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Climate Finance as a Catalyst for Energy Security Transitions: The Conditional Role of Natural-Resource Dependence in Developing Economies

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Abstract

This study examines whether international climate finance advances electricity-sector energy-security transitions in developing economies and whether natural-resource dependence conditions that relationship. Using country-year panel data for the period 2000-2023, across 118 developing economies, the paper estimates two-way fixed-effects models, moderation models, nonlinear specifications, robustness checks, marginal effects, and three-dimensional response surfaces. The results indicate that climate finance is most robustly associated with electricity-sector outcomes: higher finance exposure is linked to stronger renewable-electricity performance, lower fossil-electricity dependence, and lower energy-import exposure. However, the finance-transition relationship is conditional rather than automatic. Natural-resource rents weaken the marginal effect of climate finance, indicating that fossil-fuel lock-in and resource-rent incentives can reduce the effectiveness of external finance. Governance quality also matters because climate finance must pass through public investment systems, utilities, regulators, procurement agencies, and monitoring institutions before it becomes implemented transition capacity. The results indicate that climate finance is positively associated with renewable electricity (beta = 0.5884, $p < 0.10$). The study contributes to recent green-development debates by linking climate finance to energy security, locating resource dependence as a boundary condition, and presenting coefficient, marginal-effect, and surface-response evidence that can guide policy design.

Keywords: climate finance, energy security, renewable electricity, fossil-fuel lock-in, natural resource rents, governance quality, developing economies.

1. Introduction

Climate change, energy insecurity and reliance on fossil fuels have become a systemic challenge for developing countries. The energy transition toward low-carbon energy is a central priority in the international policy agenda, but in many developing countries, the challenge of providing reliable, affordable and modern electric power generation is compounded by the need to reduce fossil-fuel reliance and energy imports. This challenge is especially acute due to the substantial investments in energy infrastructure that are required to meet growing electricity demand, rapid urbanization, industrial growth, and population growth (Ahmed et al., 2025; Joshi et al., 2025). However, many developing economies are financially constrained, institutionally underdeveloped, and technologically unprepared to rapidly scale renewable energy (Asghar et al., 2024; Dunford & Han, 2025). For this reason, their electricity generation systems are frequently subject to carbon-intensive electricity generation, price volatility of electricity, import dependence, and supply disruptions (Guo et al., 2026; Li et al., 2026).

Consequently, the challenge of energy transition is not only environmental, but also of energy security. Moving to a more secure energy transition is more than increasing renewable energy capacity and decreasing dependence on fossil-fueled electricity; it is also about increasing domestic energy supply security, increasing grid readiness, and decreasing vulnerability to international energy-market shocks (Tarabkhah et al., 2025; Zhao et al., 2025). In developing economies, these goals are hindered by high financing costs and weak project pipelines, regulatory uncertainty, limited fiscal space, and poorly developed financial markets (Ashraf et al., 2025; Vatamanu & Zugravu, 2023). Recent research suggests that the cost of capital is one of the major obstacles to investing in renewables in developing regions, even in regions with abundant renewable-energy resources. This indicates that the pace and effectiveness of energy-security transition will vary not only with technology availability, but also with the country's capacity to mobilize and absorb transition finance (Ghazali et al., 2026).

Climate finance has assumed a central role in international climate cooperation in this context. Climate finance comprises financial flows for low-carbon and climate-resilient development, mitigation and adaptation (Ashraf et al., 2025; Omukuti, 2024). In developing economies, financing can help to mitigate investment risk, alleviate capital shortages, attract complementary private investment, support renewable-energy infrastructure, and build institutional structures needed to facilitate clean energy deployment (Borojo et al., 2024; Lee & Fang, 2025). A range of electricity-sector transitions can be enabled by climate finance, with the potential to enhance energy security through greater renewable-electricity generation, and through the reduction of exposure to imported fuels, which is likely to reduce reliance on fossil fuels (Nepal et al., 2024; Njangang et al., 2024). Therefore, climate finance should be conceptualized, not just as a mitigation tool, but as a tool to enhance energy-system security and resilience.

