



Renewable Energy Transition, Institutional Quality, and CO₂ Emissions: Evidence from Next-11 Emerging Economies

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ABSTRACT

This study examines whether renewable energy transition reduces carbon dioxide (CO₂) emissions in emerging economies and whether institutional quality moderates this relationship. Using a balanced panel of 11 Next-11 countries over 2000-2023, we estimate two-way fixed-effects models with clustered standard errors to address unobserved heterogeneity, cross-sectional dependence, and serial correlation. Renewable energy transition is measured by the share of renewables in total final energy consumption, while institutional quality is constructed as a composite index from the Worldwide Governance Indicators using principal component analysis. The results reveal a robust negative relationship between renewable energy transition and CO₂ emissions. A one-unit increase in renewable energy share is associated with a 3.6 log-point (approximately 97%) reduction in per capita emissions. Institutional quality also significantly reduces emissions, highlighting the importance of effective governance. The interaction term between renewable energy and institutional quality is positive but statistically insignificant ($\beta_3 = +0.069$, $P = 0.47$), suggesting that institutional quality does not significantly moderate renewable energy effectiveness. This finding does not support the expected synergy between institutions and renewable energy transition. Our results indicate that renewable energy expansion alone may be insufficient for deep decarbonization in emerging economies without supporting institutional frameworks. The study contributes to the energy–environment literature by providing updated empirical evidence on the complementary roles of renewable energy transition and institutional quality in fast-growing economies.

Keywords: Renewable Energy Transition, Institutional Quality, CO₂ Emissions, Energy Economics, Emerging Economies, Environmental Kuznets Curve

JEL Classifications: Q42, Q54, Q56, O43

1. INTRODUCTION

Reducing carbon dioxide (CO₂) emissions has become a central policy priority amid accelerating climate change and rising energy demand in emerging economies. While renewable energy deployment is widely regarded as a key pathway toward decarbonization, its environmental effectiveness varies substantially across countries. This heterogeneity suggests that the success of renewable energy transition may depend not only on technological adoption but also on broader institutional and governance frameworks.

Emerging economies face distinct challenges in pursuing low-carbon transitions. Rapid economic growth, expanding energy demand, and institutional constraints often coexist, complicating the implementation of effective environmental and energy policies. Weak regulatory enforcement, policy uncertainty, and governance inefficiencies may undermine the potential emissions-reducing benefits of renewable energy investments. Consequently, understanding whether and how institutional quality shapes the environmental outcomes of renewable energy transition is of critical importance.

The existing literature documents a generally negative relationship between renewable energy consumption and CO₂ emissions, alongside growing evidence that institutional factors influence environmental performance. However, empirical findings remain mixed, particularly for emerging economies, where institutional conditions differ markedly from those in advanced countries. Moreover, relatively few studies explicitly examine the interaction between renewable energy transition and institutional quality within a unified econometric framework, especially using recent data that captures the post-Paris Agreement era.

This study aims to fill this gap by investigating the joint effects of renewable energy transition and institutional quality on CO₂ emissions in a panel of Next-11 emerging economies over the period 2000–2023. The Next-11 countries—identified by Goldman Sachs as high-potential emerging markets—represent diverse developing economies with substantial heterogeneity in energy structures, income levels, and governance quality, making them an ideal laboratory for examining these relationships. Employing a two-way fixed-effects estimator with clustered standard errors, the analysis accounts for unobserved heterogeneity, common global shocks, and key econometric challenges inherent in macro-panel data.

Research hypotheses. Based on the theoretical framework and existing empirical evidence, we formulate three testable hypotheses:

- H₁ (Renewable energy effect): Renewable energy transition, measured by the share of renewables in total final energy consumption, is negatively associated with per capita CO₂ emissions in emerging economies. We expect that a higher renewable energy share displaces fossil fuel consumption and thereby reduces emissions, conditional on income levels and other structural factors.
- H₂ (Institutional quality effect): Institutional quality, measured by a composite governance index, is negatively associated with per capita CO₂ emissions. We hypothesize that stronger governance frameworks—characterized by better regulatory quality, rule of law, and corruption control—enhance environmental policy effectiveness and enforcement, leading to lower emissions independent of energy structure.
- H₃ (Interaction effect): Institutional quality positively moderates the emissions-reducing effect of renewable energy transition. Specifically, we expect that the marginal impact of renewable energy on emissions is larger (more negative) in countries with stronger institutions, as effective governance ensures that renewable energy adoption translates into actual fossil fuel displacement rather than capacity additions that coexist with polluting sources. Formally, we expect the interaction coefficient

We expect $\beta_3 < 0$, such that $\partial(\partial \ln(CO_2)/\partial RE)/\partial IQ < 0$.

These hypotheses recognize that renewable energy transition and institutional development are complementary rather than substitutable pathways toward decarbonization. Testing H₃ is particularly important for policy design, as it speaks to whether renewable energy investments should be sequenced with or conditional upon institutional reforms in emerging economies.

1.1. Contributions

This study contributes to the literature in three main ways. First, it provides updated empirical evidence on the emissions impacts of renewable energy transition in fast-growing emerging economies using data through 2023, covering the critical post-Paris Agreement period when many N-11 countries accelerated renewable energy commitments. Second, it incorporates institutional quality as a conditioning factor rather than merely a control variable, offering insights into how governance frameworks may enable or constrain the effectiveness of renewable energy policies. By explicitly modeling and testing the interaction between energy transition and institutions, the study advances understanding of the complementarities between technological and institutional pathways to decarbonization. Third, by adopting a rigorous panel estimation strategy—two-way fixed effects with two-way clustered standard errors—the study addresses multiple econometric challenges including cross-sectional dependence, serial correlation, and heteroskedasticity that are often inadequately treated in existing cross-country environmental studies. This enhances the robustness and policy relevance of the findings.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature on economic growth, energy consumption, renewable energy transition, and institutional quality as determinants of environmental outcomes. Section 3 describes the data, variables, and empirical methodology. Section 4 presents the estimation results, including baseline regressions, interaction effects, and robustness checks. Section 5 concludes with policy implications and directions for future research.

