Renewable energy adoption and socio-economic outcomes during economic transition evidence from Saudi firms (2012–2024)

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ABSTRACT

This study examines the micro-level impact of renewable energy transition on key socio-economic indicators within a resource-dependent economy. Using firm-level panel data from 42 large Saudi firms spanning 2012–2024, we employ Generalized Method of Moments (GMM) estimation and Impulse Response Function (IRF) analysis. Our purpose is to assess the effects of renewable infrastructure investment (RII) and renewable adoption on employment, energy access, and firm revenue growth (FRG). The findings indicate that RII has a short-run positive impact on employment and energy access, a trend that has been accentuated following Saudi Arabia's Vision 2030 announcement. However, the positive effect of RII on FRG manifests only in the long run and is conditional on oil price volatility. Furthermore, the employment benefits are not distributed equally between large firms and SMEs. Practical implications suggest that the initial policy should focus on infrastructure investment and subsidies to boost short-term job creation and energy access. Subsequently, policy must pivot to foster broader structural transformation through widespread adoption of renewable energy to achieve sustainable, inclusive long-term economic growth.

Contribution/ Originality: This study provides firm-level microdata on the distributional employment effects of the renewable transition in a resource-rich economy. It applies Impulse Response Function analysis to establish a temporal hierarchy of socio-economic benefits and underscores the conditional role of oil prices for sustainable growth.

1. INTRODUCTION

Although we are witnessing a widespread global shift toward renewable energy, the magnitude of the social and economic benefits of this transition in terms of employment opportunities, energy access, and the FRG remains ambiguous and disputed in the literature (Hassan et al., 2024; Khrais & Alghamdi, 2025). Furthermore, we have limited knowledge about how the adoption of renewable energy technology at the individual firm level affects social and economic outcomes.

Prior literature has extensively explored this issue from the perspectives of either economic externalities or environmental implications, without examining the firm-level determinants of social and economic outcomes (Gamarra, Banacloche, Caldés, & Lechón, 2023; Ur Rehman et al., 2024). Against this backdrop, the current study seeks to explore the extent to which renewable energy investments by firms operating in a resource-based economy

bring real socio-economic benefits. To provide a theoretical underpinning for our empirical investigation, the study employs a multi-theoretical framework comprising the endogenous growth perspective, the sustainable development paradigm, and the energy justice perspective. Endogenous growth theory posits that economic growth can be measured by analyzing technological progress and its effect on job creation (Lucas Jr, 1988; Romer, 1990). As investments in renewable energy represent a particular form of technological progress, the current study uses endogenous growth theory to examine their impact on the FRG and employment.

To examine the impacts on local access to energy, our study applies the sustainable development paradigm through the lens of endogenous growth theory. SV emphasizes the need to balance economic, environmental, and social objectives through fair outcomes (Pearce, 1989). Lastly, the energy justice view provides a normative lens for examining equity and fairness in outcomes related to the ongoing energy transition (Sovacool & Dworkin, 2015). These three perspectives together allow us to provide a comprehensive analysis of how firm-level clean energy investments in resource-driven economies not only stimulate economic growth but also achieve sustainable development and fair energy justice outcomes. While the current literature reveals both positive and negative effects of adopting renewables on these outcomes, most conclusions are based on aggregated data. On the one hand, growth theory may contribute to high-skilled employment (Acemoglu, Aghion, Bursztyn, & Hemous, 2012), whilst on the other hand, it may have had no clear aggregate employment outcome in developing economies, given the risks of job displacement in conventional and non-renewable sectors (Bowen, Kuralbayeva, & Tipoe, 2018). Framed in terms of access, there is both potential for decentralized renewables (Dagnachew, Hof, Roelfsema, & van Vuuren, 2020) and Evidence of inequities in implementation exists. At the macro-level, RE investment may be associated with FRG (Burke & Stephens, 2018), but this remains unexplained regarding the firm-level channels through which it may occur. Accordingly, as Sovacool, Newell, Carley, and Fanzo (2022) argue, this microlevel assessment places severe constraints on our understanding of firms as a channel through which energy transitions are linked to their subsequent socio-economic outcomes.

With this methodological constraint directly motivating our contribution here, we develop three associated expectations. Firstly, we argue that RII at the firm level should have positive, but temporally lagged, socio-economic outcomes, consistently or transitionally, across industries. We anticipate that employment effects should precede infrastructural access effects, with both preceding aggregate and observable FRG. Secondly, these effects should also be significantly larger following the 2016 post-policy push of the Saudi Vision 2030 program. Finally, we argue that they should also be pressed, or conditional upon, a set of structuring factors. We particularly expect: 1) larger positive employment effects for bigger enterprises compared to SMEs; and 2) a weaker, and oil price-sensitive, impact on FRG compared to more localized SE outcomes. To empirically test these premises, we employ GMM dynamic panel data on a novel company-level panel of 42 top Saudi industries, including Aramco, for 2012–2024, capturing the two policy regimes. This addresses heterogeneity and endogeneity concerns. We further apply Impulse Response Function (IRF) analysis to capture the evolution and temporal dynamics of SE outcomes' responses to renewable investments. The analysis is differentiated by industry type, size, and oil price regime, capturing the complex set of conditions under which the transition has different implications.

The remaining sections of the paper are structured as follows. Section two reviews existing theoretical and empirical literature on the subject. Section three presents the data and variables. Section four describes the empirical approach. Section five presents and discusses the findings. Section six concludes the paper with key policy implications and future research directions.

2. LITERATURE REVIEW

Whereas the nature, direction, and strength of the various socio-economic impacts of the energy transition are typically assessed using aggregate, macro-level metrics, a granular evaluation at the firm level is required to capture

the role of micro factors such as job creation across skill spectrums, local energy production, and accessibility on household and firm-level energy security, social inclusion, and territorial development.

The existing literature, however, provides several relevant insights on the connections we examine here, but is silent or inconclusive on others. We synthesize here the theoretical and empirical pillars that are most relevant to our work. Firstly, it demonstrates that each has a partial scope and highlights the necessity for microdata estimation. Regarding the employment effect, numerous studies have provided substantial insight into the topic, but the results are heterogeneous due to the aggregated nature of the approach. Generally, pro-green technologies, such as the deployment of RE, increase employment in skilled jobs (Acemoglu et al., 2012). However, sector-level studies of DCs have found that the net effect is ambiguous (Bowen et al., 2018). Loss of employment is more likely to be substantial in the fossil-fuel sector than in other sectors, due to labor-market frictions that are not captured in large-scale models. This implies that what is lacking is the mechanism for a firm's tasks, hiring, and function reallocation. The same concern applies to the energy-access aspect of renewable energy (RE). RE systems, such as decentralized systems, can increase access in rural off-grid regions (Dagnachew et al., 2020). The investigation, however, uncovered an uneven pace and persistent intraregional inequality, driven by institutional frictions, e.g., heterogeneity in subsidy provision. This suggests that additional conditions are required to capture equitable access, particularly empirical evidence on the combination of firms' investment and policy incentives in the subnational context. At the macro level, empirical evidence indicates that RE investment positively affects the creation of total financial resources (FRG) in developed economies (Burke & Stephens, 2018). However, the empirical analyses in this vein implicitly treat the economy as a black box and rarely discuss the specific channels (e.g., TFP improvements within firms, supply chains, learning-by-doing) through which green investment yields its corresponding aggregate impact. As pointed out by Sovacool et al. (2022), the current literature largely lacks micro-level (firm-level) evidence on the socioeconomic implications of the energy transition. Hence, our microdata analysis. In addition to being the primary vehicle for the above-mentioned theoretical channels, microdata analysis offers the advantage of explaining much of its heterogeneity through details too fine to be captured by aggregated data (e.g., firm size, financing availability, industrial structure). For instance, while aggregated data cannot capture which level of JG are generated as a consequence of green investment, a firm-level data analysis can even explain the industrial level heterogeneity of JG creation, e.g., whether the jobs created in the energy transition are more likely to be in big firms (rather than SMEs) or mainly in the manufacturing sector (rather than in the installation or O&M sector). While it is valuable for identifying the theoretical channels, it is also helpful in describing the EQU relationship under different policy instruments (e.g., a customized subsidy and the overall Vision 2030 in the case of KSA).

