










## **Do Natural Resource Rents Hinder or Promote Renewable Energy Investment? The Moderating Role of Institutional Quality and Financial Development in Resource-Rich Developing Economies**

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### **ABSTRACT**

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This study examines how natural resource rents, institutional quality, and financial development influence renewable energy investment across 20 resource-rich developing economies in Latin America, Middle East and North Africa (MENA), Sub-Saharan Africa, and Central Asia from 2000 to 2024. The findings confirm the resource curse hypothesis, showing that natural resource rents significantly reduce renewable energy investment. However, institutional quality emerges as the strongest positive driver, with an identified governance threshold ( $IQ^* \approx 1.47$ ) beyond which resource rents shift from crowding out to supporting clean energy investment. Financial development further promotes renewable energy investment by lowering financing costs and enhancing risk-sharing mechanisms. Employing second-generation panel tests, Method of Moments Quantile Regression (MMQR), and Dumitrescu-Hurlin causality, supported by Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) robustness checks, the study uncovers distributional heterogeneity missed by conventional mean-based approaches. The resource curse intensifies at higher investment levels, while the moderating role of institutional quality strengthens consistently across quantiles. Causality analysis identifies bidirectional links between financial development, institutional quality, and renewable energy investment, alongside a unidirectional effect running from resource rents to carbon emissions. These findings carry important policy implications. Strong governance and well-developed financial systems can effectively transform resource wealth into a catalyst for clean energy transition in resource-dependent developing economies, offering a credible pathway toward sustainable development.

The imperative to transition toward renewable energy sources has become a critical policy issue of the twenty-first century. The 2015 Paris Agreement and Sustainable Development Goal 7 emphasize the necessity to augment renewable energy investment, particularly in developing countries where energy poverty and dependence on fossil fuels are widespread. Many high-potential renewable energy markets worldwide are also resource-abundant, where significant reserves of oil, gas, and minerals have historically shaped institutional, financial, and political-economic structures, systemically disadvantaging clean energy options [1, 2].

The resource curse refers to the empirical observation that resource-abundant nations often underperform relative to resource-scarce counterparts in terms of economic growth,

institutional quality, and economic diversity [3-5]. Recent research on the determinants of renewable energy deployment has predominantly focused on macroeconomic variables such as income levels, energy prices, and trade openness [6, 7], while institutional and financial mechanisms have only recently garnered empirical scrutiny [8-10].

This study investigates this gap by analyzing three interrelated questions. First, do natural resource rents statistically and economically hinder renewable energy investment in resource-abundant developing countries? Second, does institutional quality, including Rule of law, voice and accountability, control of corruption, government effectiveness, political stability, and regulatory quality, lessen the influence of the resource curse on the adoption of green energy? Third, to what extent do well-developed and efficient

financial institutions reinforce the impact of resource revenues and institutional quality on renewable energy investment? Responding to these questions requires an empirical methodology that is robust against the dual econometric issues of cross-sectional dependence (CD) and slope heterogeneity, commonly found in macro-panel datasets from developing countries, and that is also capable of revealing distributional heterogeneity in how these forces operate across countries with differing levels of renewable energy investment.

A panel dataset is constructed comprising 20 resource-rich developing countries from Central Asia, Latin America and the Caribbean, Sub-Saharan Africa, and the Middle East and North Africa (MENA) covering the period from 2000 to 2024. This sample is chosen to enhance institutional, geographic, and structural variety while maintaining a thematic focus on resource dependency. The econometric framework methodically utilizes: (i) panel unit root tests of the second generation that control for CD (ii) Westerlund error-correction-based cointegration tests; (iii) the Common Correlated Effects Mean Group (CCEMG) estimator [11] and the Augmented Mean Group (AMG) estimator [12] for heterogeneous long-run panel estimation; (iv) the Method of Moments Quantile Regression (MMQR) of Machado and Silva [13] to characterize how the long-run elasticities vary across the conditional distribution of renewable energy investment; and (v) the Dumitrescu and Hurlin [14] panel Granger causality test for directional inference. Robustness is validated through Dynamic Ordinary Least Squares (DOLS) and Fully Modified Ordinary Least Squares (FMOLS) estimators.

The study makes three principal contributions. First, it offers the first systematic panel-econometric evidence that natural resource rents exert a long-run, causally precedent drag on renewable energy investment specifically in resource-rich developing economies, an empirical setting that has remained underexplored despite its prominence in policy debates surrounding the global energy transition. Second, it elevates the conditional resource-curse hypothesis from a theoretical proposition into an operational benchmark by identifying and explicitly calibrating the governance threshold at which institutional quality fully offsets the crowding-out effect of resource rents. Third, by combining a moments-based quantile regression with directional causality analysis, the study uncovers two features that mean-based estimators cannot detect: the resource curse and the institutional-mediation channel both intensify monotonically along the conditional distribution of renewable energy investment, and the relationship between governance and renewable investment is bidirectional, indicating that the energy transition itself helps reshape the institutional environment. Together, these contributions reframe the dominant view that resource wealth is an inevitable barrier to the clean-energy transition and identify governance reform and domestic financial deepening as the two most actionable levers available to resource-rich developing countries.

The remainder of this study is organized as follows. Section 2 examines the pertinent theoretical and empirical literature and constructs the research hypotheses. Section 3 describes the data, sample selection, and variable construction. Section 4 presents the econometric methodology, encompassing CD tests, unit root analysis, cointegration procedures, long-run estimation methods, and the MMQR approach. Section 5 presents the empirical evidence, and Section 6 discusses it within the context of

existing studies and formulates policy implications. Section 7 concludes the study by summarizing the primary findings, highlighting contributions, acknowledging limitations, and proposing avenues for further research.

## 2. LITERATURE REVIEW

The discourse on the natural resource curse originated with the seminal cross-country analysis by Sachs and Warner [3], demonstrating that an abundance of natural resources, particularly when measured by primary exports as a percentage of Gross Domestic Product (GDP), negatively correlates with per capita economic growth. Subsequent research has contested the universality of this finding [15], yet the preponderance of evidence, particularly at the subnational level and over prolonged durations, corroborates the assertion that resource revenues precipitate Dutch disease effects, undermining tradable manufacturing and knowledge-intensive sectors [16, 17]. Torvik [18] and Robinson et al. [19] suggested the mechanisms by which resource rents lead to institutional deterioration, encompassing rent-seeking, reduced state capacity, and weakened accountability. Mehlum et al. [20] empirically demonstrated that the growth impacts of resource wealth are contingent upon institutional quality.

The concept of the resource curse has been utilized in energy economics literature to explain why fossil fuel exporters consistently fall behind in the adoption of renewable energy. The Dutch disease mechanism directly impacts the energy sector: abundant fossil fuel revenues reduce the relative price of energy, weaken the incentive for efficiency improvements, and generate fiscal revenues that supplant extensive economic transformation. Fossil fuel rents create powerful stakeholders, including state energy companies, fossil fuel laborers, and dependent financial authorities, who strongly resist energy transition initiatives [21, 22]. Gorji and Martek recently analyzed the impact of renewable energy policies on technology implementation in 20 developed and 20 developing oil-producing countries, revealing that the resource curse considerably diminishes the efficacy of policy support for renewables in resource-dependent nations [23]. Destek et al. [24] examined the influence of economic complexity in mitigating the resource curse across a comprehensive panel, discovering that diversified economic structures diminish the adverse relationship between resource dependency and sustainable development outcomes. Rasmoun and Ben-Salha [25] further demonstrated that oil rents adversely affect environmental quality in Saudi Arabia, whereas renewable energy consumption and green technological innovation improve it, providing country-level evidence that resource wealth impedes clean energy transitions in the absence of technological upgrading. Complementing this sectoral evidence, Sobirov et al. [26] tested the Environmental Kuznets Curve in ten Association of Southeast Asian Nations (ASEAN) economies using FMOLS, DOLS, and CCR estimators, showing that scale effects from GDP expansion and trade openness dominate composition effects, and that Foreign direct investment (FDI) exerts no statistically significant aggregate effect on CO<sub>2</sub> emissions. These findings reinforce the view that structural dependence on fossil fuels and regulatory gaps remain core barriers to sustainable growth in resource-dependent developing regions.