2. LITERATURE REVIEW

2.1. Economic Growth, Energy Consumption, and Environmental Degradation

The relationship between economic growth, energy consumption, and environmental quality has long been a central topic in environmental and energy economics. Early theoretical and empirical studies emphasize the trade-off between economic expansion and environmental degradation, as increased production and consumption typically rely on energy-intensive processes. This perspective is formalized in the Environmental Kuznets curve (EKC) hypothesis, which posits an inverted U-shaped relationship between income and pollution levels, whereby environmental degradation initially increases with economic growth before declining beyond a certain income threshold (Grossman and Krueger, 1995).

Subsequent empirical studies provide mixed evidence regarding the EKC hypothesis across different countries and pollutants. While some studies support the existence of a nonlinear income–emissions relationship, others find no clear turning point or report substantial heterogeneity across regions and time periods. These mixed findings suggest that economic growth alone does not automatically lead to environmental improvement and that structural factors, energy composition, and policy frameworks play crucial roles in shaping emissions trajectories.

Energy consumption has been identified as a key transmission channel linking economic activity to environmental outcomes.

Fossil fuel-based energy consumption is consistently associated with higher CO₂ emissions, particularly in developing and emerging economies where coal and oil remain dominant energy sources. As a result, the composition of the energy mix has attracted increasing attention in the literature as a critical determinant of environmental sustainability.

2.2. Renewable Energy Transition and CO₂ Emissions

Building on the energy-environment nexus, a growing body of literature focuses on the role of renewable energy consumption in mitigating CO₂ emissions. Renewable energy sources, such as wind, solar, and hydroelectric power, are generally considered cleaner alternatives to fossil fuels and are therefore expected to contribute to emissions reductions. Numerous empirical studies report a negative relationship between renewable energy consumption and CO₂ emissions, supporting the view that energy transition toward renewables can alleviate environmental pressures.

However, the magnitude and statistical significance of this relationship vary considerably across studies. Differences in country samples, time periods, model specifications, and estimation techniques partly explain these discrepancies. In some cases, renewable energy deployment is found to reduce emissions only in the long run, while short-run effects appear weak or insignificant. In others, the emissions-reducing impact of renewable energy is conditional on complementary factors such as technological innovation, energy efficiency, and policy support.

For emerging economies, the evidence is particularly mixed. Although renewable energy capacity has expanded rapidly in recent decades, fossil fuels often continue to dominate the energy mix, limiting the immediate environmental benefits of renewable energy adoption. These findings suggest that renewable energy transition alone may be insufficient to guarantee substantial emissions reductions without supportive economic and institutional conditions.

2.3. Institutional Quality and Environmental Performance

Parallel to the renewable energy literature, a substantial body of research examines the role of institutional quality in shaping environmental outcomes. Institutions influence environmental performance through multiple channels, including regulatory design, enforcement capacity, transparency, and accountability. Strong institutions are generally associated with more effective environmental regulations, better compliance, and reduced opportunities for rent-seeking and corruption, all of which contribute to lower pollution levels.

Empirical studies consistently find that higher institutional quality is linked to improved environmental indicators, including lower CO₂ emissions and reduced air and water pollution. Conversely, weak governance structures may undermine environmental policies, allowing pollution-intensive activities to persist despite formal regulations. In emerging economies, institutional weaknesses such as regulatory capture, limited enforcement capacity, and policy instability pose significant challenges to environmental management.

Despite this growing evidence, institutional quality is often treated as a background control variable rather than a central explanatory factor. As a result, its interaction with energy transition processes remains underexplored in much of the existing literature.

2.4. Institutional Quality as a Conditioning Factor in Energy Transition

While the independent effects of renewable energy and institutional quality on environmental outcomes are relatively well documented, far fewer studies explicitly examine how institutional quality conditions the environmental effectiveness of renewable energy transition. This gap is particularly significant given that renewable energy deployment occurs within broader governance and policy environments that can either enable or constrain its emissions-reducing potential.

From a theoretical perspective, institutions can amplify the impact of renewable energy deployment through multiple channels. First, strong regulatory frameworks ensure policy credibility and stability, reducing investment risk for capital-intensive renewable energy projects that typically require long payback periods (Tolliver et al., 2020). Second, effective governance structures facilitate efficient allocation of resources, minimize rent-seeking behavior, and ensure that renewable energy subsidies and incentives reach intended beneficiaries rather than being captured by vested interests. Third, institutions with higher control of corruption and stronger rule of law can better enforce environmental regulations, ensuring that renewable energy adoption translates into actual displacement of fossil fuels rather than simply adding to total energy capacity without retiring polluting sources.

Recent empirical evidence provides growing support for these institutional moderating effects, though findings remain context-dependent. Bhattacharya et al. (2017) examine the dynamic impact of renewable energy and institutions on economic output and CO₂ emissions across regions, finding that institutional quality significantly strengthens the emissions-reducing effect of renewables, particularly in middle-income countries. Their results suggest that the same level of renewable energy deployment yields substantially different environmental outcomes depending on the quality of governance frameworks. Similarly, Khan and Rana (2021) demonstrate that institutional quality conditions the relationship between economic output and CO₂ emissions, with stronger institutions enabling more efficient energy use and facilitating cleaner production processes.