Our research lies at the intersection of this theoretical necessity and an empirical opportunity; it, to a reliable extent, responds to the call in Sovacool et al. (2022) directly through a unique analysis of a large panel of Saudi firms. In this way, it bridges the gap between the broader picture and the underlying firm-specific characteristics, showing how growth through renewable energy is distributed over time in a resource-rich society. This allows us to offer a firm-level empirical model that captures trends identified across the literature on growth, sustainable development, and energy justice, shifting the focus from the creation of socio-economic benefits through renewable energy to a more resource-specific understanding of how these benefits are created, for whom, and when.

3. DATA ANALYSIS AND VARIABLES

We contextualize the adoption and diffusion of renewable energy within the broader energy transition in KSA, a resource-rich, pre-transitional Middle Eastern economy. Our variables of interest concerning the impact of renewable energy adoption on socio-political challenges across KSA are employment rate (EMP), local energy access (LEA), and firm revenue growth rate (FRG). This approach aligns with similar firm-level studies on resource economies, e.g., (Sovacool et al., 2022; Taghizadeh-Hesary, Rasoulinezhad, & Yoshino, 2021). We select our variables based on the broader categories of local effect (decentralized energy supply), vertical integration, and political-economic

linkage (innovation-driven growth). In doing so, we focus on the energy transition, which is integral to the findings, and on the diffusion of renewable energy adoption within this resource-based, pre-transitional, oil-dependent economy. In light of this, we measure the progress of the energy transition through renewable energy adoption, aligning with KSA's social, political, and economic transition to a more market-based, diversified, and sustainable energy system, as envisioned in its Vision 2030 program. Our dependent variables, including employment rate (EMP), local energy access (LEA), and firm revenue growth rate (FRG), are widely used in the literature on energy transition. Renewable energy adoption is known to lead to greater employment through more job creation per GWh of energy delivered compared to fossil-based energy plants (Carley & Konisky, 2020). It also provides greater local access through more evenly distributed, decentralized renewable energy systems compared to centralized fossil-based energy systems (Bhattacharya et al., 2022) and greater revenue growth across the firms in an oil-rich economy through reduced dependency on the oil sector that is more prone to external revenue shocks. (e. g., Acemoglu et al. (2012). Our explanatory variables, including renewable energy-related infrastructure investment (RII) or capacity (RE), and R&D expenses (R&D), are observable through firm-level data. Specifically, R&D is linked to employment and innovation gains (Horbach & Rennings, 2013) while infrastructure investment can play a significant role in reducing time-to-market (Popp et al., 2010) or in minimizing energy poverty (Johnstone, Haščič, & Popp, 2010). Accordingly, to control for external and strategic factors, we include control variables such as oil price volatility (OILV) and Vision 2030 investment (V2030) following Taghizadeh-Hesary et al. (2021) and Alshehry and Belloumi (2015). Furthermore, we include several firm-based controls, such as size, age, and debt, since these financial indicators can influence investment strategies (Horbach, 2008). Table 1 reports the complete list and description of the variables.

Table 1. Variables description.

Variable	Notation	Definition	Sources
Dependent variables			
Employment rate	EMP	Annual percentage change in the firm's total number of employees	Firm annual reports, financial statements
Local energy accessibility	LEA	Share of the firm's total energy consumption supplied by its dedicated renewable energy infrastructure, such as solar PV and wind turbines.	Firm sustainability reports, energy audits
Firm Revenue Growth	FRG	Firm's annual revenue growth (%)	Firm financial statements
		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 the 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); data stream
Vision 2030 progress	V2030	% annual target completion	Saudi Vision 2030 Progress Reports

The descriptive statistics for the sample of 42 firms (2012–2024) show the following empirical observations (Table 2). On the socio-economic indicators, the mean employment rate (EMP) is 68%, but it varies somewhat across firms. By contrast, a higher standard deviation is observed for local energy access (LEA), suggesting heterogeneous spatial adaptation in renewable use. Although the firm revenue growth (FRG) has a mean of 3.8%, its negative values may be driven by oil shocks. Furthermore, on renewable drivers, substantial heterogeneity is observed among the firm sample: the mean infrastructure investment (RII) widely differs, and the mean renewable share (RE) is only moderate but reaches around 29% in the top share, while there is a wide variation in the R&D mean, suggesting different firm innovation priorities. It appears likely that these variables influence the socio-economic effects through multiple channels. For example, RII and RE might be linked to new clean-energy jobs, whereas R&D is associated with the creation of skilled jobs and with productivity-driven revenue growth. The relative stability of the time series allows us to focus on linear models that are likely to be robust under most specifications. The source of higher RE share through innovation is a renewal that keeps environmental and climate conditions in check. We now turn to whether such renewal in medium-sized industrial firms affects socio-economic progress.

Table 2. Summary statistics.

Notation	Mean	Std. Dev.	Min.	Max.	Kurtosis	Skewness	Jarque-Bera (p-value)	Obs.	IPS Test (p-value)	Unit/Scale
EMP	68.2	5.8	58.4	79.1	2.1	-0.15	0.485	504	0.024*	% of working-age pop
LEA	32.7	12.4	8.5	63.2	3.4	0.42	0.087	504	0.007*	% households/firms
FRG	3.8	1.9	-2.1	7.5	3.8	-0.28	0.210	504	0.011*	% annual change
RII	-1.2	0.6	-2.8	-0.3	2.9	-0.65	0.018*	504	0.032*	Log(CAPEX/revenue)
RE	9.5	6.3	1.2	28.7	2.5	1.12	0.003*	504	0.041*	% of total energy
R&D	18.4	9.7	2.1	45.6	3.1	0.93	0.025*	504	0.048*	USD million (scaled)
FSIZE	21.3	1.8	17.5	24.9	2.7	0.21	0.312	504	0.000*	Log(total assets)
FAGE	18.6	11.2	3	52	1.9	1.08	0.001*	504	0.000*	Years
OIL	76.5	29.3	30.2	119.8	2.3	0.35	0.245	504	0.180	USD/barrel
DER	1.4	0.7	0.2	3.5	4.2	1.52	0.000*	504	0.000*	Ratio
GOV	42.8	25.1	5.0	110.0	3.6	0.78	0.012*	504	0.000*	USD million
EP	0.22	0.07	0.12	0.35	2.8	0.62	0.095	504	0.000*	SAR/kWh
OILV	16.4	6.2	7.8	31.5	3.9	0.95	0.008*	504	0.125	% (annualized SD)
V2030	58.3	14.7	30.0	82.0	2.4	-0.18	0.422	504	0.000*	% targets met

Note: Stationarity is tested using the Im-Pesaran-Shin (IPS) panel unit root test, which allows for heterogeneous autoregressive coefficients across firms. The null hypothesis is that all panels contain a unit root. * indicates rejection of the null at the 5% significance level. Normality is tested using the Jarque-Bera test; * indicates rejection of normality at the 5% level.