The empirical investigation into the factors influencing renewable energy investment includes microeconomic,

sectoral, and macroeconomic analysis. Sadorsky [6] established a cointegrating relationship between per capita income and renewable energy consumption at the national level, employing panel data from emerging economies. Apergis and Payne [7] expanded the analysis utilizing FMOLS and DOLS, confirming the positive income elasticity of renewable energy demand. Shahbaz et al. [27] identified financial development as a catalyst, arguing that more sophisticated capital markets diminish the financing costs associated with capital-intensive renewable projects. Asongu and Odhiambo [10] employed Generalized Method of Moments (GMM) and quantile regression on African panel data to confirm that financial accessibility and institutional governance are key determinants of renewable energy uptake. Premph et al. [28] validated the environmental Kuznets curve hypothesis and renewable energy within Sub-Saharan Africa, demonstrating through Dumitrescu and Hurlin causality tests that financial development and governance jointly determine renewable energy consumption within a panel of 38 Sub-Saharan Africa (SSA) countries. Marques et al. [8] conducted a cross-national regression analysis to identify the determinants of renewable electricity, emphasizing energy dependency, carbon emissions commitments, and market structure as key factors. Polzin et al. [9] implemented a more nuanced investment-flow perspective and show that institutional investors whose participation depends on regulatory transparency and governance standards account for an increasing share of global renewable energy financing. Egli et al. [29] established that country risk, closely associated with institutional quality, substantially elevates the cost of capital for renewable projects, therefore impeding investment.

Recent empirical research has further corroborated these links. Anton and Nucu [30] utilized panel data from European Union (EU) nations and illustrated that financial development, quantified by domestic credit and stock market capitalization, substantially enhances renewable energy consumption, even when accounting for income and energy prices. Li et al. [31] examined productive capacity, renewable energy investments, and climate mitigation technologies alongside fiscal policy challenges in the top-10 resource-exporting economies, finding that responsible resource production and consumption require coordinated fiscal frameworks to support sustainable energy transitions. Imtiaz et al. [32] investigated the impact of debt, renewable energy, and energy imports on Pakistan's carbon emissions, demonstrating that leapfrogging toward sustainability is feasible when renewable energy adoption is coupled with prudent debt management and reduced fossil fuel import dependency. Haldar and Sethi [33] presented cross-national evidence indicating that institutional quality substantially decreases CO<sub>2</sub> emissions by fostering renewable energy utilization in developing nations, employing CCEMG and AMG estimators that address CD. In a methodologically parallel study, Shanyazov et al. [34] applied second-generation Cross-sectionally Augmented Autoregressive Distributed Lag (CS-ARDL) and AMG estimators to G7 economies over 2000 to 2022, showing that ICT goods exports and R&D expenditure both contribute to lowering energy intensity, with long-run elasticities of  $-0.082$  and  $-0.155$  respectively, offering evidence that supports this study's findings on the role of innovation-enabling institutions in the energy transition. Rafiq et al. [35] validated the beneficial impact of institutional quality on the advancement of renewable energy in Organisation for Economic Co-operation and Development (OECD) countries, utilizing rigorous panel unit root and

cointegration methodologies. In a complementary comparative Bayesian analysis of 22 developing and 26 developed economies, Nguyen and Le [36] demonstrated that both economic freedom and institutional quality positively drive sustainable development outcomes, with institutional quality exerting a particularly strong effect in developing economies, reinforcing the centrality of governance for development and environment objectives.

Tambari et al. [37] studied the connection between oil prices and renewable energy investment in African net oil-importing and net oil-exporting nations, revealing that oil price volatility exerts asymmetric effects on renewable energy investment based on a country's net trade status. Mahmood et al. [38] investigated institutional quality, renewable energy investment, financial development, and ecological risks in ASEAN nations utilizing AMG and CCEMG estimators, demonstrating that institutional quality and financial development markedly enhance environmental outcomes, whereas renewable energy investments exert a more pronounced effect on reducing per capita carbon emissions over the long term. This literature together indicates that institutional quality and financial development are both theoretically coherent and empirically substantiated factors affecting renewable energy investment, but extensive panel evidence from resource-rich developing nations remains limited, and quantile-based evidence on how these effects vary across the conditional distribution of renewable energy investment is virtually absent.

The theoretical framework incorporates three elements of economic theory: the resource curse hypothesis, the political economy of energy transition, and financial intermediation theory. The following hypotheses are hereby proposed:

Hypothesis 1 (H1): Natural resource rents have a negative and statistically significant impact on renewable energy investment in resource-abundant developing nations.

Hypothesis 2 (H2): Institutional quality positively moderates the relationship between natural resource rents and renewable energy investment, mitigating the crowding-out effect.

Hypothesis 3 (H3): Financial development has a positive and statistically significant impact on renewable energy investment, mediated by cost-of-capital and risk-pooling mechanisms.

### 3. DATA, SAMPLE, AND VARIABLES

The sample comprises 20 resource-rich developing economies selected through a two-step procedure. First, a country is classified as resource-rich if total natural resource rents exceed 5% of GDP in at least 10 years (consecutive or non-consecutive) of the 2000-2024 window. Both elements of this rule are grounded in the resource-curse literature: the 5% rents-to-GDP cut-off lies in the middle of the 4-8% range routinely used to demarcate structural resource dependence in classic and contemporary studies [3, 15, 20], and the 10-year persistence requirement screens out countries whose elevated rents reflect transient commodity windfalls rather than entrenched fiscal and political-economy dependence. Second, only economies with continuous availability of all eight model variables across the full sample period are retained. The final sample covers four geographic regions: Sub-Saharan Africa (Ghana, Angola, Nigeria, Gabon, Côte d'Ivoire, Cameroon, Zambia, Republic of Congo, Democratic Republic of Congo),

MENA (Iran, Algeria, Iraq, Egypt), Latin America and the Caribbean (Ecuador, Venezuela, Colombia, Bolivia, Trinidad and Tobago), and Central Asia (Kazakhstan, Uzbekistan). Several other resource-dependent developing economies were excluded due to data gaps in either the International Renewable Energy Agency (IRENA) Renewable Capacity Investment series or the International Monetary Fund (IMF) Financial Development Index over the full sample window: Equatorial Guinea, Chad, South Sudan, Mauritania, Yemen, Libya, and Turkmenistan. The selected sample period from 2000 to 2024 encompasses the full trajectory of modern renewable energy sector development, from the earliest commercialisation of wind and solar technologies to the investment surge that followed the Paris Agreement

Table 1 delineates the variables, their definitions, and the corresponding data sources. The dependent variable, renewable energy investment (REI), is defined as the natural logarithm of annual gross capital expenditure on renewable-energy generating capacity, expressed in constant 2015 USD, drawn exclusively from the IRENA Renewable Capacity Investment database [39]. IRENA reports country-level investment values that are derived from a single, internally consistent methodology that converts annual installed-capacity additions, by technology and country, into capital outlays using technology-specific weighted-average capital-cost benchmarks. Where IRENA reports a positive but unverified annual flow, the value is retained without imputation; missing observations are not interpolated but are excluded from the unbalanced panel. The resulting panel covers the 20 economies for at least 21 of the 25 sample years per country, yielding 487 country-year observations. The principal independent variable, natural resource rents (NRR), is measured as the share (0-1) of total natural resource rents in GDP, sourced from the World Bank World Development Indicators [40]; the variable is rescaled from the percentage form (0-100) reported in the original source to a 0-1 share scale

prior to estimation, as discussed in Section 4. The composite indicator of institutional quality (IQ) is derived by principal component analysis (PCA) from the six dimensions of the Worldwide Governance Indicators [41, 42]. The IMF Financial Development Index [43, 44] is used to measure financial development.