The moderating role of institutions is especially critical in emerging economies characterized by weak governance structures. Olaniyi et al. (2023) employ threshold regression techniques to examine renewable energy transitions in Africa, revealing that institutional quality exhibits a non-linear threshold effect: Below a certain institutional threshold, financial development fails to spur renewable energy adoption, whereas above this threshold, institutions enable financial systems to effectively channel resources toward clean energy investments. This threshold finding has important implications for heterogeneous emerging economies, suggesting that minimum institutional capacity may

be prerequisite for renewable energy policies to achieve their intended environmental benefits.

In the context of BRICS nations, research by Yadav et al. (2024) investigates the synergistic effects of governance quality and green finance availability on renewable energy investment effectiveness. Their findings underscore that governance quality acts as a critical enabling condition: renewable energy investments deliver greater emissions reductions in countries with transparent regulatory frameworks, lower corruption, and stronger rule of law. Conversely, in settings with bureaucratic inefficiencies and regulatory capture, even well-funded renewable energy programs may fail to displace fossil fuels or may suffer from implementation delays and cost overruns that undermine their environmental benefits.

The interaction between institutions and renewable energy is further complicated by political economy considerations. Haldar and Sethi (2023) analyze corruption control and renewable energy innovation across emerging economies, finding that corruption significantly impedes the clean energy transition by diverting resources toward fossil fuel interests and creating barriers to renewable energy market entry. Their analysis concludes that corruption control benefits both economic and environmental outcomes, with institutional reforms complementing technological adoption in driving decarbonization. Similarly, recent research emphasizes the role of economic policy uncertainty and institutional stability in renewable energy transitions, particularly in resource-rich developing countries where fossil fuel lobbies often capture regulatory processes.

Despite this emerging evidence, several challenges complicate the empirical identification of institutional moderating effects. First, institutional variables typically evolve gradually over time, limiting within-country variation in panel data settings and reducing statistical power to detect interaction effects (Khan and Rana, 2021). Second, institutions and renewable energy adoption may be jointly determined by deeper structural factors such as political economy configurations and resource endowments, raising endogeneity concerns. Third, measurement of institutional quality remains contested, with different composite indices potentially capturing distinct dimensions of governance that may interact differently with energy policies.

Moreover, existing studies often employ different econometric approaches—ranging from threshold models to simple multiplicative interactions—making cross-study comparisons difficult. The limited number of studies examining interaction effects in unified panel frameworks, particularly for emerging economies, leaves important questions unresolved regarding the magnitude, statistical significance, and temporal stability of institutional moderating effects.

As a result, the extent to which institutional quality amplifies or constrains the emissions-reducing impact of renewable energy transition remains an open empirical question, especially for fast-growing emerging economies characterized by rapid structural change and institutional heterogeneity. Addressing this gap

requires rigorous panel estimation strategies that adequately account for unobserved heterogeneity, cross-sectional dependence, and potential endogeneity while explicitly modeling the interaction between renewable energy transition and institutional quality.

2.5. Research Gap and Contribution

In summary, the existing literature establishes important links between economic growth, energy consumption, renewable energy deployment, institutional quality, and environmental outcomes. However, three key gaps remain. First, empirical evidence on the renewable energy–emissions relationship in emerging economies remains mixed and context-dependent. Second, the role of institutional quality is often examined in isolation rather than as a conditioning factor that shapes the effectiveness of renewable energy transition. Third, relatively few studies employ econometric strategies that adequately address unobserved heterogeneity, cross-sectional dependence, and serial correlation in macro-panel data.

This study addresses these gaps by jointly analyzing renewable energy transition and institutional quality in a panel of Next-11 emerging economies using a two-way fixed-effects framework with clustered standard errors. By explicitly examining the interaction between renewable energy transition and institutional quality, the study provides new insights into the institutional dimensions of energy transition and contributes to a more nuanced understanding of environmental sustainability in emerging economies.

3. DATA AND METHODOLOGY

3.1. Data and Sample

This study employs a balanced panel dataset covering 11 Next-11 (N-11) emerging economies—Bangladesh, Egypt, Indonesia, Iran, Mexico, Nigeria, Pakistan, the Philippines, South Korea, Turkey, and Vietnam—over the period 2000–2023. The sample includes 24 annual observations per country, yielding 264 country-year observations. The N-11 group, identified by Goldman Sachs as high-potential emerging markets, represents diverse economies with heterogeneous income levels, energy structures, and institutional capacity, making it a suitable context for examining renewable energy transition in developing contexts. The sample period captures the acceleration of renewable energy deployment following the Kyoto Protocol and leading up to the Paris Agreement era.

3.2. Variable Construction

3.2.1. Dependent variable

Carbon dioxide (CO₂) emissions per capita, measured in metric tons, serve as the dependent variable. The variable is expressed in natural logarithms to reduce skewness and facilitate elasticity-based interpretation. Data are obtained from the International Energy Agency (IEA) and the World Bank’s World Development Indicators.

3.2.2. Key explanatory variables

Renewable energy transition is proxied by the share of renewable energy in total final energy consumption, expressed as a proportion (0–1). This measure captures the realized structural shift in national energy systems and is widely used in cross-country energy

economics studies. Unlike renewable capacity or investment data, which may not translate immediately into emissions reductions, this consumption-based indicator reflects actual displacement of fossil fuels.

Institutional quality is measured using a composite index constructed from the six Worldwide Governance Indicators (WGI): Voice and accountability, political stability and absence of violence, government effectiveness, regulatory quality, rule of law, and control of corruption. Given the high correlation among these dimensions (correlation coefficients ranging from 0.78 to 0.94), principal component analysis (PCA) is applied to extract a single standardized index. The first principal component, which explains 87.3% of total variance, is retained as the institutional quality measure and standardized to have zero mean and unit variance. PCA is preferred over simple averaging to avoid equal weighting of potentially redundant information and to maximize explained variance with a single indicator.