Table 3 reports the correlations among the variables show that RE share and employment/energy access are positively associated (0.45; 0.62). Infrastructure investment also correlates positively with these outcomes (0.38; 0.51). Progress on Vision 2030 is strongly linked to RE share (0.63), indicating the importance of continued efforts. The most significant positive association for FRG is with RE share (0.39). Additionally, the instability of conventional energy (oil) prices has a significant adverse effect (e.g., FRG = -0.33), highlighting the limitations of fossil fuel market volatility. Overall, a positive correlation of 0.30-0.60 suggests that renewable energy use, combined with energy policies and infrastructure investment, can benefit job creation and energy and economic co-benefits. This evidence at the firm level not only supports but also extends the national-based findings summarized above.

Table 3. Correlation matrix.

Variable	EMP	LEA	FRG	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
FRG			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
FAGE								1.00	0.05	0.22	0.08	0.03	0.07	0.10
OIL									1.00	-0.12	-0.35	0.60	0.72	-0.40
DER										1.00	0.18	-0.10	-0.08	0.15
GOV											1.00	-0.28	-0.22	0.55
EP												1.00	0.55	-0.32
OILV													1.00	-0.25
V2030														1.00

The panels in Figure 1 show the observed correlation between RII and employment (upper panel). We observe two sub-trends with different slopes. Large firms record stronger employment growth than SMEs at comparable investment levels. It is also clear that the relatively sharper upward trend line is due to investments after 2016, which coincide with the launch of Saudi Arabia's Vision 2030 reform agenda. This suggests that the Vision 2030 agenda has improved overall investment and employment, as shown by the (blue) post-2016 data clustered in the high-investment, high-employment box.
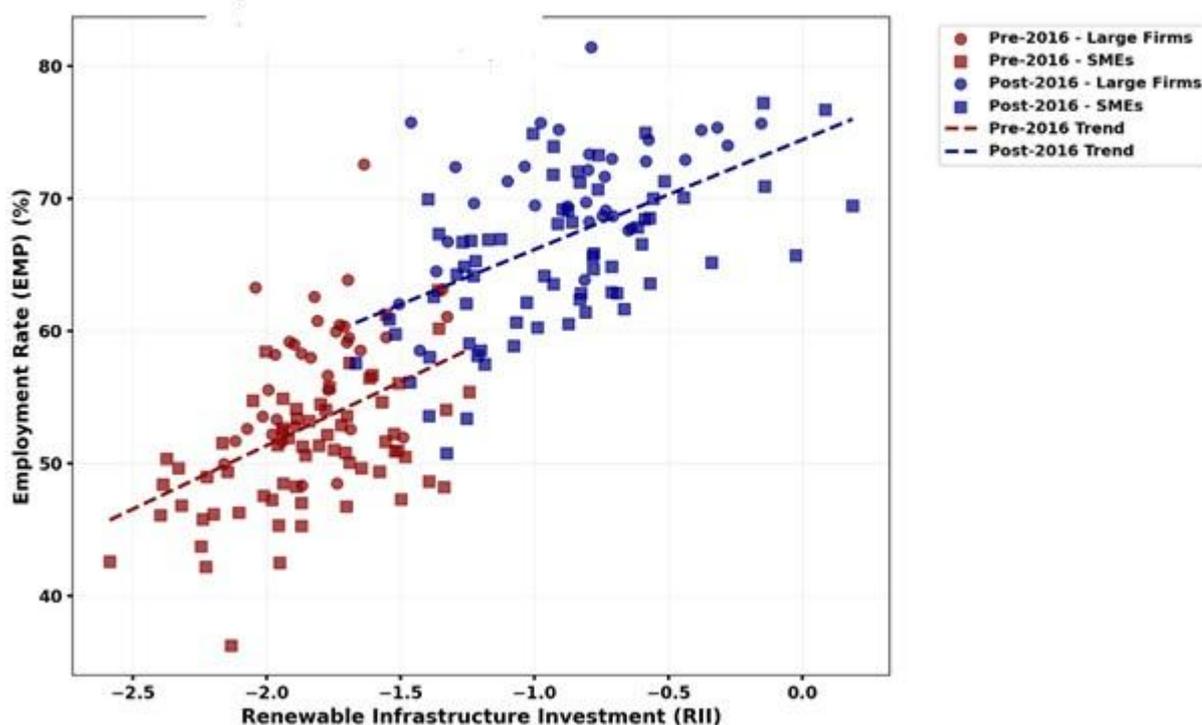

Figure 1. Differential impacts of renewable infrastructure investment on employment by firm size and policy period.

Figure 2 explores the interaction of RE adoption with RII and LEA across the period, which is represented in a bubble chart. Inspection of the slope of the trendline and the scatter of observations suggests that during the immediate post-2016 period, there was broad-based improvement, with larger bubbles indicating greater RII and darker points representing post-2016 data. This supports the earlier inference of resource mobilization gains due to policy acceleration triggered by V2030, with mutual progress of RE adoption and LEA. It confirms that the increase

in electricity generation capacity was primarily driven by infrastructure investments, extending access to previously underserved areas through distributed renewable energy sources.
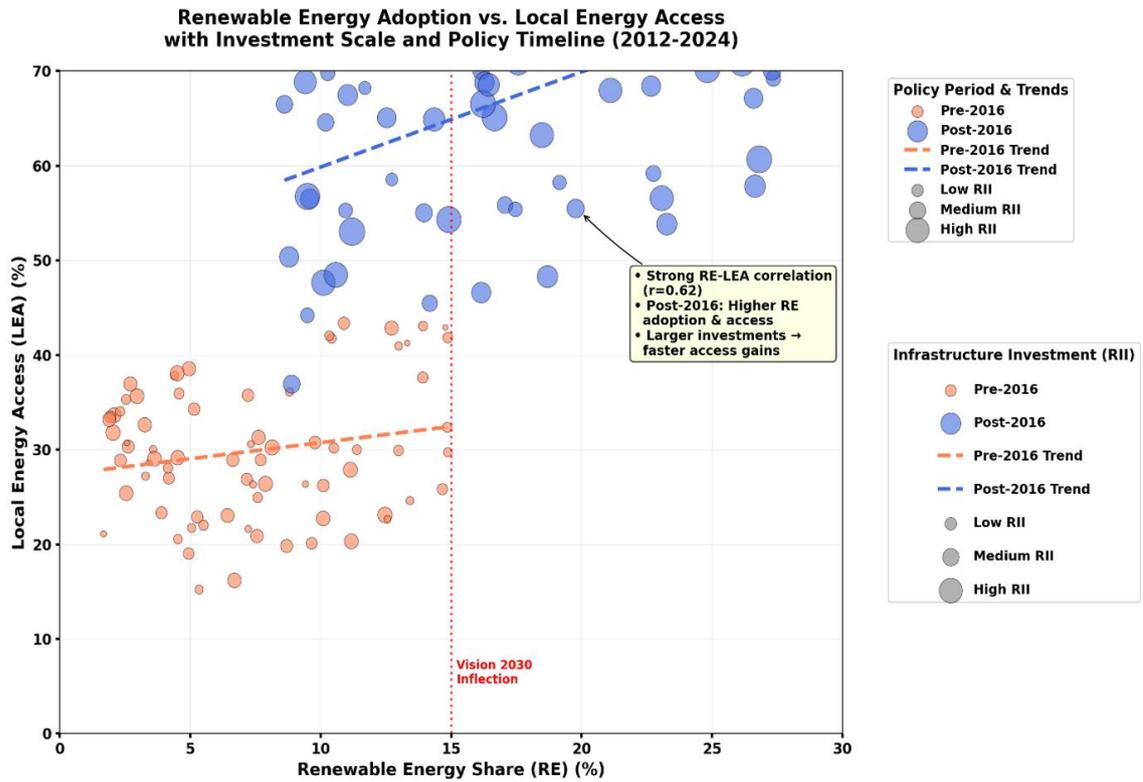

