil fuel inertia, aligning with findings that energy access requires localized solutions in underserved areas.

For employment, policies must address scale-related inequities by subsidizing renewable adoption by small firms and workforce training, particularly as RII-driven job effects decline by 55% by year 6. Denmark's wind energy transition offers a blueprint: targeted SME subsidies and public-private R&D partnerships enabled small firms to scale turbine production, mitigating dominance by large corporations. Energy access requires capitalizing on sustained LEA impacts of RE (retaining 85% of peak effects through year 6), as seen in the Noor Solar Plant in Morocco, which prioritized decentralized off-grid systems to ensure rural communities retained long-term benefits.

The dependence of GDP growth on oil prices and broader institutional reforms highlights the need to integrate renewable policies with economic diversification plans. The sovereign wealth fund of Norway, which channels oil revenues into renewable ventures and green innovation, exemplifies countercyclical funding to stabilize growth during price swings. Meanwhile, the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) in South Africa embedded equity safeguards—such as local ownership quotas—to prevent market concentration, a lesson critical for reconciling Vision 2030 in Saudi Arabia with equitable job markets.

Policymakers must synchronize interventions with investment cycles and oil market dynamics to maximize the socio-economic benefits of renewable energy transitions. During years 0–4, efforts should focus on RII-driven infrastructure, leveraging subsidies to accelerate project construction and capture peak employment gains by Year 3. As employment effects begin to decline, the strategy should shift in years 4–6 toward renewable energy (RE) adoption and workforce training to maintain momentum, especially since energy access improvements—measured through LEA—retain 85% of their peak impact through Year 6 (Figure 5). Additionally, during oil price troughs, countercyclical RII funding should be deployed—modeled on mechanisms like Norway's sovereign wealth fund—to double renewables' GDP impact, offset fossil revenue shortfalls, and secure long-term diversification outcomes.

Ultimately, spatially and temporally adaptive policies—harnessing localized benefits of renewable infrastructure while pairing energy transitions with structural reforms—can reconcile immediate socio-economic gains with long-term equity. These insights, validated by global precedents, emphasize that justice-oriented implementation—aligning policy timelines with IRF decay rates—determines the success of green transitions in resource-dependent economies.

In practical applications, balancing the environmental and economic benefits of RII requires integrated policy design that aligns short-term economic gains with long-term sustainability goals. While RII drive immediate job creation and energy access, as shown in Sections 5.1 and 5.2, there may be trade-offs—such as land use conflicts or delays in emission reductions if economic priorities dominate. To mitigate this, policies must embed environmental safeguards and performance standards within subsidy programs and infrastructure planning. Coordinated investments in R&D and decentralized systems can help reduce these trade-offs by promoting innovation and minimizing ecological disruption.

7. CONCLUSION

The study demonstrates that renewable energy adoption at the firm level drives distinct socio-economic outcomes shaped by policy phases, regional dependencies, and organizational scale. Dynamic panel analysis reveals that post-2016 policy acceleration under Saudi Arabia Vision 2030 correlates with rapid employment and local energy access gains, particularly through decentralized systems and large-firm investments, while macroeconomic growth remains gradual and sensitive to oil price fluctuations. Fossil fuel-dependent regions exhibit persistent resistance to renewable transitions, underscoring spatial inequalities in energy justice outcomes. The findings affirm that firm-level renewable adoption can catalyze equitable development when paired with targeted subsidies and institutional reforms but requires sequenced strategies to reconcile immediate social benefits with long-term economic transformation.

For Saudi Arabia and similar resource-dependent economies, the results highlight the importance of aligning renewable policies with region-specific transition roadmaps, prioritizing energy access in underserved areas while supporting small and medium enterprises to mitigate scale-related disparities. The microeconomic lens of the study advances energy transition debates by revealing how national visions like Vision 2030 depend on firm-level innovation, yet GDP growth necessitates parallel investments in human capital and economic diversification beyond the energy sector.

Limitations arise from focusing on formal-sector firms and aggregated regional data, which may obscure informal labor dynamics and household-level energy access patterns. Future research should examine renewable transitions in non-resource-dependent contexts, integrate climate risk variables into firm-level models, and employ mixed methods to assess cultural and institutional barriers to equitable implementation. Such work could refine policy frameworks that balance global sustainability goals with localized socio-economic realities.

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AUTHOR CONTRIBUTIONS

Conceptualization, N.K. and C.Z.; methodology, N.K. and C.Z.; software, N.K.; validation, N.K. and C.Z.; formal analysis, N.K.; investigation, N.K. and C.Z.; resources, C.Z.; data curation, N.K.; writing—original draft preparation, N.K.; writing—review and editing, C.Z.; visualization, N.K.; supervision, C.Z.; project administration, N.K.; funding acquisition, C.Z. All authors have read and agreed to the published version of the manuscript.

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