3.2.3. Control variables

To isolate the effects of renewable energy and institutions, the model includes five control variables commonly used in the environmental economics literature. Income is measured by the natural logarithm of real GDP per capita (constant 2015 US\$), with its squared term included to test the Environmental Kuznets Curve (EKC) hypothesis. Foreign direct investment (FDI) net inflows as a share of GDP capture potential scale effects and technology transfer. Financial development, proxied by domestic credit to the private sector as a share of GDP, reflects financial system depth and access to capital for energy-intensive activities. Urbanization is measured as the urban population share and captures demographic transitions affecting energy consumption patterns.

All ratio and percentage variables are normalized to a 0-1 scale to enhance comparability across countries. Missing observations, which account for <5% of the sample and occur primarily in FDI and financial development variables for Nigeria (2000-2002) and Pakistan (2001), are addressed using within-country linear interpolation. This approach preserves temporal continuity without introducing cross-sectional bias. Descriptive statistics are reported in Table 1.

3.3. Empirical Model Specification

To empirically assess the relationship between renewable energy transition, institutional quality, and CO₂ emissions, we adopt a panel data estimation framework that explicitly accounts for unobserved heterogeneity and time-specific shocks. The baseline empirical model is specified as follows:

$$\ln(CO_{2,it}) = \alpha + \beta_1 RE_{it} + \beta_2 IQ_{it} + \beta_3 (RE_{it} \times IQ_{it}) + \gamma' X_{it} + \mu_i + \lambda_t + \varepsilon_{it} \quad (1)$$

where $\ln(CO_{2,it})$ denotes the natural logarithm of per capita CO₂ emissions in country i at time t ; RE_{it} is the renewable energy share; IQ_{it} is the institutional quality index; $RE_{it} \times IQ_{it}$ is their interaction term; X_{it} is a vector of control variables including GDP per capita, its squared term, FDI, financial development, and urbanization; μ_i represents country-specific fixed effects capturing time-invariant

Table 1: Descriptive statistics

Variable	Obs	Mean	Standard Deviation	Min	Max
Ln (CO ₂ emissions per capita)	264	0.704	1.021	-1.607	2.565
Renewable energy transition	264	0.275	0.241	0.004	0.881
Institutional quality	264	0.001	2.136	-3.294	6.257
RE×IQ	264	-0.279	0.674	-2.625	0.442
ln (GDP per capita)	264	1.119	1.087	-0.932	3.559
[ln (GDP per capita)] ²	264	2.429	3.079	0.000	12.666
Foreign direct investment (FDI)	264	0.018	0.016	-0.028	0.097
Financial development	264	0.465	0.356	0.081	1.761
Urbanization	264	0.532	0.184	0.236	0.819

This table reports descriptive statistics for the balanced panel of 11 Next-11 economies over the period 2000-2023 (264 observations). CO₂ emissions are measured in metric tons per capita and expressed in natural logarithms. Renewable energy transition, FDI, financial development, and urbanization are normalized to a 0-1 scale. Institutional quality is a standardized composite index constructed using principal component analysis (PCA). Missing values (<5%) are interpolated within countries

unobserved heterogeneity; λ_t denotes year fixed effects controlling for common global shocks; and ε_{it} is the idiosyncratic error term.

The coefficients of interest are β_1 , β_2 , and β_3 . We expect $\beta_1 < 0$ if renewable energy transition reduces emissions, and $\beta_2 < 0$ if stronger institutions improve environmental outcomes. The interaction coefficient β_3 tests whether institutional quality moderates the emissions-reducing effect of renewable energy. A negative β_3 would indicate that the marginal effect of renewable energy on emissions is more pronounced in countries with stronger governance frameworks.

The two-way fixed-effects specification addresses several identification concerns. Country fixed effects control for time-invariant characteristics such as geographic endowments, historical development paths, and cultural factors that may simultaneously affect energy choices, institutional development, and emissions. Year fixed effects absorb common temporal shocks including global energy price movements, international climate agreements, and technology diffusion trends. The inclusion of both dimensions ensures that identification relies on within-country variation over time, purged of global trends.

3.4. Diagnostic Tests and Estimation Strategy

Prior to estimation, several diagnostic tests are conducted to evaluate key econometric assumptions and guide the choice of estimator. Results are summarized in Table 2.

- Cross-sectional dependence. The Pesaran (2004) CD test strongly rejects the null hypothesis of cross-sectional independence (CD = -3.310, P = 0.0009), indicating the presence of common shocks and spillover effects across countries. This is consistent with the increasing economic and energy market integration among emerging economies.
- Serial correlation. The Wooldridge (2002) test for first-order autocorrelation in panel data rejects the null of no serial correlation (F = 22.078, P < 0.0001), confirming that errors are correlated over time within countries.
- Heteroskedasticity. The modified Wald test for groupwise heteroskedasticity rejects the null of constant variance

across panels ($\chi^2 = 28.348, P = 0.0029$), indicating that error variances differ across countries.

- Fixed effects versus random effects. The Hausman (1978) specification test does not decisively reject the random-effects estimator ($\chi^2 [8] = 6.50, P = 0.591$). However, fixed effects are preferred on theoretical grounds, as unobserved country-specific characteristics (e.g., resource endowments, political economy factors) are likely correlated with both renewable energy adoption and institutional development, violating the orthogonality assumption required for random effects consistency.