Figure 2. Renewable energy adoption and infrastructure investment drive local energy access gains.
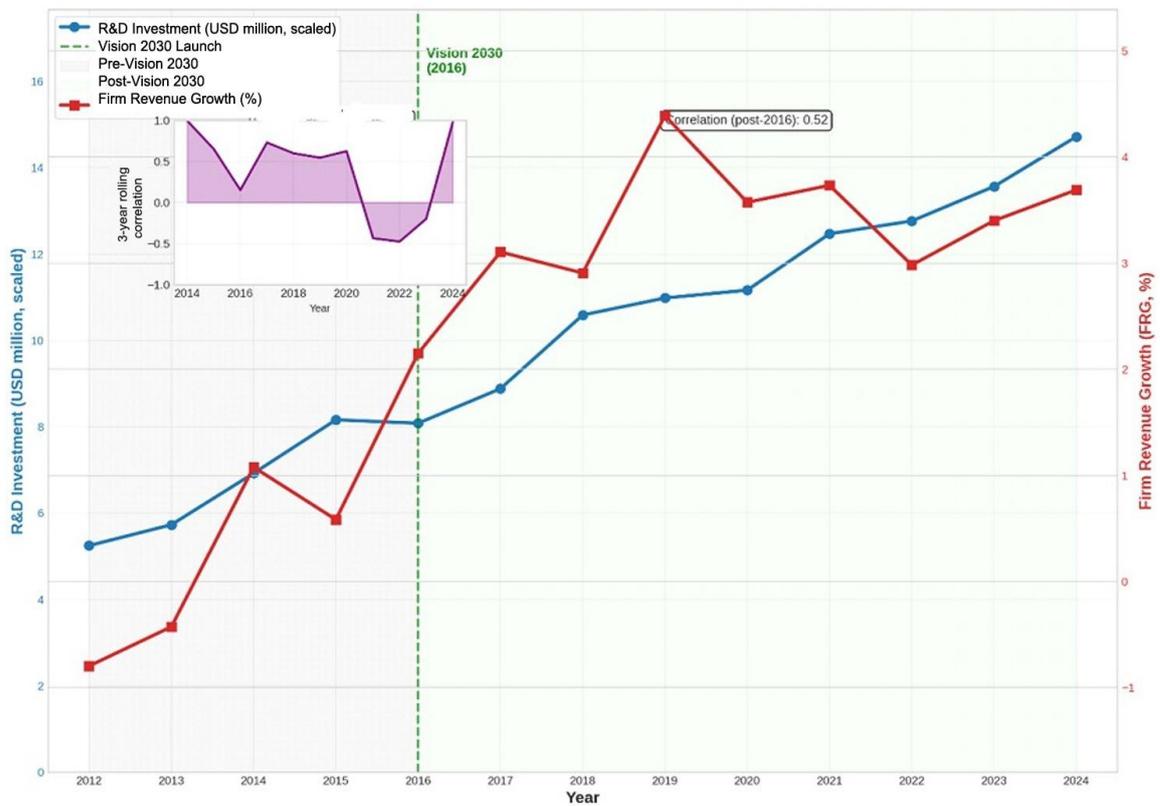

Figure 3. Innovation-driven growth transformation: R&D investment and economic performance before and after vision 2030.

Figure 3 shows a dual-axis time-series line chart of the strength (i.e., density) of the innovation-growth (i.e., firm-level productivity) relationship in the Saudi Arabian context. The upward linear trajectory of R&D exponential expenditure (reaching a maximum around end-2023) with a more precise starting point in 2016, at the start of V2030, indicates an improving trend. The FRG trend, previously irregular with some negative growth readings, now shows no negative values post-2016. The correlation coefficient, which has increased from 0.84 to 0.93 over the same period for R&D and FRG, further suggests a strengthening relationship. The inset in Panel Figure 3, showing a rolling correlation, indicates that this relationship has become more robust, reflecting an increasingly mature and maturing economic growth path as policy effectiveness improves.

4. EMPIRICAL METHODOLOGY

Following widespread practice in the panel data literature, we estimate a dynamic panel GMM with fixed effects and examine endogeneity reduction using IRF analysis. This approach addresses endogeneity concerns related to reverse causality (profitable firms disproportionately invest in renewables), omitted-variable bias (unobserved heterogeneity in business practices, environmental attitudes, etc.), and measurement error (self-reported RENE). Specifically, we use System GMM estimation in the tradition of Arellano and Bond (1991) and Blundell and Bond (1998), which instruments endogenous variables using past levels and differences, assuming that lagged values affect current adoption but are uncorrelated with contemporaneous shocks. The equation also includes a lagged dependent variable to model time dependence and firm fixed effects to capture time-invariant unobserved heterogeneity. A GMM estimator is appropriate given the structure of our panel (42 units, 13 time periods), as it controls for bias and improves efficiency when the number of time periods is short relative to the cross-sectional dimension.

$$Y_{it} = \alpha + \beta_1 \, RII_{it} + \beta_2 \, RE_{it} + \beta_3 \, R\&D_{it} + \gamma \, Controls_{it} + \delta V2030_t + \eta_i + \varepsilon_{it} \qquad (1)$$

Where:

- Y_{it}: Socio-economic outcome variables (EMP, LEA, FRG) 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).
- $V2030_t$: Vision 2030 progress (Time-variant policy variable).
- η_i: Firm fixed effects (Controls for unobserved time-invariant heterogeneity).
- ε_{it}: Error term.

We perform the Hansen J test for weak instruments and the Arellano-Bond AR(p) test for serial correlation. This addresses the endogeneity and omitted-variable concerns outlined above. Firstly, beyond the GMM coefficient results, the IRF analysis allows us to trace the dynamic responses of socio-economic indicators (i.e., employment, energy, financial accessibility, firm density, firm size, and firm turnover) following the renewables shock. This enables us to assess not just the average size of each outcome but also the time path and duration of the response, providing more detailed information about the direction and strength of the renewables-induced effects. The combination of empirical models and IRF methodology, controlling for firm-level fixed effects and standard business cycle shocks, allows us to trace lagged responses. Together, they provide a robustness check and offer more detailed insights into how the spillover effects of renewables evolve across different time horizons. Secondly, we include interactions of the three core renewables variables (i.e., RII×RE, RII×R&D, and RE×R&D) in our model to examine potential complementarities. This enables us to determine whether the concurrent adoption of renewables infrastructure, deployment, and innovation yields socio-economic benefits that exceed the sum of their individual effects. It also provides a robustness check for the hypothesis that the complementarities between these variables could produce non-linear co-benefits that the sum of their individual effects fails to capture (Popp, Newell, & Jaffe, 2010). For

example, firms pursuing both heavy infrastructure rollout and own-funded renewables R&D may experience tangible employment gains compared to those focusing solely on one aspect. Thirdly, we account for temporal and structural heterogeneity.