Table 2 presents the descriptive statistics. Descriptive statistics reveal considerable cross-national diversity across all variables. Natural resource rents range from a share of 0.011 (1.1% of GDP) to 0.524 (52.4% of GDP). The institutional quality composite displays a pronounced left skew, indicating that most countries in the sample lie well below the global governance average, a feature of resource-abundant developing economies consistent with political-economy theory. The financial development index averages 0.231, considerably lower than the global emerging-market average of roughly 0.45 [43], reflecting the well-documented underdevelopment of financial systems in resource-dependent economies.

Table 3 presents the pairwise correlation matrix which offers preliminary validation for the proposed hypotheses. Investment in renewable energy demonstrates an inverse relationship with natural resource rents and a direct relationship with institutional quality and financial development, consistent with hypotheses H1 to H3. The inverse correlation between NRR and IQ demonstrates the recognized adverse effect of resource rents on governance, whereas the positive relationship between IQ and FD confirms the institutional basis of financial development.

To formally assess multicollinearity, Variance Inflation Factor (VIF) tests were applied to all explanatory variables in the baseline model. The highest VIF value recorded is 3.21, which is well below the commonly used threshold of 10, while the average VIF of 2.07 also falls within acceptable limits. These results indicate no serious multicollinearity among the regressors. Table 4 presents the VIF values for each variable.

**Table 1.** Variables and data sources

Variable	Definition	Source
REI	Logarithm of renewable energy investment (constant 2015 USD)	IRENA Renewable Capacity Investment Database
NRR	Total natural resource rents as a share (0-1) of GDP	World Bank WDI
IQ	Composite institutional quality index constructed using PCA from World Governance Indicators	World Bank WGI
FD	Financial Development Index (0 to 1) measuring depth, access, and efficiency of financial systems	IMF Financial Development Database
NRR × IQ	Interaction term between natural resource rents and institutional quality	Authors' calculation
GDPPC	Logarithm of real GDP per capita (constant prices)	World Bank WDI
TRADE	Trade openness measured as total trade (% of GDP)	World Bank WDI
CO2PC	Carbon dioxide emissions per capita (metric tons)	World Bank WDI; IEA
FDI	Net foreign direct investment inflows as a percentage of GDP	World Bank WDI

Note: IEA = International Energy Agency; WDI = World Development Indicators; WGI = Worldwide Governance Indicators.

**Table 2.** Descriptive statistics

Variable	Mean	Std. Dev.	Min	Median	Max
ln(REI)	1.874	1.432	-0.693	1.792	5.236
NRR (share, 0-1)	0.147	0.114	0.011	0.115	0.524
IQ (PCA composite)	-0.512	0.816	-2.341	-0.489	1.892
FD (0 to 1)	0.231	0.158	0.041	0.198	0.712
ln(GDPPC)	7.913	1.024	5.891	7.867	10.433
TRADE (% GDP)	71.432	33.217	20.432	63.772	188.324
CO2PC (t CO <sub>2</sub> /cap.)	3.412	3.201	0.234	2.112	18.934
FDI (% GDP)	4.231	4.892	-5.432	3.112	34.872

**Table 3.** Pairwise correlation matrix

	lnREI	NRR	IQ	FD	lnGDPPC	TRADE	CO2PC
lnREI	1.000						
NRR	-0.342***	1.000					
IQ	0.512***	-0.421***	1.000				
FD	0.467***	-0.312***	0.543***	1.000			
lnGDPPC	0.589***	0.112*	0.487***	0.623***	1.000		
TRADE	0.213***	0.087	0.231***	0.289***	0.412***	1.000	
CO2PC	-0.198***	0.298***	-0.312***	0.102*	0.312***	0.087	1.000

Notes: \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.10.

**Table 4.** Variance inflation factor (VIF) test results

Variable	VIF	1/VIF	Decision
IQ	3.21	0.312	No multicollinearity
FD	2.87	0.348	No multicollinearity
ln(GDPPC)	2.64	0.379	No multicollinearity
NRR	2.31	0.433	No multicollinearity
NRR × IQ	2.08	0.481	No multicollinearity
CO2PC	1.74	0.575	No multicollinearity
TRADE	1.42	0.704	No multicollinearity
FDI	1.21	0.826	No multicollinearity
Mean VIF	2.07	—	—

Notes: VIF values below 10 indicate the absence of harmful multicollinearity; values below 5 indicate that multicollinearity is unlikely to bias coefficient estimates. The maximum VIF in the model is 3.21, and the mean VIF is 2.07, confirming that the regressors are sufficiently independent for reliable inference.

**4. METHODOLOGY**

The econometric framework addresses four key issues in sequence: (i) non-stationarity in panel time-series variables; (ii) the presence of a long-run cointegrating relationship; (iii) efficient estimation of long-run elasticities and short-run dynamics under slope heterogeneity and CD; and (iv) distributional heterogeneity in long-run relationships across the conditional distribution of renewable energy investment. The analysis is conducted as follows.

Before performing unit root and cointegration tests, it is crucial to determine whether the panel data display CD, as this greatly affects the choice of subsequent tests and estimators. The Pesaran [45] CD test is employed; it is suitable for both large-N and large-T panels and has superior power characteristics relative to the Breusch and Pagan LM test [46]. The rejection of the null hypothesis of no CD necessitates the use of second-generation panel unit root and cointegration tests.

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^N \rho_{ij} \sim N(0,1) \tag{1}$$

In light of the evidence of CD, the Cross-sectionally Augmented Im, Pesaran, and Shin (IPS) (CIPS) test proposed by Pesaran [47] is applied due to its robustness to both CD and slope heterogeneity. This test extends the standard ADF regression by including cross-sectional averages of lagged levels and first differences. The CIPS statistic is computed as the simple average of the individual cross-sectionally augmented Dickey-Fuller (CADF) statistics. For comparison purposes, the first-generation IPS test [48] is also reported, despite its limitations under CD.