In response to these diagnostic results, the main estimations rely on a two-way fixed-effects estimator with standard errors clustered at both the country and year levels (Cameron et al., 2011). This approach accounts simultaneously for unobserved heterogeneity, cross-sectional dependence, serial correlation, and heteroskedasticity, ensuring reliable statistical inference. Two-way clustering is conservative and allows for arbitrary correlation structures within countries over time and across countries within years.

For comparison purposes, pooled ordinary least squares (OLS) and random-effects (RE) estimators are also reported. The preferred specification is the two-way fixed-effects model with two-way clustered standard errors (Column 4 in Table 3).

Table 2: Multicollinearity diagnostics

Variable	VIF
Renewable energy transition	6.721
Institutional quality	6.056
RE×IQ	6.872
ln (GDP per capita)	10.062
(ln[GDP per capita]) ²	12.152
Foreign direct investment	1.262
Financial development	2.997
Urbanization	7.761

RE: Renewable energy, IQ: Institutional quality, VIFs: Variance inflation factors. Variance inflation factors (VIFs) are reported. Values below 10 are generally considered acceptable. Elevated VIFs for ln (GDP) and its squared term are expected due to the quadratic Environmental Kuznets Curve (EKC) specification. Overall multicollinearity is manageable for the fixed-effects panel design

Table 3: Effects of renewable energy transition and institutional quality on CO₂ emissions

Variable	Dependent variable: ln (CO ₂ emissions per capita)			
	(1) Pooled OLS	(2) RE	(3) FE	(4) FE (Two-way cluster)
Renewable energy transition	-1.321** (0.624)	-3.543*** (0.197)	-3.598*** (0.833)	-3.598*** (0.802)
Institutional quality	-0.128*** (0.044)	-0.091*** (0.016)	-0.096*** (0.037)	-0.096** (0.040)
RE×IQ	-0.001 (0.192)	0.046 (0.062)	0.069 (0.096)	0.069 (0.095)
ln (GDP per capita)	0.503***	0.097***	0.091	0.091
(ln[GDP per capita]) ²	-0.070	0.026***	0.025	0.025
Foreign direct investment	5.290	0.416	0.372	0.372
Financial development	1.106***	0.421***	0.430***	0.430***
Urbanization	2.247**	-1.704***	-1.928*	-1.928*
Observations	264	264	264	264
Country fixed effects	No	No	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes

RE: Renewable energy, IQ: Institutional quality. Robust standard errors are reported in parentheses. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. Column (4) reports the preferred specification using two-way fixed effects with standard errors clustered by both country and year to address cross-sectional dependence and serial correlation

4. EMPIRICAL RESULTS

4.1. Baseline Regression Results

Table 3 presents the baseline regression results examining the effects of renewable energy transition and institutional quality on CO₂ emissions across the sample of emerging economies. Columns (1) and (2) report the pooled ordinary least squares and random-effects estimates, respectively, while columns (3) and (4) present the fixed-effects results. Column (4), which incorporates country and year fixed effects with standard errors clustered at both the country and year levels, is treated as the preferred specification.

Across all fixed-effects specifications, renewable energy transition is associated with a negative and statistically significant coefficient, indicating that a higher share of renewable energy in total final energy consumption contributes to lower per capita CO₂ emissions. This finding supports the view that energy transition toward renewable sources plays a central role in mitigating environmental degradation in emerging economies, even after controlling for income levels, financial factors, and demographic characteristics.

Institutional quality also enters the model with a negative and statistically significant coefficient, suggesting that stronger governance frameworks are linked to improved environmental outcomes. This result is consistent with the argument that effective institutions enhance regulatory enforcement, policy implementation, and environmental monitoring, thereby contributing to lower emissions. Importantly, the magnitude and significance of the institutional quality coefficient remain stable across alternative specifications, underscoring the robustness of this relationship.

Regarding the control variables, income exhibits a nonlinear relationship with CO₂ emissions. The coefficient on the logarithm of GDP per capita is positive, while the squared income term is negative, providing partial support for the Environmental Kuznets Curve hypothesis. This pattern suggests that emissions tend to increase during earlier stages of economic development before stabilizing as income levels rise. Financial development is positively associated with emissions, indicating that expanded

access to finance may stimulate energy-intensive economic activities in the absence of sufficiently stringent environmental regulations. Urbanization displays a negative coefficient in the fixed-effects models, which may reflect efficiency gains, structural transformation, and a shift toward less carbon-intensive activities in more urbanized economies. In contrast, foreign direct investment does not exhibit a statistically significant effect on emissions once country-specific heterogeneity is accounted for.

Overall, the baseline results indicate that renewable energy transition and institutional quality independently contribute to reducing CO₂ emissions in emerging economies. These findings provide a solid empirical foundation for the subsequent analysis of interaction effects and robustness checks.

4.2. Interaction Effects between Renewable Energy Transition and Institutional Quality

This section examines whether institutional quality conditions the emissions-reducing effect of renewable energy transition by analyzing the interaction term included in the fixed-effects specifications reported in Table 3. The interaction coefficient tests Hypothesis 3 (H₃), which predicted that stronger institutions would amplify the negative effect of renewable energy on CO₂ emissions.

Interaction coefficient and statistical significance. The estimated coefficient on the interaction term (*REit* × *IQit*) is positive (+0.069) across fixed-effects specifications, but does not reach conventional levels of statistical significance (standard error = 0.095, *t* = 0.73, *P* = 0.47 in the preferred Column 4 specification). The 95% confidence interval ranges from -0.117 to +0.255, encompassing both negative and positive values. This limited statistical precision indicates that we cannot reject the null hypothesis of no interaction effect.

The positive sign of the interaction coefficient is contrary to the theoretical prediction embedded in H3. A positive interaction implies that the marginal effect of renewable energy on emissions becomes less negative (weaker in absolute terms) as institutional quality increases, rather than more negative as hypothesized.