The available timeseries is divided into two sub-samples covering 2012–2016 and 2017–2024. First, we consider whether the effect differs before and after Vision 2030. This division allows us to assess whether the implementation of Vision 2030 in 2016 marked a structural break in the socio-economic spillovers from renewables, in line with how the broader policy agenda shapes transition pathways (Alshehry & Belloumi, 2015). We consider the role of high and low oil prices, given the importance of conditions in fossil-fuel markets for the deployment of renewables (Taghizadeh-Hesary et al., 2021). Further granularity is added by examining sub-samples. Firms are separated by sector into either energy-intensive or non-energy-intensive, as the implications for labor and growth are likely to be heterogeneous (Carley & Konisky, 2020). Finally, we separate by large and small/medium enterprises, as the ability to innovate, obtain resources, and achieve economies of scale can have different effects across heterogeneous organizations (Horbach & Rennings, 2013). Second, we take the natural logarithms of RII, firm size FSIZE, and all dependent variables. This step is standard practice in the literature (Colombelli, Krafft, & Quatraro, 2016; Han, Kang, & Shin, 2018) for at least three reasons. First, taking natural logarithms addresses skewness and heteroscedasticity common in firm-level financial variables. Second, it allows us to interpret coefficients as elasticities, which are easier to understand. Third, since RII measures log (CAPEXrevenue) for a firm, taking the natural logarithm enables comparison of firms' ability to use renewables across markets and helps address outlier effects. We estimate all regressions using the two-step System GMM estimator rather than the more consistent but less efficient one-step estimator. Given our relatively short panel (T=13), 62 we report results with standard errors corrected for downward bias in the two-step using the finite-sample correction proposed by Windmeijer (2005). Refinements to the model specification, sample definition, and estimation framework deepen our insights into the socio-economic spillovers of RES transitions. They clarify how, when, and for which groups of firms these effects occur. The findings have significant implications for well-informed policy and business decisions in the region's rapidly evolving energy system.

5. RESULTS AND DISCUSSION

This part shows the results for the three variables and discusses the effects of the key variables promoting renewable energy on economic and social variables.

5.1. Panel Data Analysis

There is a relatively clear distinction in the order of criteria regarding the socio-economic impact of renewable energy. Specifically, localized economic impacts can be achieved to a much higher magnitude and in a shorter period than the overall economic impact. As shown in Table 4, Renewable Infrastructure Investment (RII) appears to be the most robust across all models used to estimate employment, with coefficients ranging from 0.102 to 0.173. Importantly, the coefficient of the interactive term (RII×RE) in all models is both positive and significant (with the highest at 0.215), suggesting that infrastructure investment during the entire project implementation and the actual operation period of renewable power jointly produce an employment effect greater than the sum of their individual effects.

This highlights that combined policies should be prioritized over single initiatives. Additionally, the coefficients for the Vision 2030 progress (0.201) and government subsidy (0.118) components emphasize the importance of subsidies and relevant policies for a green economic transition toward more jobs.

Table 4. Impact on Employment Rate (EMP).

Variable	(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				
Hansen test (p-value)	0.125	0.210	0.180	0.155
AR(1) Test (p-value)	0.032**	0.028**	0.025**	0.030**
AR(2) Test (p-value)	0.456	0.510	0.432	0.401
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 from four specifications, with estimates referring to the equation with Employment Rate as the dependent variable. The models are estimated using a two-step System GMM with Windmeijer-corrected standard errors. 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. GMM diagnostics include the Hansen test, which reports the p-value for the null hypothesis that the instruments are valid (p > 0.05 indicates valid instruments). The AR(1) and AR(2) tests assess first-order and second-order autocorrelation in the first-differenced errors, with the null hypothesis of no autocorrelation. Significant AR(1) and insignificant AR(2) support the model specification.

Table 5 presents the response of Local Energy Accessibility (LEA) and indicates a more pronounced effect of RII than in integrated employment estimation (e.g., as high as 0.214). It stems from the close linear relationship of capital investments with power accessibility, especially for distributed generation projects. Similar to employment estimation, the interactive term is significantly positive (RII×RE max as 0.258), reconfirming that integrating policies is more effective than adopting a single policy to mitigate energy poverty. Additionally, the subsidy (0.153) and the progress of Vision 2030 (0.236) show relatively larger coefficients than those in the employment equation. This may indicate that these effects are more significant in reducing disparities and targeting the otherwise excluded when

these policies are applied. Estimates for FRG present a more modest view of RII's role and its negative association with a firm's business growth.

Table 5. Impact on local energy accessibility (LEA).

Variable	(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				
Hansen test (p-value)	0.115	0.195	0.165	0.140
AR(1) Test (p-value)	0.029**	0.025**	0.022**	0.027**
AR(2) Test (p-value)	0.442	0.498	0.420	0.388
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. The models are estimated with a two-step System GMM and Windmeijer-corrected standard errors. Column (1) employs 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. Significance levels are indicated by *, **, and *** at 10%, 5%, and 1%, respectively, with standard errors in parentheses.

The results in Table 6 show that the RE coefficient is only 0.092, which is less than half the estimated RII effect on increasing EA (see Table 4). Compared with previous estimates for other aspects of green investment, these estimates are broadly consistent with the literature, which finds that the multiplier for environmental innovation ranges from 0.04 to 0.10 in European firms (Horbach & Rennings, 2013). Other estimates of investment in renewable energy range from 0.07 to 0.15 for emerging economies (Taghizadeh-Hesary et al., 2021). Thus, our estimate of 0.092 appears broadly comparable and perhaps moderate relative to other green-related investment types. Akin to the

relative weakness of the RII multiplier on FRG compared to EA, our findings suggest that overall macroeconomic gains may lag behind more localized socioeconomic gains, often delayed by the costs of transition and widespread macroeconomic reform. This is supported by the sign and estimate for RE, which appear to be strongly dependent on the model specification and depiction of the market; additionally, the negative impact of oil prices appears large at −0.128 in the FRG estimation. This partially supports previous findings for hydrocarbon producers, indicating that the growth potential of renewable energy is considerably influenced by the conditions of the global fossil-fuel markets (Alshehry & Belloumi, 2015). Additionally, the relatively low significance of the estimated interaction variables in Table 6 likely indicates that sustainable increases in FRG from an initial boost to the firm's green investment may not be realized without further, widespread sectoral changes. This may align with the notion that firm-level energy transitions must be accompanied by more systemic innovation and institutional change for tangible economic outcomes to arise (Sovacool et al., 2022).

Table 6. Impact on FRG rate.

Variable	(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
	(0.030)	(0.033)	(0.034)	(0.031)
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				
Hansen Test (p-value)	0.135	0.225	0.190	0.170
AR(1) Test (p-value)	0.035**	0.031**	0.020**	0.024**
AR(2) Test (p-value)	0.467	0.471	0.418	0.392
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 FRG Rate as the dependent variable, using four specifications. The models are estimated with two-step System GMM and Windmeijer-corrected standard errors. 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. Significance levels are indicated by *, **, and *** at 10%, 5%, and 1%, respectively, with standard errors in parentheses.

Table 7, as a robustness check, may help us identify the causes of the trends observed in the baseline estimations. It provides important insights at both the temporal and structural levels. The strongest signal in terms of time heterogeneity, as expected, relates to the magnified role of the new development plan under Vision 2030. For employment, the coefficient for RII increased from 0.121 before the policy's onset in 2016 (i.e., 2012–2016) to 0.189 since then (i.e., 2017–2024).

We observe a similar pattern of increase for LEA, with the RII coefficient rising from 0.158 to 0.227 for the periods following and preceding the policy, respectively. Table 7 also provides strong evidence for cross-sectional heterogeneity. It appears that the employment of large firms reacted more sensitively to RII (0.177) compared with that of small and medium-sized firms (0.098).