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \sum_{j=0}^p \delta_{ij} \Delta \bar{y}_{t-j} + e_{it} \tag{2}$$

The Westerlund [49] panel cointegration test is employed to investigate long-run cointegrating relationships by testing the null hypothesis of no cointegration within an error correction model framework. The test produces four statistics:  $G\tau$  and  $G\alpha$  (group-mean statistics) and  $P\tau$  and  $P\alpha$  (panel statistics). It is preferred over the Pedroni [50] and Kao [51] tests because it allows for serially correlated errors, heterogeneous short-run dynamics, and CD when bootstrap critical values are applied [52]. Both asymptotic and bootstrap p-values based on 800 replications are reported.

$$\Delta y_{it} = \delta'_i d_t + \alpha_i (y_{i,t-1} - \beta'_i x_{i,t-1}) + \sum_{j=1}^p \alpha_{ij} \Delta y_{i,t-j} + \sum_{j=0}^q \gamma_{ij} \Delta x_{i,t-j} + \varepsilon_{it} \tag{3}$$

In light of the cointegration evidence, long-run coefficients are estimated utilizing two complementary estimators: The CCEMG estimator proposed by Pesaran [11] and AMG estimator developed by Eberhardt and Bond [12] are employed. Both estimators accommodate slope heterogeneity, allowing coefficients to vary across countries, as well as CD. The CCEMG approach augments the regression by including cross-sectional averages of the dependent variable and all regressors to capture unobserved common factors, with the mean group estimate obtained as the simple average of country-specific coefficients. The AMG estimator operates in two stages: it initially estimates a common dynamic process using a first-differenced pooled regression augmented with year dummies, then subsequently subtracts this process prior to estimating individual country regressions. Both estimators exhibit consistency as N and T tend towards infinity and yield asymptotically normal mean group estimates.

The empirical model is specified as:

$$\ln(REI_{it}) = \alpha_{0i} + \alpha_{1i}NRR_{it} + \alpha_{2i}IQ_{it} + \alpha_{3i}FD_{it} + \alpha_{4i}(NRR_{it} \times IQ_{it}) + \alpha_{5i}\ln(GDPPC_{it}) + \alpha_{6i}TRADE_{it} + \alpha_{7i}CO2PC_{it} + \alpha_{8i}FDI_{it} + v_{it} \tag{4}$$

For estimation, all variables enter in their natural levels except for renewable energy investment and GDP per capita, which are log-transformed to linearise multiplicative effects, and natural resource rents, which are rescaled from the percentage form (0-100) reported in the World Development Indicators to a 0-1 share of GDP. This rescaling ensures that the estimated semi-elasticity  $\partial \ln(REI)/\partial NRR$  is interpretable as the proportional change in renewable investment associated with a unit (i.e. 100-percentage-point) change in resource dependence, so that a 10-percentage-point increase in NRR

translates into a 0.1-unit shift in the rescaled regressor. The interaction term  $NRR \times IQ$  is constructed after this rescaling, so that the implied governance threshold  $IQ^* = -\beta_1/\beta_4$  is dimensionally consistent and economically interpretable. Without this rescaling, a one-percentage-point increase in resource rents would translate into an implausibly large response in renewable investment; the share-based scaling adopted here is consistent with the standard practice in the resource-curse literature.

To ensure robustness, the group-mean FMOLS estimator [53, 54] and the group-mean DOLS estimator [55] are also presented. FMOLS addresses serial correlation and endogeneity in the regressors using non-parametric kernel estimation, while DOLS mitigates endogeneity by incorporating leads and lags of the first differences of the regressors into the regression. These estimators exhibit consistency in the context of cointegration and serve as a valuable benchmark for comparison with the CCEMG and AMG estimates. Empirical applications of these cointegration techniques to the energy-economic growth nexus in developing economies are exemplified by Hdom and Fuinhas [56] and Ouedraogo [57].

Conventional mean-based panel estimators such as CCEMG, AMG, FMOLS, and DOLS provide a single average elasticity for the entire panel and are therefore silent on whether the determinants of renewable energy investment exert different effects on countries situated at different points of the conditional distribution. To address this limitation, this study implements the MMQR with fixed effects developed by Machado and Silva [13]. Unlike traditional quantile regression, the MMQR estimator allows individual fixed effects to influence the entire conditional distribution rather than acting only as location shifters, which is essential when unobserved heterogeneity is correlated with both the level and the dispersion of the dependent variable, as is typical in macro panels of resource-rich developing economies.

Formally, the conditional location-scale model underlying the MMQR is given by:

$$Y_{it} = \alpha_i + X'_{it}\beta + (\delta_i + Z'_{it}\gamma)U_{it} \quad (5)$$

where  $Y_{it}$  denotes the natural logarithm of renewable energy investment,  $X_{it}$  is the vector of regressors specified in Eq. (4),  $Z_{it}$  is a vector of known differentiable transformations of the components of  $X_{it}$ ,  $\alpha_i$  and  $\delta_i$  capture the individual location and scale fixed effects, and  $U_{it}$  is an i.i.d. disturbance term that is statistically independent of  $X_{it}$ . Under the standard regularity conditions of Machado and Silva [13], the conditional quantile function of  $Y_{it}$  is recovered as:

$$Q_Y(\tau | X_{it}) = (\alpha_i + \delta_i q(\tau)) + X'_{it}\beta + Z'_{it}\gamma q(\tau) \quad (6)$$

where  $q(\tau)$  is the  $\tau$ -th quantile of the standardized error  $U_{it}$ . The coefficient on each regressor at quantile  $\tau$  is therefore  $\beta + \gamma q(\tau)$ , so that  $\gamma$  measures the heterogeneous component of the effect across the conditional distribution while  $\beta$  captures the average location effect. Eq. (6) is estimated at the 10th, 25th, 50th, 75th, and 90th quantiles, which provides a comprehensive characterization of how the effects of natural resource rents, institutional quality, financial development, and the  $NRR \times IQ$  interaction varies across countries with low, intermediate, and high levels of renewable energy investment. This approach is particularly informative in the present setting because it reveals whether the resource curse and the

institutional mediation channel intensify or attenuate as countries advance along the renewable energy investment frontier.

To investigate directional causal linkages among the variables, this study employs the Dumitrescu and Hurlin [14] panel Granger non-causality test, which is specifically designed for heterogeneous panels and remains valid in the presence of slope heterogeneity and CD, two features that invalidate first-generation panel causality tests in macro datasets such as ours. Unlike the homogeneous Granger causality test that imposes the restrictive assumption that the causal relationship is identical across all cross-sectional units, the Dumitrescu and Hurlin procedure allows the autoregressive parameters and the regression coefficients to differ across countries while testing the joint null hypothesis of no Granger causality from variable X to variable Y for any country in the panel against the alternative that causality runs from X to Y in at least one country.

The test is based on country-specific Granger causality regressions of the form:

$$y_{it} = \alpha_i + \sum_{k=1}^K \gamma_{ik} y_{i,t-k} + \sum_{k=1}^K \beta_{ik} x_{i,t-k} + \varepsilon_{it} \quad (7)$$

from which the individual Wald statistics  $W_{i,t}$  for the joint nullity of all  $\beta_{ik}$  are computed. The Dumitrescu and Hurlin average statistic is then defined as:

$$\bar{W} = \frac{1}{N} \sum_{i=1}^N W_i \quad (8)$$

and its standardized counterpart  $\tilde{Z}$  converges to a standard normal distribution under the null hypothesis as both T and N tend towards infinity, while a semi-asymptotic version  $\tilde{Z}$  is also available for finite T. A rejection of the null indicates that there is a Granger causal relationship from X to Y for a non-trivial fraction of countries in the panel, which constitutes the empirically relevant interpretation in heterogeneous macro samples. Causality is tested in both directions for all theoretically relevant variable pairs, namely NRR and REI, IQ and REI, FD and REI, NRR and CO2PC, and GDPPC and REI, in order to discriminate among unidirectional, bidirectional, and feedback structures and thereby illuminate the temporal precedence underlying the long-run elasticities estimated by the CCEMG, AMG, FMOLS, DOLS, and MMQR estimators.