Marginal effects analysis. To better understand the conditioning relationship, we compute the marginal effect of renewable energy transition on CO₂ emissions at different levels of institutional quality. The marginal effect is given by:

$$\partial \ln(CO_2) / \partial RE = \beta_1 + \beta_3 \times IQ = -3.598 + 0.069 \times IQ$$

Table 4 reports these marginal effects evaluated at five institutional quality levels spanning the sample distribution. Several important

patterns emerge. First, renewable energy transition is associated with statistically significant and economically large emissions reductions at all institutional quality levels, with *t*-statistics ranging from -3.17 to -4.54. This provides robust support for Hypothesis 1 (H₁), confirming that renewable energy deployment reduces emissions regardless of governance context.

Second, the magnitude of the emissions-reducing effect is largest in countries with the weakest institutions. At the minimum institutional quality level (*IQ* = -3.29, representing countries like Nigeria and Pakistan during weak-governance periods), a one-unit increase in renewable energy share is associated with a 3.825 log-point reduction in per capita emissions. In contrast, at the maximum institutional quality level (*IQ* = 6.26, representing South Korea in recent years), the marginal effect is -3.166 log points. While both effects are economically substantial, the difference of 0.66 log points represents approximately a 17% weaker effect in high-governance contexts compared to low-governance settings.

Interpretation and potential mechanisms. The positive (though insignificant) interaction coefficient contradicts H₃ and warrants careful interpretation. We propose three potential explanations for this counterintuitive pattern:

First, energy rebound and scale effects may be more pronounced in countries with stronger institutions. Effective governance facilitates broader economic development, industrialization, and energy access expansion. In such contexts, renewable energy additions may primarily serve growing demand rather than displacing existing fossil fuel consumption. In weaker institutional settings, by contrast, renewable energy may more directly substitute for unreliable or expensive conventional electricity, yielding larger immediate emissions reductions.

Second, incumbent fossil fuel interests may be better organized and politically entrenched in countries with stronger institutions and more developed energy sectors. In Next-11 countries like Mexico, Turkey, and South Korea, established fossil fuel industries possess substantial lobbying capacity and political influence. These vested interests may slow the retirement of conventional power plants even as renewable capacity expands, leading to a dual energy system where both sources coexist. In weaker governance environments, fossil fuel infrastructure may be less entrenched, allowing renewables to achieve faster displacement.

Third, the positive interaction may reflect measurement and specification limitations rather than a true causal relationship. Institutional quality evolves very slowly over time (the

Table 4: Marginal effects of renewable energy transition on CO₂ emissions at different institutional quality levels

Institutional quality level	IQ value	Marginal effect	Standard error	t-statistics	Significance
Min (Nigeria, Pakistan)	-3.294	-3.825	0.861	-4.44	***
25 th percentile	-1.439	-3.697	0.814	-4.54	***
Median (Mean)	0.001	-3.598	0.802	-4.49	***
75 th percentile	1.441	-3.499	0.814	-4.30	***
Max (South Korea)	6.257	-3.166	0.998	-3.17	***

Marginal effects calculated as $\partial \ln(CO_2) / \partial RE = \beta_1 + \beta_3 \times IQ$ based on Column 4 of Table 3. Standard errors computed using the delta method assuming zero covariance between β_1 and β_3 . ***denotes significance at the 1% level. All marginal effects are statistically significant, indicating that renewable energy reduces emissions across the entire range of institutional quality observed in the sample. The variation in magnitude reflects the positive interaction coefficient, though this moderating effect is not statistically significant

within-country standard deviation of IQ is only 0.63 compared to a between-country standard deviation of 2.09 in our sample). This limited temporal variation reduces statistical power to precisely identify interaction effects in a 24-year panel. Moreover, the linear multiplicative interaction may be insufficiently flexible to capture potential nonlinear or threshold effects suggested by recent literature (Olaniyi et al., 2023). Alternative specifications allowing for threshold effects or regime-switching models may be better suited to detect institutional conditioning effects.

Robustness checks. We conduct additional robustness tests for the interaction effect. First, we estimate a quadratic interaction specification including both RE × IQ and RE × IQ² terms to allow for non-monotonic moderating effects. Neither interaction term achieves statistical significance, and the linear interaction remains positive. Second, we employ subsample analysis by splitting the sample at the median institutional quality level. Renewable energy coefficients are -3.41 (SE = 0.89) in the low-IQ subsample and -3.29 (SE = 1.12) in the high-IQ subsample; these estimates are not statistically distinguishable (P = 0.38 for equality test). Both robustness checks confirm that institutional quality does not significantly moderate the emissions-reducing effect of renewable energy in this sample.

Implications for hypothesis testing. Based on the empirical evidence, Hypothesis 3 (H3) is not supported. While both renewable energy transition (H1) and institutional quality (H2) independently reduce emissions, we find no evidence that stronger institutions amplify the environmental effectiveness of renewable energy deployment. If anything, the point estimates suggest the opposite pattern, though the lack of statistical significance precludes strong conclusions.

This finding contrasts with some prior studies reporting positive institutional moderating effects (Bhattacharya et al., 2017) but aligns with others documenting weak or context-dependent interactions in emerging economy settings. The lack of synergy between renewable energy and institutions may reflect the specific characteristics of Next-11 countries during the 2000-2023 period, where renewable energy expansion occurred rapidly but institutional development remained gradual and uneven.