The result contrasts with the general view that small and medium-sized firms with higher management adaptability would have better outcomes. It might suggest some evidence of capital and scale effects in the distribution of transition benefits. Regarding FRG, we have an interesting ambiguity concerning the condition of the global oil market.

The magnitude of returns to renewables, as measured by FRG, is larger during periods of low oil prices (RII coefficient of 0.077) than during periods of high oil prices (RII coefficient of 0.031). The direction of this relationship might imply an overall increase in the competitiveness of renewables amid cheap fossil fuels, as well as the more expansive fiscal space it creates for new strategic and long-term investment projects amid a fiscal surplus. For all outcomes, we observe significant disparities in estimated coefficients for RE subsamples. It is noteworthy that the coefficient sometimes turns negative, most notably and most reliably for energy-intensive companies in column 4 of tables 4–6, despite being generally insignificant. This likely reflects heterogeneous adjustment costs and sectoral characteristics.

Energy-intensive companies may (i) have higher short-term adjustment and retraining costs, or have capital that is (ii) harder to redeploy for renewable, thus limiting compounding benefits, a result of the prevalence of fossil fuels in their product lines historically. Furthermore, (iii) if their adoption is disproportionately compliance-driven rather than efficiency-driven, benefits may not materialize in the short run.

The magnitude and significance of the RE term vary between the three oil price sets and the four firm-size categories. This shows that the returns to renewables adoption are sensitive to market conditions and idiosyncratic firm-level characteristics. These findings suggest that a one-size-fits-all policy would not suffice and that lower rates of return for energy-intensive firms (and possibly for related characteristics, such as firm size) point towards the need for a mix of assistance programs to ensure a green transition for these companies (such as phased subsidies, targeted technology assistance, transition financing, etc.).

In sum, Tables 4, 5, 6, and 7 present evidence for a two-track, targeted approach to policy. The timing results, estimated benefits peak earlier for employment and persist longer for access, suggest that the first part of the policy agenda should prioritize the former through targeted access infrastructure investment and subsidies. The second part should focus on increasing the renewable energy share via higher investments in transmission, distribution, and renewable access to boost follow-on investment. Additionally, implementing stronger economy-wide structural reforms can help create the potential for local effects to become cross-state spillover effects. The persistence of large SME gaps and their widening dependence on oil prices indicate that there is no one-size-fits-all solution. Therefore, a fair and effective energy transition requires policies that are both temporally graded and tailored to the structural issues of various regional and firm typologies across the national territory.

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

Variable	2012–2016	2017–2024	High Oil	Low Oil	Large Firms	SMEs
Impact on Employment (EMP)						
RII	0.121**	0.189	0.073*	0.164**	0.177	0.098*
	(0.056)	(0.062)	(0.042)	(0.070)	(0.058)	(0.050)
RE	0.085*	0.142**	0.052	0.118	0.133**	0.073
	(0.048)	(0.063)	(0.038)	(0.055)	(0.059)	(0.047)
R&D	0.063*	0.112**	0.038	0.095	0.101**	0.055
	(0.035)	(0.051)	(0.028)	(0.043)	(0.046)	(0.037)
RII×RE	0.142*	0.231**	0.098	0.203	0.198**	0.116
	(0.075)	(0.091)	(0.065)	(0.092)	(0.087)	(0.079)
V2030	—	0.195	0.083*	0.167**	0.181**	0.104*
		(0.068)	(0.046)	(0.073)	(0.079)	(0.057)
Impact on Local energy accessibility (LEA)						
RII	0.158**	0.227	0.102*	0.203**	0.213	0.134*
	(0.068)	(0.074)	(0.053)	(0.087)	(0.070)	(0.065)
RE	0.124**	0.191	0.076	0.162**	0.176**	0.109*
	(0.059)	(0.071)	(0.048)	(0.070)	(0.072)	(0.061)
R&D	0.097**	0.153	0.061	0.132**	0.142**	0.085
	(0.046)	(0.058)	(0.040)	(0.055)	(0.063)	(0.051)
RII×RE	0.188**	0.274	0.124	0.247**	0.239**	0.153
	(0.088)	(0.102)	(0.081)	(0.110)	(0.108)	(0.095)
V2030	—	0.243	0.112**	0.204**	0.223**	0.141*
		(0.081)	(0.058)	(0.092)	(0.096)	(0.073)
Impact on FRG rate (FRG)						
RII	0.048	0.094**	0.031	0.077*	0.083**	0.042
	(0.039)	(0.043)	(0.028)	(0.041)	(0.037)	(0.035)
RE	0.037	0.068	0.019	0.063	0.059	0.028
	(0.032)	(0.037)	(0.025)	(0.039)	(0.034)	(0.031)
R&D	0.029	0.055	0.014	0.048	0.053*	0.023
	(0.023)	(0.029)	(0.019)	(0.027)	(0.029)	(0.020)
RII×RE	0.071	0.135	0.052	0.112*	0.127*	0.064
	(0.049)	(0.070)	(0.043)	(0.065)	(0.068)	(0.053)
V2030	—	0.122**	0.055	0.098*	0.115*	0.067
		(0.053)	(0.037)	(0.051)	(0.059)	(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. *, ** indicate statistical significance at the 10% and 5% levels, respectively.

5.2. IRFs Visualizations

To capture dynamics beyond the static associations in our panel regressions, we conduct Impulse Response Function (IRF) analysis, which allows us to observe the temporal evolution of socio-economic indicators in response to shocks to renewable energy outcomes.

To compare output dynamic outcomes, we first construct IR functions following (Dimitropoulos, Simons, & Hall, 2016). Then, we apply a series of one-standard-deviation shocks to renewable energy investment (RII) and access (RE), observing the corresponding dynamic patterns in employment (EMP), local energy access (LEA), and firm revenue growth (FRG) over a decade-long horizon. In addition to the magnitude of the response to the shock, the IR function analysis provides estimates of the impact's longevity and the trajectory back to the original mean, with 90% confidence bands around the means before and after the shock indicating data uncertainty. We first estimate the dynamic economic impact of an unexpected shock to RII. The simulation captures the time deviation of our three economic indicators, Employment, Local Energy Access, and FRG, from their steady state following the RII shock (Figure 4). The plot indicates that an investment shock of this nature elicits a near-term increase in FRG, while simultaneously triggering positive responses in employment and energy access. This pattern illustrates how context-specific infrastructure spending can produce an economic multiplier that increases short-term economic returns and

lays the groundwork for far-reaching social benefits down the line, as employment opportunities and access to energy rise.