## 5. EMPIRICAL RESULTS

Table 5 reports the cross-sectional dependence and panel unit root test results. The Pesaran [45] CD test unequivocally rejects the null hypothesis of cross-sectional independence for all variables, hence validating the use of second-generation panel techniques. The first-generation IPS test [48], which is influenced by CD, does not reject the unit root null hypothesis for most variables in levels; however, all first-differenced series demonstrate stationarity at the 1% significance level, confirming I(1) integration. The second-generation CIPS test [47] corroborates this finding: all variables, except for FDI, are I(1), while FDI is at the boundary of I(0)/I(1). The consistent pattern of integration is a crucial prerequisite for cointegration analysis.

**Table 5.** Cross-sectional dependence (CD) and panel unit root test results

	CD Test	IPS (Level)	IPS (1st Diff.)	CIPS (Level)	CIPS (1st Diff.)
ln(REI)	21.43*** (0.000)	-1.234 (0.109)	-4.823*** (0.000)	-1.891 (0.234)	-4.412*** (0.000)
NRR	18.67*** (0.000)	-1.089 (0.138)	-5.234*** (0.000)	-1.712 (0.267)	-4.891*** (0.000)
IQ	15.32*** (0.000)	-0.934 (0.175)	-4.678*** (0.000)	-1.543 (0.312)	-4.123*** (0.000)
FD	19.87*** (0.000)	-1.432* (0.076)	-5.012*** (0.000)	-1.891 (0.198)	-4.567*** (0.000)
ln(GDPPC)	23.12*** (0.000)	-1.123 (0.131)	-4.434*** (0.000)	-1.678 (0.281)	-4.234*** (0.000)
TRADE	17.45*** (0.000)	-1.321* (0.093)	-4.789*** (0.000)	-1.789 (0.245)	-4.456*** (0.000)
CO2PC	20.34*** (0.000)	-0.876 (0.190)	-4.912*** (0.000)	-1.612 (0.298)	-4.312*** (0.000)
FDI	16.78*** (0.000)	-3.341*** (0.001)	-5.234*** (0.000)	-3.123*** (0.002)	-5.012*** (0.000)

Notes: CD = Cross-Sectional Dependence test [45]; p-values in parentheses. IPS = Im, Pesaran, and Shin [48] panel unit root test; CIPS = Cross-sectionally Augmented IPS [47]. All tests include individual fixed effects; lag length selected by the Schwarz Information Criterion. \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.10. FDI is integrated of order zero I(0) at the 5% level under CIPS.

**Table 6.** Westerlund panel cointegration test results

Statistic	Value	Z-Value	Asymptotic P-Value	Bootstrap P-Value (800 reps.)
Gτ	-3.412	-8.234	0.000	0.002
Gα	-12.891	-4.123	0.000	0.004
Pτ	-18.234	-9.891	0.000	0.000
Pα	-11.234	-5.432	0.000	0.002

Notes: The null hypothesis is no cointegration. Lags and leads selected by Akaike Information Criterion (AIC). Bartlett kernel used with bandwidth 3. Bootstrap p-values based on 800 replications. All four statistics reject the null at the 1% level under both asymptotic and bootstrap critical values.

**Table 7.** Long-run panel estimates

Variable	CCEMG (1)	AMG (2)	FMOLS (3)	DOLS (4)
NRR	-0.412*** (0.089)	-0.398*** (0.094)	-0.371*** (0.101)	-0.389*** (0.096)
IQ	0.587*** (0.121)	0.562*** (0.134)	0.531*** (0.143)	0.571*** (0.129)
FD	0.334*** (0.098)	0.312*** (0.103)	0.298*** (0.110)	0.321*** (0.102)
NRR × IQ	0.281*** (0.072)	0.263*** (0.078)	0.247*** (0.083)	0.271*** (0.075)
ln (GDPPC)	0.812*** (0.156)	0.789*** (0.167)	0.754*** (0.178)	0.798*** (0.162)
TRADE	0.008** (0.003)	0.007** (0.003)	0.006* (0.004)	0.007** (0.003)
CO2PC	-0.143** (0.063)	-0.131** (0.068)	-0.118* (0.071)	-0.138** (0.066)
FDI	0.041** (0.018)	0.038** (0.019)	0.034* (0.020)	0.040** (0.018)
CD Test (Residuals)	1.234 (0.217)	0.987 (0.324)	N/A	N/A
RMSE	0.312	0.321	0.334	0.318

Notes: Standard errors in parentheses. \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.10. CCEMG = Common Correlated Effects Mean Group [11]; AMG = Augmented Mean Group [12]; FMOLS = Fully Modified OLS [53, 54]; DOLS = Dynamic OLS (leads/lags = 1) [55]. CD test on residuals [45]; p-values in parentheses; values below 1.96 indicate residual cross-sectional independence, confirming adequate model specification. Country fixed effects included in all specifications

Table 6 presents the Westerlund [49] cointegration test results, which demonstrate strong evidence of a long-run cointegrating relationship among all variables. All four statistics reject the null hypothesis of no cointegration at the 1% significance level, utilizing both asymptotic and bootstrap critical values. This result is robust to the choice of lag length and bandwidth. The concurrent rejection by both group-mean and panel statistics signifies that cointegration exists for individual country relationships and for the overall panel, providing robust empirical support for the long-run equilibrium relationships specified in the model.

The long-run estimation results are presented in Table 7. All four estimators produce notably consistent coefficient estimates, providing strong evidence that the results are not artifacts of a specific estimation method.

The coefficient on NRR is negative and statistically significant at the 1% level across all four estimators, with a CCEMG estimate of -0.412 and AMG, FMOLS, and DOLS estimates within a narrow band of -0.371 to -0.398. Because NRR enters the regression as a 0-1 share of GDP, the CCEMG coefficient implies that a 10-percentage-point increase in resource dependence (i.e. a 0.1-unit shift on the share scale) is associated with a long-run reduction of approximately 4.1% in renewable energy investment, holding other factors constant. The estimated effect is economically meaningful but quantitatively plausible and lies within the range reported by

recent panel studies of resource dependence and clean-energy outcomes. The finding constitutes substantial panel evidence in support of the resource-curse hypothesis within the framework of the energy transition.

The coefficient on IQ is positive and statistically significant across all specifications, with a CCEMG estimate of 0.587. A one-unit increase in the institutional quality composite index is associated with a 0.587 log-point increase in renewable energy investment, controlling for resource rents and other factors. This represents the most substantial marginal effect in the baseline model, indicating that governance quality is not merely a contextual moderator but a primary determinant of renewable energy investment in resource-rich settings.

The coefficient on the NRR × IQ interaction term is positive and statistically significant at the 1% level (CCEMG = 0.281), corroborating the institutional-mediation hypothesis. The conditional marginal effect of resource rents on renewable energy investment is therefore  $\partial \ln(\text{REI})/\partial \text{NRR} = \beta_1 + \beta_4 \times \text{IQ}$ , which equals zero at the threshold  $\text{IQ}^* = -\beta_1/\beta_4$ . Substituting the CCEMG estimates yields  $\text{IQ}^* = 0.412/0.281 \approx 1.466$ . Given that the institutional-quality composite has a sample mean of -0.512 and a standard deviation of 0.816, this threshold corresponds to a Z-score of  $(1.466 - (-0.512))/0.816 \approx 2.42$ , that is, approximately 2.42 standard deviations above the sample mean.

The coefficient on FD is positive and statistically significant

at the 1% level across all estimators (CCEMG = 0.334). An increase of 0.1 units in the IMF Financial Development Index, a substantial but feasible improvement for developing economies, is associated with an approximate 3.4% increase in renewable energy investment. The relatively smaller magnitude of the FD coefficient compared with the IQ coefficient suggests that financial development operates primarily as a transmission channel through which investment decisions, themselves shaped by political-economy and governance factors, are implemented.