Policy implications. From a policy perspective, this result carries an encouraging message: Renewable energy investments can deliver substantial emissions reductions even in weak-governance contexts. Policymakers in emerging economies should not delay renewable energy deployment while waiting for institutional reforms. The direct emissions-reducing effect of renewable energy appears robust across diverse governance environments. However, the absence of positive interaction also implies that institutional improvements alone may not automatically enhance renewable energy effectiveness. The pathways through which institutions and renewable energy affect emissions appear to operate largely independently, at least over the time horizon examined here. Future policy design should therefore pursue renewable energy expansion and institutional reform as parallel rather than sequential or conditional strategies.

Table 5: Diagnostic tests

Test	Statistic	P-value
Pesaran CD test	-3.310	0.0009
Wooldridge test for AR (1)	F=22.078	<0.0001
Modified Wald test	χ ² =28.348	0.0029
Hausman test (FE vs. RE)	χ ² (8)=6.50	0.591

Diagnostic tests indicate the presence of cross-sectional dependence, serial correlation, and heteroskedasticity, justifying the use of two-way clustered standard errors. Although the Hausman test does not reject the random-effects estimator, fixed effects are preferred to control for unobserved country-specific heterogeneity

4.3. Robustness Checks and Diagnostic Discussion

To ensure the reliability of the baseline findings, a series of diagnostic tests and robustness checks are conducted, as summarized in Table 5. Diagnostic results indicate the presence of key econometric challenges commonly encountered in macro-panel data. Specifically, the Pesaran cross-sectional dependence test strongly rejects the null hypothesis of cross-sectional independence, suggesting the existence of common shocks and spillover effects across countries. In addition, the Wooldridge test confirms first-order serial correlation in the error structure, while the modified Wald test indicates heteroskedasticity.

In light of these diagnostics, the empirical analysis relies on a two-way fixed-effects estimator with standard errors clustered at both the country and year levels. This approach effectively addresses cross-sectional dependence, serial correlation, and heteroskedasticity, thereby ensuring consistent statistical inference. Although the Hausman test does not decisively reject the random-effects specification, the fixed-effects model is retained as the preferred estimator due to the potential correlation between unobserved country-specific characteristics and the explanatory variables.

Further robustness checks confirm the stability of the main results. The estimated coefficients on renewable energy transition and institutional quality remain negative and qualitatively unchanged when alternative institutional measures are employed, when individual countries are excluded from the sample, and when the analysis is restricted to post-2005 subsamples. These findings reinforce the conclusion that the observed relationships are not driven by model specification choices, outliers, or specific time periods.

Taken together, the diagnostic tests and robustness checks support the credibility of the baseline results and strengthen confidence in the empirical strategy adopted in this study.

5. CONCLUSION AND POLICY IMPLICATIONS

5.1. Summary of Main Findings

This study examines the roles of renewable energy transition and institutional quality in shaping CO₂ emissions in 11 Next-11 emerging economies over the period 2000-2023. Employing a two-way fixed-effects estimation framework with clustered standard errors to address unobserved heterogeneity, cross-sectional dependence, and serial correlation, the analysis yields three principal findings.

First, renewable energy transition significantly reduces CO₂ emissions across all institutional contexts. The preferred specification indicates that a one-unit increase in renewable energy share (from 0 to 1) is associated with a 3.6 log-point reduction in per capita emissions, equivalent to approximately 97% lower emissions. This effect is statistically significant ($P < 0.001$) and robust across alternative specifications, providing strong support for Hypothesis 1. Marginal effects analysis reveals that renewable energy reduces emissions at all observed institutional quality levels, with t-statistics ranging from -3.17 to -4.54 .

Second, institutional quality independently contributes to emissions reductions. A one-standard-deviation improvement in the composite institutional quality index is associated with approximately 9.6% lower per capita emissions ($P < 0.05$), supporting Hypothesis 2. This finding underscores that effective governance—characterized by stronger rule of law, regulatory quality, and corruption control—enhances environmental outcomes through better policy enforcement, reduced rent-seeking, and improved monitoring capacity.

Third, institutional quality does not significantly moderate the emissions-reducing effect of renewable energy. The interaction coefficient is positive ($+0.069$) but statistically insignificant ($P = 0.47$), with a 95% confidence interval that includes both negative and positive values. This finding does not support Hypothesis 3, which predicted that stronger institutions would amplify renewable energy effectiveness. While the positive point estimate suggests that renewable energy may be slightly more effective in weak-governance contexts, the limited statistical precision precludes strong conclusions. The pathways through which renewable energy and institutional quality affect emissions appear to operate independently rather than synergistically over the 24-year period examined.

Additional findings support a nonlinear income–emissions relationship consistent with the Environmental Kuznets Curve, with emissions increasing in early development stages before stabilizing at higher income levels. Financial development is positively associated with emissions, while urbanization shows a negative relationship in fixed-effects specifications, potentially reflecting efficiency gains and structural transformation in more urbanized economies.

5.2. Policy Implications

The empirical findings carry several important policy implications for climate mitigation strategies in emerging economies.

Accelerate renewable energy deployment without waiting for institutional reforms. The robust negative effect of renewable energy across all governance contexts demonstrates that emerging economies can achieve substantial emissions reductions through renewable energy investments even in weak institutional environments. Policymakers should not delay renewable energy deployment while waiting for governance improvements. Countries like Bangladesh, Pakistan, and Nigeria—which rank lower on institutional quality indicators—can still benefit significantly from expanding solar, wind, and hydroelectric

capacity. This finding challenges the view that institutional reforms are necessary preconditions for effective environmental policy.

Pursue renewable energy expansion and institutional reforms as parallel strategies. While renewable energy and institutional quality both independently reduce emissions, their lack of interaction suggests that these pathways operate through distinct mechanisms. Policymakers should therefore pursue both strategies simultaneously rather than sequentially. Renewable energy investments can deliver immediate emissions reductions, while institutional reforms strengthen broader environmental governance capacity. Countries should not view these policies as substitutes; both are complementary components of comprehensive climate strategies.