The figure shows the percentage deviations from the mean for employment and energy access, and the percentage-point deviations from the mean for FRG, over seven years after the initial RII shock. All variables display a consistently positive response, indicating that infrastructure spending has a multiplier effect. In particular, the results indicate that a shock to RII positively influences contemporaneous short-term economic activity (FRG peaks immediately) and far-reaching social outcomes, such as employment and energy access, which are essential for development. That all three indicators trend positively in tandem demonstrates the potential for public spending to deliver multiple economic and social priorities when structured effectively.
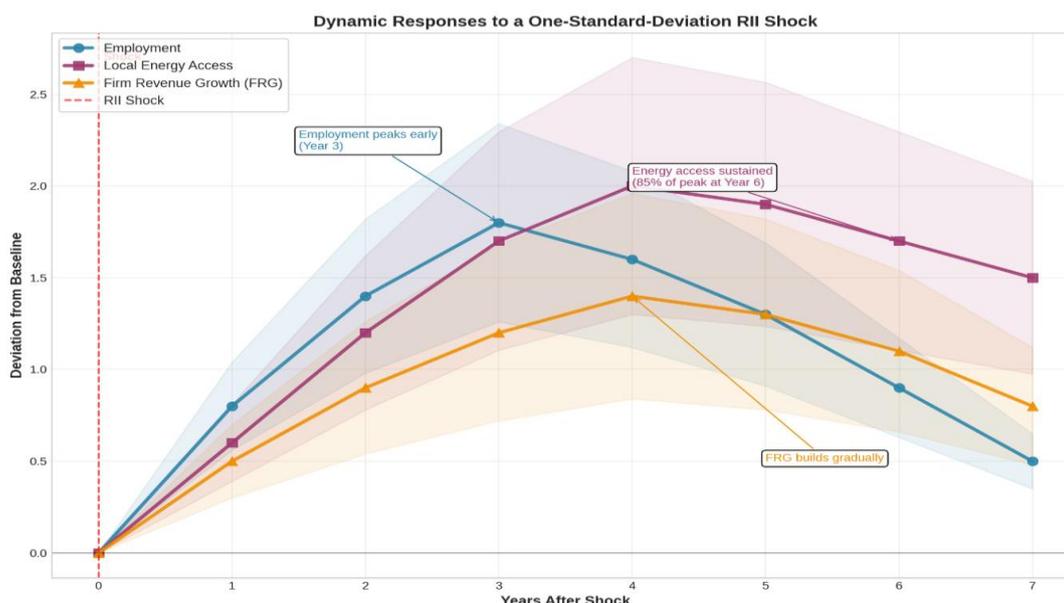
Figure 4. The Macroeconomics and Social Impact of a Regional Infrastructure Investment (RII) Shock.

The net of the empirical findings in this paper provides strong overall support for the three main hypotheses outlined at the start of the paper. Firstly, our study finds that firm-level RII has positive but heterogeneous socio-economic impacts over time. Our empirical analysis first demonstrates that employment effects peak rapidly. In contrast, local electricity access shows greater persistence, and the benefits of firm revenue growth (FRG) take longer to materialize (and remain relatively minor). This observation is consistent with our a priori notion of the trajectory of transition outcomes. Secondly, our subsample analysis provides robust empirical support for our hypothesis that the socio-economic impacts of renewable investment became much stronger following the policy stimulus and emphasis after 2016 within the rubric of Saudi Vision 2030. The size and statistical significance of the overall coefficients for RII, RE, and policy remained consistent across all three dependent variables in the 2017–2024 sub-sample, underscoring the crucial value of an integrated national plan. Lastly, we have evidence that the impacts indeed differ across socioeconomic classes. The results suggest an interesting difference in the magnitude of employment RII between large firms and SMEs. Secondly, although the FRG effect of renewable energy is small, it is more sensitive to changes in oil prices than regional effects such as employment and accessibility. Overall, these results prove our assumption that the distributional net benefits of firm-level renewable energy transition will be non-linear and contingent on policy timing, firm size, and economic conditions.

6. POLICY IMPLICATION

Several concrete policy implications emerge from these data-driven findings. First, because our data show that the most robust short-term employment and access benefits come via RII (vs. EDR), especially after 2016 Vision

2030, we infer a strategic sequencing role. As benefits are conditional on future firm behavior, there is a phase of emphasis on biased policy.

Specifically, our results show that RII's coefficient for job creation peaked at 0.189 post-2016, compared with 0.121 pre-Vision 2030. This confirms the accelerator effect of long-term Vision 2030 plans. We argue that policy should simplify and incentivize near-term RII, especially decentralized RII, implying on-site capital funding policies. Such policies could include fast-tracking permitting processes for corporate renewable projects, facilitating grid connection, or providing direct grants or soft loans for renewable energy investment. This could be particularly important in locations or governorates where the transition has not yet reached, meaning households rely on non-grid-connected sources of power. Second, the persistence of the divide in the employment benefits of large and SMEs, where large businesses receive a more substantial spillover (0.177) compared to SMEs (0.098 from RII), suggests a challenge to distributive justice. If left unaddressed, the transition may lead to the monopolization of its economic benefits, diverging from the distributive and energy-justice objectives of Vision 2030.

To ensure a broader spread of employment gains from the low-carbon transition across business sizes, policy would need to incorporate targeted distributive planning. Such planning here could entail: (i) the provision and/or fast-tracking of either/or combined access to subsidy granting programs, particularly access-to-finance programs, to empower smaller businesses to invest in renewable energy projects to overcome investment financing bottlenecks; (ii) capacity building to upskill workers, especially about building and operating renewable projects; and (iii) the provision of supply-chain facilitation to ensure a linkage is created between SMEs and downstream elements of renewable projects operationalized by large businesses. This, coupled with the implication of a declining trend in RII's effect on employment (the spillover declines after approximately six years, Figure), means that, to sustain these employment gains as the transition progresses, continuous vocational training and integration centers would be needed. Third, the mixed trend effects and the muted response of firm revenue (FRG) to renewable investment in our baseline case represent another strong planning challenge. A muted, more lagged response from FRG to green investment further makes it more reactive to global oil prices. Indeed, we find that the effect of RII on FRG almost doubled during the low-oil-price era. This denotes that renewable energy policy cannot stand alone. It should be included in policy packages for economic stability and diversification. Since our results indicate that the indirect effect of the hydrocarbon sector is dampening the firm-level economic impact of green infrastructure, there is a need to implement counter-cyclical financing measures for renewable energy projects, as the sovereign wealth fund did for green innovation projects. In addition, to unlock the full potential of green infrastructure for firm-level growth, additional structural policies are required. These include, for example, tax credits for private R&D investments in renewables (which, as we show, are more strongly correlated with growth in the post-2016 data), updates to the regulatory framework to encourage energy-efficient and green product development, and training and capacity building for skilled and digitally-enabled human capital to facilitate a knowledge-based green transition. Third, the transition path suggested by this paper is a prioritization and a schedule for policy actions. A complete set of transition roadmaps would, first, unlock employment and energy access through large-scale infrastructure projects facilitated by Vision 2030, and, at the same time, where necessary, take specific actions to ensure the inclusion of SMEs and disadvantaged governorates, and, lastly, integrate this into an overall policy package of economic stabilization and revenue diversification. By designing policy interventions that address differential impacts, Saudi Arabia and other oil-dependent countries can ensure their energy transition is environmentally sustainable, socially inclusive, and economically resilient.

7. CONCLUSION

This paper demonstrates that there are firm-level socio-economic implications from renewable energy adoption and that policy timing, regional economic development, and firm size play critical roles. Using firm-level microdata from Saudi Arabia, we find that policy intervention after 2016, as part of Vision 2030, has led to fast socio-economic

71

benefits (i.e., employment and local energy access), where these benefits are more pronounced when larger firms make investments through decentralized technologies. However, firm revenue growth benefits materialize over a more extended period and remain vulnerable to oil price fluctuations due to continued financial linkages in a hydrocarbon-based economy. We also highlight that long-term regional inequalities are emerging, as local economies heavily reliant on fossil fuels are moving more slowly. Energy justice is a primary concern here.