All control variables yield theoretically consistent signs. GDP per capita demonstrates a substantial positive association, confirming the income elasticity of renewable energy investment. Trade openness exhibits a modest but significant positive effect, consistent with the diffusion of technology through the importation of renewable equipment. Per capita CO<sub>2</sub> emissions are negatively associated and statistically significant, indicating that carbon-intensive economies, characterized by strong fossil fuel lobbying and

high barriers to renewable energy entry, exhibit lower investments in renewables, even when controlling for income and resource rents. FDI has a small positive coefficient, signifying its contribution to enhancing domestic renewable investment via international project financing.

The CD test on model residuals produces statistics well below the 1.96 critical value for both CCEMG and AMG, demonstrating that the incorporation of cross-sectional averages (CCEMG) and the common dynamic process (AMG) has successfully removed CD, thus reinforcing the validity of inferences derived from these estimators.

Table 8 reports the MMQR estimates of Eq. (6) at the 10th, 25th, 50th, 75th, and 90th quantiles of the conditional distribution of renewable energy investment. The MMQR results corroborate the sign and significance of the mean-based CCEMG and AMG estimates while uncovering a pronounced and economically meaningful pattern of distributional heterogeneity that is invisible to the average estimators.

**Table 8.** Method of moments quantile regression (MMQR) estimates

Variable	Q10	Q25	Q50	Q75	Q90
NRR	-0.291*** (0.082)	-0.342*** (0.079)	-0.408*** (0.076)	-0.472*** (0.081)	-0.523*** (0.087)
IQ	0.412*** (0.118)	0.487*** (0.114)	0.578*** (0.111)	0.661*** (0.116)	0.731*** (0.123)
FD	0.276*** (0.094)	0.298*** (0.091)	0.328*** (0.089)	0.354*** (0.093)	0.378*** (0.098)
NRR × IQ	0.198*** (0.068)	0.231*** (0.066)	0.276*** (0.064)	0.312*** (0.067)	0.342*** (0.071)
ln(GDPPC)	0.687*** (0.149)	0.741*** (0.144)	0.804*** (0.140)	0.862*** (0.146)	0.918*** (0.155)
TRADE	0.005* (0.003)	0.006** (0.003)	0.008** (0.003)	0.009** (0.003)	0.010** (0.004)
CO2PC	-0.092 (0.061)	-0.114* (0.059)	-0.141** (0.057)	-0.168*** (0.060)	-0.191*** (0.064)
FDI	0.028 (0.018)	0.034* (0.017)	0.041** (0.017)	0.047*** (0.018)	0.052*** (0.019)
Pseudo R <sup>2</sup>	0.412	0.451	0.487	0.512	0.534

Notes: Standard errors in parentheses. \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.10. MMQR estimator of Machado and Silva [13] with individual fixed effects. Q10, Q25, Q50, Q75, and Q90 denote the 10th, 25th, 50th, 75th, and 90th quantiles of the conditional distribution of ln(REI). All specifications control for the location and scale fixed effects of the resource-rich developing economies in the sample.

The coefficient on natural resource rents is negative and statistically significant at every quantile, but its magnitude grows monotonically from -0.291 at the 10th quantile to -0.523 at the 90th quantile. This pattern indicates that the resource curse is far from uniform: in countries situated at the lower end of the renewable energy investment distribution, where projects are scarce and largely donor-financed, the crowding-out effect of fossil fuel rents is comparatively muted, whereas in frontier countries that have already begun to scale up renewable capacity, additional resource rents exert a substantially stronger drag on investment. Economically, this is consistent with the political economy interpretation that fossil fuel incumbencies become more entrenched and more capable of resisting reallocation of capital precisely as the renewable energy sector grows large enough to threaten incumbent rents.

The coefficient on institutional quality is positive and significant across the entire distribution and rises from 0.412 at the 10th quantile to 0.731 at the 90th quantile. Governance reforms therefore deliver larger marginal payoffs in countries that are already further along the renewable energy investment trajectory, which is consistent with the hypothesis that high-quality institutions are increasingly indispensable for attracting the more sophisticated, longer-tenor, and risk-sensitive capital required by mature renewable energy markets.

The NRR × IQ interaction term is positive and significant at all quantiles, and its magnitude likewise rises across the distribution from 0.198 to 0.342. This monotonic strengthening confirms that the institutional mediation channel

is most powerful precisely where the resource curse bites hardest, namely in countries with relatively well-developed renewable energy sectors. The implied conditional governance threshold at which the net marginal effect of NRR turns positive is broadly stable across quantiles, varying within a narrow band around the  $IQ^* \approx 1.47$  estimate obtained from the mean-based specification, indicating that the threshold result is not an artifact of averaging.

Financial development is positive and significant throughout the distribution and is mildly increasing across quantiles, from 0.276 to 0.378, indicating that the cost-of-capital and risk-pooling channels gain importance as renewable energy markets mature and demand more sophisticated financial intermediation. The control variables retain the theoretically expected signs at all quantiles, with GDP per capita exerting a strong positive effect throughout, CO<sub>2</sub> per capita exerting a negative effect that strengthens at upper quantiles, and trade openness and FDI exerting modest positive effects. Collectively, the MMQR results confirm the robustness of the baseline findings while revealing that the policy levers identified in this study, namely governance reform and financial deepening, deliver disproportionately larger benefits to countries that have already begun the renewable energy transition, providing a strong empirical case for front-loading institutional and financial reforms in resource-rich economies that are approaching the renewable investment frontier.

The Dumitrescu and Hurlin [14] panel non-causality test, which is robust to slope heterogeneity and CD, is employed to disentangle the directional structure of the relationships

estimated in the long run. Table 9 reports the average Wald statistic  $\bar{W}$ , the standardized  $\bar{Z}$  statistic, and the corresponding p-value for each tested causal direction, along with the substantive interpretation of the test outcome. Because the Dumitrescu and Hurlin test rejects the null whenever Granger

causality is present in at least one country of the panel, a rejection should be read as evidence of a heterogeneous causal mechanism that operates in a non-trivial fraction of the cross-section, rather than as a uniform causal relationship that holds identically across all 20 countries.

**Table 9.** Dumitrescu and Hurlin panel Granger causality results

Causal Direction	$\bar{W}$ Statistic	$\bar{Z}$ Statistic	P-Value	Conclusion
NRR → REI	4.231	3.891***	0.000	Unidirectional causality
REI → NRR	1.234	0.782	0.217	No causality
IQ → REI	5.421	5.123***	0.000	Bidirectional causality
REI → IQ	3.812	3.234***	0.001	Bidirectional causality
FD → REI	4.891	4.567***	0.000	Bidirectional causality
REI → FD	2.891	2.123**	0.034	Bidirectional causality
NRR → CO2PC	6.234	6.891***	0.000	Unidirectional causality
CO2PC → NRR	2.112	1.732*	0.083	Weak feedback (10%)
GDPPC → REI	5.891	5.432***	0.000	Bidirectional causality
REI → GDPPC	3.123	2.567***	0.010	Bidirectional causality

Notes:  $\bar{W}$  = average Wald statistic;  $\bar{Z}$  = standardized statistic of Dumitrescu and Hurlin [14]. The null hypothesis is no Granger causality from X to Y for any cross-sectional unit. Lag selection by Akaike Information Criterion (AIC) (optimal lag = 2). \*\*\* p < 0.01, \*\* p < 0.05, \* p < 0.10. All tests include individual fixed effects.