Design renewable energy policies with explicit fossil fuel phase-out mechanisms. The positive (though insignificant) interaction coefficient suggests that renewable energy additions in high-governance countries may not fully displace fossil fuel consumption. To maximize emissions reductions, renewable energy policies should be coupled with explicit fossil fuel retirement schedules, carbon pricing mechanisms, or regulatory mandates that prevent new fossil fuel capacity. This is particularly important in countries like Mexico, Turkey, and South Korea, where incumbent fossil fuel interests may be politically entrenched. Feed-in tariffs, renewable portfolio standards, and auction mechanisms should be designed to accelerate coal and gas plant closures rather than simply adding renewable capacity to existing systems.

Strengthen institutions to enhance overall environmental governance. Although institutional quality does not amplify renewable energy effectiveness, it remains independently important for emissions reductions. Emerging economies should prioritize reforms that strengthen regulatory quality, rule of law, and corruption control. Specific measures include establishing independent environmental regulatory agencies, enhancing transparency in environmental permitting and enforcement, implementing robust monitoring and reporting systems, and strengthening judicial capacity to enforce environmental violations. These institutional improvements will enhance not only renewable energy outcomes but also broader environmental policy effectiveness across air quality, water management, and land use regulation.

Tailor renewable energy policies to country-specific contexts. The heterogeneity across Next-11 countries suggests that one-size-fits-all policies are unlikely to succeed. Countries with weak grid infrastructure (Bangladesh, Pakistan, Nigeria) may benefit from decentralized solar and wind systems that reduce reliance on centralized fossil fuel generation. Countries with stronger institutional capacity and developed energy sectors (South Korea, Mexico) should focus on grid modernization, energy storage, and demand-side management to integrate higher renewable shares. Resource-rich countries (Iran, Mexico, Nigeria) face unique political economy challenges in transitioning away from fossil fuel revenues and may require targeted fiscal reforms and diversification strategies.

Mobilize climate finance mechanisms for renewable energy in weak-governance settings. The finding that renewable energy is effective even in weak institutional contexts justifies international climate finance flows to lower-governance emerging economies. Multilateral development banks, bilateral donors, and climate funds should not impose overly stringent governance conditionalities that exclude countries most in need of support. Instead, climate finance mechanisms should incorporate safeguards and technical assistance to strengthen project implementation capacity while maintaining accessibility for countries with weaker institutional environments.

5.3. Limitations and Directions for Future Research

This study has several limitations that suggest directions for future research. First, the sample is restricted to 11 Next-11 countries over a 24-year period, limiting generalizability to other emerging economy groups such as least developed countries or small island developing states. Future research should extend the analysis to broader country samples to test whether the findings hold across different development contexts and income levels.

Second, institutional quality is measured using a composite index from the Worldwide Governance Indicators, which evolves slowly over time and may not capture recent institutional reforms or crisis-induced governance changes. Alternative institutional measures—such as regulatory stringency indices, environmental enforcement capacity, or sector-specific governance indicators—may reveal moderating effects not detected with broad governance indices. Future studies should explore which specific institutional dimensions matter most for renewable energy effectiveness.

Third, the linear multiplicative interaction specification may be insufficient to capture threshold effects or nonlinear moderating relationships. Recent literature suggests that institutional quality may exhibit threshold effects, whereby renewable energy becomes effective only above minimum governance thresholds. Future research should employ threshold regression models, regime-switching frameworks, or machine learning techniques to identify potential nonlinearities in the renewable energy–institutions–emissions nexus.

Fourth, the analysis does not address potential endogeneity concerns arising from reverse causality or omitted variable bias. While two-way fixed effects control for time-invariant country characteristics and common temporal shocks, renewable energy adoption and institutional quality may be jointly determined by deeper structural factors such as political economy configurations or resource endowments. Future research should employ instrumental variable approaches, difference-in-differences designs around policy reforms, or quasi-experimental methods to strengthen causal identification.

Fifth, the study focuses on aggregate CO₂ emissions rather than sector-specific emissions patterns. Renewable energy may have heterogeneous effects across electricity generation, transportation, industry, and residential sectors. Future research should disaggregate emissions by source and examine how renewable energy and institutions interact to affect sectoral emissions

trajectories. This would provide more granular policy guidance for sector-specific climate strategies.

Finally, the analysis does not examine heterogeneity across renewable energy sources (solar, wind, hydro, geothermal, biomass). Different technologies may face distinct institutional barriers and may interact differently with governance frameworks. Future studies should investigate whether the renewable energy–institutions relationship varies by technology type, which would inform technology-specific policy design and investment priorities.

5.4. Concluding Remarks

Climate change mitigation in emerging economies requires navigating the dual challenges of rapid energy demand growth and institutional constraints. This study demonstrates that renewable energy transition and institutional quality both contribute independently to emissions reductions in Next-11 emerging economies, but their effects do not exhibit the synergistic relationship predicted by theory. Most encouragingly, renewable energy deployment delivers substantial emissions reductions even in weak-governance contexts, suggesting that emerging economies should not delay climate action while awaiting institutional reforms.

As global attention increasingly focuses on emerging markets as the primary source of future emissions growth, understanding the drivers of effective climate policy in these contexts becomes ever more critical. The findings of this study suggest that renewable energy investments can succeed across diverse governance environments, but that maximizing their impact requires complementary policies addressing fossil fuel phase-out, grid modernization, and financial mobilization. By pursuing renewable energy expansion and institutional development as parallel strategies, emerging economies can chart pathways toward sustainable development that reconcile economic growth, energy access, and environmental protection.

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