Overall, our results highlight to policymakers in resource-rich countries such as Saudi Arabia the need to adopt time- and space-specific policies. National renewable energy targets must be tailored to local energy transition pathways. Our results suggest the need for time-specific policies to close the energy access gap, as well as spatially specific policies that provide targeted financial and technical assistance to small and medium-sized enterprises (SMEs) to address firm-size inequity. From a firm-level perspective, we see that translating a national vision for inclusive development requires firms to serve as agents of change and to invest in human capital and diversified economic development outside the energy sector. Despite the potential implications of our findings, the study has some limitations that can be addressed in future work. Firstly, the analysis was restricted to large enterprises in the formal sector. Although this consideration yields more robust and reliable data, it ignores micro-enterprises, the informal sector, and household-level analysis, which could lead to missing an important piece of the labor market and energy poverty phenomenon. Secondly, measurement error still exists. It is hard to quantify the total regional energy availability and R&D intangible assets. Moreover, the use of firm-level data, particularly when obtained from firm reports, could be subject to firm-level bias. Lastly, while we attempt to control for heterogeneity, the model may not generalize to other countries due to country-specific institutions and cultural factors.

This raises several avenues for future research. For example, the aforementioned studies could use a mixed-methods approach, combining a quantitative panel analysis with qualitative case studies to investigate cultural, behavioral, and institutional barriers that firms face during the transition. A second approach would be to include variables on physical and transition climate risk in the firm-level models to investigate the extent to which environmental exposures affect investment decisions and socio-economic outcomes. A third approach could be to conduct firm-level studies of the renewable energy transition in non-resource-rich countries to isolate policy impacts from the pervasive influence of hydrocarbon wealth. Finally, new data on SMEs and the informal sector are needed to fully grasp the distributional implications of the energy transition. This will help researchers and policymakers develop more nuanced models that account for both global technological needs and local socioeconomic conditions to achieve a technologically feasible and socially just green transition.

REFERENCES

Acemoglu, D., Aghion, P., Bursztyn, L., & Hemous, D. (2012). The environment and directed technical change. *American Economic Review, 102*(1), 131-166. https://doi.org/10.1257/aer.102.1.131

Alshehry, A. S., & Belloumi, M. (2015). Energy consumption, carbon dioxide emissions and economic growth: The case of Saudi Arabia. *Renewable and Sustainable Energy Reviews, 41*, 237-247. https://doi.org/10.1016/j.rser.2014.08.004

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies, 58*(2), 277-297. https://doi.org/10.2307/2297968

Bhattacharya, S., Chengoden, R., Srivastava, G., Alazab, M., Javed, A. R., Victor, N., . . . Gadekallu, T. R. (2022). Incentive mechanisms for smart grid: State of the art, challenges, open issues, future directions. *Big Data and Cognitive Computing, 6*(2), 47. https://doi.org/10.3390/bdcc6020047

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics, 87*(1), 115-143. https://doi.org/10.1016/S0304-4076(98)00009-8

Bowen, A., Kuralbayeva, K., & Tipoe, E. L. (2018). Characterising green employment: The impacts of 'greening' on workforce composition. *Energy Economics, 72*, 263-275. https://doi.org/10.1016/j.eneco.2018.03.015

Burke, M. J., & Stephens, J. C. (2018). Political power and renewable energy futures: A critical review. *Energy Research & Social Science, 35*, 78-93. https://doi.org/10.1016/j.erss.2017.10.018

Carley, S., & Konisky, D. M. (2020). The justice and equity implications of the clean energy transition. *Nature Energy, 5*(8), 569-577. https://doi.org/10.1038/s41560-020-0641-6

Colombelli, A., Krafft, J., & Quatraro, F. (2016). The emergence of new technology-based sectors: A knowledge-based analysis of nanotechnology. *Research Policy, 45*(4), 784–798.

Dagnachew, A. G., Hof, A. F., Roelfsema, M. R., & van Vuuren, D. P. (2020). Actors and governance in the transition toward universal electricity access in Sub-Saharan Africa. *Energy Policy, 143*, 111572. https://doi.org/10.1016/j.enpol.2020.111572

Dimitropoulos, J., Simons, A., & Hall, S. (2016). The economic and environmental impact of renewable energy development: Evidence from panel VAR models. *Energy Economics, 56*, 364–376.

Gamarra, A. R., Banacloche, S., Caldés, N., & Lechón, Y. (2023). The socio-economic benefits of renewable energy projects. In Handbook on the Economics of Renewable Energy. In (pp. 118-137). Edward Elgar Publishing: Spain.

Han, J., Kang, J., & Shin, Y. (2018). Firm-level productivity, financial constraints, and innovation. *Journal of Economic Behavior & Organization, 152*, 67–84.

Hassan, Q., Viktor, P., Al-Musawi, T. J., Ali, B. M., Algburi, S., Alzoubi, H. M., . . . Jaszczur, M. (2024). The renewable energy role in the global energy Transformations. *Renewable Energy Focus, 48*, 100545. https://doi.org/10.1016/j.ref.2024.100545

Horbach, J. (2008). Determinants of environmental innovation—new evidence from German panel data sources. *Research Policy, 37*(1), 163-173. https://doi.org/10.1016/j.respol.2007.08.006

Horbach, J., & Rennings, K. (2013). Environmental innovation and employment dynamics in different technology fields–an analysis based on the German community innovation survey 2009. *Journal of Cleaner Production, 57*, 158-165. https://doi.org/10.1016/j.jclepro.2013.05.034

Johnstone, N., Haščič, I., & Popp, D. (2010). Renewable energy policies and technological innovation: Evidence based on patent counts. *Environmental and Resource Economics, 45*(1), 133-155. https://doi.org/10.1007/s10640-009-9309-1

Khrais, L. T., & Alghamdi, A. M. (2025). Evaluating the socioeconomic and environmental impacts of renewable energy transition and green e-business on urban sustainability. *Sustainability, 17*(8), 3404. https://doi.org/10.3390/su17083404

Lucas Jr. R. E. (1988). On the mechanics of economic development. *Journal of Monetary Economics, 22*(1), 3-42. https://doi.org/10.1016/0304-3932(88)90168-7

OPEC. (2023). *Annual statistical bulletin 2023.* Vienna, Austria: OPEC.

Pearce, D. (1989). *Blueprint for a green economy.* London: Earthscan Publications.

Popp, D., Newell, R. G., & Jaffe, A. B. (2010). Energy, the environment, and technological change. In B. H. Hall & N. Rosenberg (Eds.), Handbook of the economics of innovation. In (Vol. 2, pp. 873–937). Amsterdam, The Netherlands: Elsevier/Academic Press.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy, 98*(5, Part 2), S71-S102 https://doi.org/10.1086/261725.

Sovacool, B. K., & Dworkin, M. H. (2015). Energy justice: Conceptual insights and practical applications. *Applied Energy, 142*, 435-444. https://doi.org/10.1016/j.apenergy.2015.01.002

Sovacool, B. K., Newell, P., Carley, S., & Fanzo, J. (2022). Equity, technological innovation and sustainable behaviour in a low-carbon future. *Nature Human Behaviour, 6*(3), 326-337. https://doi.org/10.1038/s41562-021-01257-8

Taghizadeh-Hesary, F., Rasoulinezhad, E., & Yoshino, N. (2021). The role of renewable energy investments in labor market outcomes: Evidence from global energy transitions. *Energy Economics, 99*, 105291.

Ur Rehman, A., Iqbal, S., Shafiq, A., Alshammari, N. F., Dar, S. H., & Iqbal, R. T. (2024). Multifaceted impacts of widespread renewable energy integration on socio-economic, ecological, and regional development. *Sustainable Futures, 8*, 100241. https://doi.org/10.1016/j.sftr.2024.100241

Windmeijer, F. (2005). A finite sample correction for the variance of linear efficient two-step GMM estimators. *Journal of Econometrics, 126*(1), 25-51. https://doi.org/10.1016/j.jeconom.2004.02.005