The results reveal a coherent directional architecture that complements and substantively enriches the long-run elasticities reported in Tables 7 and 8. First, natural resource rents Granger-cause renewable energy investment in a unidirectional fashion: the null of no causality from NRR to REI is decisively rejected at the 1% level ( $\bar{Z} = 3.891$ ), whereas the reverse direction from REI to NRR fails to reject the null ( $p = 0.217$ ). This asymmetry establishes that the negative long-run elasticity of renewable energy investment with respect to resource rents documented by the CCEMG, AMG, and MMQR estimators reflects a genuine causal influence running from the fossil fuel sector to the renewable sector, rather than a mechanical correlation driven by reverse feedback or by an omitted third factor that simultaneously moves the two variables. The crowding-out mechanism implied by the resource curse hypothesis is therefore not merely a long-run statistical association: it is a temporally precedent causal force operating through fiscal, political-economic, and price-distortion channels in the panel of resource-rich developing countries examined here.

Second, the test uncovers a strong bidirectional causal relationship between institutional quality and renewable energy investment: IQ Granger-causes REI at the 1% level ( $\bar{Z} = 5.123$ ), and REI in turn Granger-causes IQ at the 1% level ( $\bar{Z} = 3.234$ ). The causal flow from IQ to REI confirms the standard governance channel, whereby transparent regulation, contract enforceability, and political stability lower the country-risk premium attached to long-tenor renewable energy projects and thereby unlock private investment. The reverse flow from REI to IQ is more striking: it indicates that the very act of building a renewable energy sector creates new political constituencies, regulatory bodies, transparency requirements, and accountability mechanisms that subsequently improve the broader institutional environment. The two directions reinforce each other into a virtuous circle in which governance reform and the renewable transition are mutually self-sustaining. The detailed positioning of this finding within the existing literature is reserved for the Discussion (Section 6).

Third, financial development and renewable energy investment display bidirectional causality, with FD Granger-causing REI at the 1% level ( $\bar{Z} = 4.567$ ) and REI Granger-causing FD at the 5% level ( $\bar{Z} = 2.123$ ). The forward channel reflects the cost-of-capital and risk-pooling mechanisms by

which deeper, more liquid financial systems lower the financing barriers facing capital-intensive renewable projects. The feedback channel, by which a maturing renewable energy sector subsequently deepens the financial system, is consistent with the worldwide proliferation of green bonds, climate-aligned infrastructure funds, and dedicated renewable energy financing vehicles, all of which expand the menu of instruments available in domestic capital markets.

Fourth, natural resource rents Granger-cause per capita CO<sub>2</sub> emissions in a strongly unidirectional fashion ( $\bar{Z} = 6.891$  at the 1% level), with only weak feedback in the reverse direction (significant at the 10% level). This asymmetry quantifies the environmental cost of resource dependence: not only do fossil fuel rents crowd out renewable investment, as established above, but they also exert a direct and temporally precedent causal pressure on the carbon intensity of the economy, thereby compounding the environmental damage associated with resource specialization.

Finally, GDP per capita and renewable energy investment exhibit bidirectional causality ( $\bar{Z} = 5.432$  from GDPPC to REI at the 1% level and  $\bar{Z} = 2.567$  from REI to GDPPC at the 1% level). This finding strengthens the case for treating renewable energy investment as a development strategy in its own right rather than as a passive by-product of income growth: rising income unlocks renewable investment through the standard demand and affordability channels, and renewable investment in turn supports income growth through job creation, energy-cost reduction, technology diffusion, and reduced exposure to fossil fuel price volatility.

Taken together, the Dumitrescu and Hurlin results paint a coherent and policy-relevant picture. The two destructive causal forces in the system, namely NRR → REI and NRR → CO<sub>2</sub>PC, are unidirectional, indicating that resource dependence operates as an exogenous brake on the energy transition rather than as a passive correlate of it. By contrast, the two constructive forces, namely IQ ↔ REI and FD ↔ REI, are bidirectional and self-reinforcing, indicating that governance reform and financial deepening trigger feedback dynamics that compound the initial impact over time. This causal architecture provides direct empirical justification for sequencing energy transition policy in resource-rich developing economies around governance and financial sector reform, since each unit of effort invested in these two domains

is amplified by the feedback loops uncovered here, while no such amplification mechanism is available for the resource curse channel itself.

## 6. DISCUSSION AND POLICY IMPLICATIONS

The empirical findings of this study carry several dimensions of policy significance for resource-rich developing countries navigating the global energy transition. This section contextualizes the findings within the current empirical literature and formulates specific policy recommendations.

The negative and statistically significant coefficient for NRR ( $-0.412$ , CCEMG) in the resource curse channel (H1), corroborated by the monotonically increasing magnitude of the NRR coefficient across MMQR quantiles, provides robust panel evidence that natural resource rents directly impede renewable energy investment in developing nations and that this drag intensifies as countries advance toward the renewable investment frontier. This finding is consistent with the foundational resource curse literature of Sachs and Warner [3] and the theoretical models proposed by Torvik [18] and Robinson et al. [19], illustrating how resource dependence fosters rent-seeking, diminishes state capacity, and undermines accountability. The findings of this study extend this reasoning to the domain of energy transition. The magnitude of the NRR coefficient broadly corresponds with the findings of Gorji and Martek [23], who reported that the resource curse substantially undermines the efficacy of renewable energy policy in oil-producing developing nations, based on panel data from 2010 to 2020. Likewise, Destek et al. [24] observed that resource dependence obstructs sustainable development outcomes unless counterbalanced by economic complexity, which is consistent with the finding that the crowding-out effect can be mitigated by institutional quality. Similarly, Rasmoun and Ben-Salha [25] provide country-level evidence from Saudi Arabia that oil rents degrade environmental quality, while renewable energy and green technological innovation improve it, reinforcing the mechanism by which fossil fuel dependence impedes clean energy adoption. The unidirectional Granger causality from NRR to REI documented by the Dumitrescu and Hurlin test substantiates the hypothesized causal direction posited in the Dutch disease literature [16, 17], confirming that this relationship is not driven by reverse feedback but rather reflects a temporally precedent causal pressure exerted by the fossil fuel sector on the renewable sector. This creates a self-reinforcing cycle: fossil fuel revenues finance public services, reducing the motivation for economic diversification; they also subsidize energy consumption, distorting market price signals that would typically encourage renewables; and they establish political economy incumbencies that resist clean energy policies [21, 22]. To break this cycle, deliberate institutional design is required, rather than merely economic growth or technology diffusion.

The identification of institutional quality as the foremost positive determinant of renewable energy investment (H2), with a CCEMG coefficient of  $0.587$  and an MMQR coefficient that rises from  $0.412$  at the 10th quantile to  $0.731$  at the 90th, signifies the most substantial marginal effect in the model, exceeding that of financial development by nearly 76%. This finding directly supports the foundational work of Mehlum et al. [20], who demonstrated that the growth consequences of resource wealth depend on institutional quality. Li et al. [31],

examining the top-10 resource-exporting economies, demonstrated that renewable energy investments and climate mitigation technologies require coordinated fiscal policy frameworks and productive capacity enhancements for responsible resource management, reinforcing the governance and investment nexus identified in the results. Imtiaz et al. [32] provided complementary evidence from Pakistan, showing that renewable energy adoption combined with prudent debt and energy import management facilitates leapfrogging toward sustainability, a finding consistent with the institutional mediation mechanism identified in this study. Halder and Sethi [33], utilizing the same CCEMG and AMG estimators as this study, confirmed that institutional quality enhances renewable energy consumption and reduces CO<sub>2</sub> emissions in developing economies; this study extends that work by incorporating the interaction between institutional quality and resource rents and by characterizing the distributional heterogeneity of the moderating mechanism through MMQR. Rafiq et al. [35] further corroborated the positive association between institutional quality and renewable energy for OECD nations, indicating that this relationship holds across both developed and developing contexts, while the comparative Bayesian evidence of Nguyen and Le [36] reinforces that institutional quality is particularly decisive for sustainable development in developing economies.

The interaction result indicates that improvements in governance can mitigate the resource curse within the energy sector, and the MMQR estimates further reveal that this mediating effect is strongest where the resource curse itself is strongest, namely at the upper quantiles of the renewable energy investment distribution. The threshold analysis identifies a governance score of  $IQ^* \approx 1.466$  (approximately 2.42 standard deviations above the sample mean) as the tipping point at which resource rents transition from impeding to facilitating renewable investment. The bidirectional Granger causality between IQ and REI documented in Table 9 shows that progress toward this threshold is self-reinforcing, since improvements in governance trigger renewable investment, which in turn generates new constituencies and regulatory capacity that further upgrade institutional quality. This result provides an empirical basis for the design of institutional conditionality in international climate finance instruments, such as the IMF and World Bank Climate Policy Assessment Framework and the EU Global Gateway initiative. Policymakers in countries approaching this governance threshold should consider sovereign green bonds supported by resource revenue allocation as a mechanism to operationalize the institutional mediation channel.

The substantial and statistically significant effect of financial development (H3), reflected in a CCEMG coefficient of  $0.334$  and a mildly increasing MMQR profile across quantiles, underscores the critical yet underappreciated role of domestic capital market development in the renewable energy transition of developing countries. This finding supports Shahbaz et al. [27], who identify financial development as a significant determinant of energy consumption in China via multivariate framework analysis, and Asongu and Odhiambo [10], who confirm the positive association between financial access and renewable energy consumption in Sub-Saharan Africa utilizing GMM. Prempeh et al. [28] extend this evidence to a broader SSA panel of 38 nations, confirming through the Renewable Energy Environmental Kuznets Curve (REKC) framework that financial development substantially

influences renewable energy consumption, with bidirectional causality between financial development and renewable energy further supporting the virtuous cycle identified in the results. Notably, the FD coefficient is smaller than the IQ coefficient, consistent with the findings of Anton and Nucu [30], who identify a substantial although moderate effect of domestic credit on renewable energy consumption in EU nations. The results are further supported by Egli et al. [29], who demonstrate that country risk, intrinsically linked to institutional and financial development, substantially elevates the cost of financing for renewable projects. Mahmood et al. [38], employing AMG and CCEMG estimators on ASEAN data, indicate that financial development substantially affects environmental outcomes via renewable energy channels, although that investigation prioritizes ecological risks over investment itself. Evidence from Shanyazov et al. [34] on G7 economies further confirms, via CS-ARDL estimation, that innovation-related channels such as R&D expenditure and ICT exports are significant long-run drivers of energy-sector outcomes, suggesting that financial deepening operates in tandem with technology and knowledge investments. The relatively lower coefficient of FD compared to IQ supports the notion that financial development facilitates the implementation of investment decisions primarily shaped by political economy and governance factors. Most international climate finance discussions emphasize external financial inflows; the findings suggest that strengthening domestic financial systems through banking sector reform, expanding the green bond market, and de-risking pension funds could yield comparable investment multipliers at lower fiscal cost.

The bidirectional causality between IQ and REI documented in the Dumitrescu and Hurlin test represents a novel finding that enriches the existing literature. While prior research, such as Polzin et al. [9] and Egli et al. [29], highlights the unidirectional effect of governance on investment, the results indicate that renewable energy investment also Granger-causes improvements in institutional quality, which is consistent with the political economy argument that renewable energy transitions generate new constituencies advocating for regulatory reform and transparent governance [22]. The bidirectional FD and REI causality suggests a virtuous cycle, consistent with the financial deepening hypothesis proposed by King and Levine [58]. The unidirectional causality from NRR to CO<sub>2</sub> emissions underscores the environmental costs of resource dependence, corroborating the findings of Tambari et al. [37], which illustrate that oil price fluctuations exert asymmetric effects on renewable energy investment depending on a nation's net trade position in fossil fuels. Taken together with the sectoral ASEAN evidence of Sobirov et al. [26], these results suggest that the resource, environment, and investment nexus in developing economies is fundamentally shaped by the interaction of structural composition effects, governance quality, and financial depth.

## 7. CONCLUSION

This study examines the relationship among natural resource rents, institutional quality, financial development, and renewable energy investment in 20 resource-rich developing countries from 2000 to 2024. Employing a comprehensive econometric framework that includes the CIPS unit root test, Westerlund cointegration tests, CCEMG and

AMG long-run estimators, the MMQR, and Dumitrescu and Hurlin panel causality tests, the analysis has yielded the following key findings.

First, natural resource rents have a negative and statistically significant impact on renewable energy investment, providing the most extensive panel evidence to date of a resource curse directly affecting the energy transition sector. Second, institutional quality is the foremost positive determinant of renewable energy investment, and its interaction with resource rents confirms a robust institutional mediation mechanism: beyond a governance threshold of approximately 2.42 standard deviations above the sample mean, resource rents shift from impeding to promoting renewable investment. Third, financial development exerts a clear positive effect, consistent with the proposition that deeper capital markets reduce financing barriers for capital-intensive clean energy projects. Fourth, the MMQR estimation reveals that the magnitude of the resource curse and the strength of the institutional moderation channel both intensify monotonically across the conditional distribution of renewable energy investment, indicating that frontier countries face the largest crowding-out pressures and simultaneously derive the largest benefits from governance reform. Fifth, the bidirectional Dumitrescu and Hurlin causality between institutional quality and renewable energy investment, together with that between financial development and renewable energy investment, suggests positive feedback dynamics among governance reform, financial deepening, and clean energy deployment, while resource rents exert a robust unidirectional causal pressure on renewable investment and on carbon emissions.

These findings collectively challenge the deterministic view that resource wealth constitutes an insurmountable barrier to the clean energy transition. They suggest an alternative pathway: resource-rich developing countries can overcome the fossil fuel lock-in challenge by simultaneously investing in governance reform and financial market development, the two mechanisms that facilitate the reallocation of resource revenues towards clean energy investment. This finding directly informs the design of international climate finance conditionalities, sovereign green bond structures, and multilateral development bank engagement strategies for the world's most resource-intensive developing nations.

The study identifies three limitations that future research should address. First, the operationalization of renewable energy investment as a monolithic aggregate obscures considerable heterogeneity across technology types (solar, wind, geothermal, hydropower), each with distinct financing and governance requirements. Second, the analysis is limited to 20 nations due to data availability; a broader sample could enhance external validity but may require further refinement of the resource-rich classification. Third, while the Dumitrescu and Hurlin test confirms Granger causality, discerning structural causal mechanisms necessitates instrumental variable techniques or natural experiments, which are challenging to implement in long-horizon macro panels.

Future research should disaggregate renewable energy investments by technology type to determine whether governance and financial mechanisms operate differentially across solar, wind, and geothermal technologies. The emergence of sovereign green bond markets and blended finance instruments in developing countries offers new data opportunities to assess whether the institutional mediation mechanism identified here applies to project-level financing. Policymakers should recognize that the resource curse is not

inevitable; strategic governance reforms, coupled with financial sector deepening, can transform resource wealth from an impediment into a catalyst for the clean energy transition.

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