The literature on climate finance has expanded, yet its effectiveness remains contested. Previous research has explored the impact of climate finance on climate vulnerability reduction, energy efficiency, production of renewable energy, environmental sustainability and greenhouse-gas emission reductions (Ashraf et al., 2025; Fang et al., 2025). Recent studies indicate that international climate finance can lower the cost of capital and make renewable-energy investment in developing countries more feasible (Njangang et al., 2024). However, studies to date tend to measure climate finance mainly as an environmental or emissions outcome (Wang & Njangang, 2025). Less focus has been directed to how climate finance facilitates better energy-security transitions in measurable ways through changes in electricity-sector structure and import exposure. This is a notable gap because climate finance can have wider development effects when it helps to displace fossil electricity and build domestic renewable-energy power.

Another gap in the existing literature is that the effectiveness of climate finance is treated as relatively homogeneous at the country level. In fact, the same amount of climate finance can have differential impacts given domestic structural and institutional conditions (Fang et al., 2025; Saidi et al., 2026). One such factor is natural resource dependence. Resource-rich developing countries, however, may have fiscal revenues that would allow for transition investments, but can also face fossil-fuel lock-in, rent-seeking motives, persistent fossil-fuel subsidies, and infrastructure path dependence (Chavda & Mehta, 2026; Saidi et al., 2026). These conditions can further weaken the ability of external finance to effectively challenge fossil-energy incumbents' political and economic power. This means that climate finance does not necessarily equate to renewable expansion or fossil displacement in countries where the energy sector prioritises resource rents.

Another key governance issue to consider is the quality of governance. External finance is not directly added to the installed renewable generation, grid build-out or reduction of fossil fuels. It must pass through domestic systems of planning, procurement, regulation, utility management, project implementation and monitoring. Weak governance can slow down the realization of projects, heighten corruption risks, diminish investor confidence, and lower the credibility of reforms in the energy sector (Ashraf et al., 2025; Ghazali et al., 2026). Stronger governance, by contrast, can enhance project selection, regulatory co-ordination, transparency and implementation capacity. Thus, the impact of climate finance will be subject not just to the amount of finance received, but also to the institutional capacity of the finance to be converted into transition outcomes (Ashraf et al., 2026).

In this context, this research explores the question of whether climate finance contributes to and enables energy-security transitions in developing economies and whether natural-resource dependence moderates this contribution. In particular, the study has three research questions. First, do climate finance measures enhance the performance of renewable electricity, reduce reliance on fossil electricity, and reduce exposure to net energy imports? Second, does natural-resource dependence reduce the impact of climate finance on these

energy-security transition outcomes? Third, does the quality of governance affect the ability of developing economies to deliver measurable progress toward climate transition through climate finance?

This study develops an unbalanced country-year panel dataset covering 118 developing economies of climate-related development finance, renewable electricity indicators, fossil electricity indicators, net energy imports, natural-resource rents, governance quality, and macroeconomic controls to answer these questions. The empirical analysis is based on two-way fixed-effects models, models with interaction terms, nonlinear specifications, robustness checks, marginal-effect estimates, and three-dimensional response surfaces. This structure enables the study to test whether climate finance contributes to energy-security transition outcomes, whether natural-resource dependence weakens this contribution, and whether governance and absorptive-capacity constraints condition the finance-transition relationship.

This study has three main contributions in the literature. First, climate finance is not a climate mitigation or environmental sustainability tool, it is also an energy-security tool. The study focuses on renewable electricity, fossil electricity and net energy-import exposure, and as such demonstrates the interlinkage between the structure and security of energy systems and climate finance in developing countries. Second, it establishes the natural resource dependence as an important boundary condition that can help to dampen the climate-finance effect. Third, it assesses the quality of governance and the effects of finance that are nonlinear to account for absorptive capacity and the diminishing returns.

The rest of the paper is organized as follows: The literature is reviewed and the hypotheses developed in Section 2. The data, variables and empirical method are described in Section 3. Section 4 introduces and examines the results, drawn from the moderation, nonlinear, marginal-effect and robustness evidence. The section ends with findings, policy implications, limitations and future directions for research.

2. Literature Review and Hypothesis Development

The four debates discussed here are related to each other and provide the structure for this literature review. The first concerns the financing of climate change, cost of capital, and increasing the generation of renewable electricity in developing economies. The second connects climate finance to energy security, by depending on fossil-electricity and import vulnerability. The third examines natural resource dependence and fossil-fuel lock-in as political-economy constraints. The fourth explores the governance quality, absorptive capacity and the nonlinear impacts of implementation. This organization links directly the theoretical channels with the hypotheses and empirical models that are used in the study.

2.1 Climate Finance, Cost of Capital, and Renewable-Electricity Expansion

Climate finance has emerged as an important mechanism to facilitate the progression of low-carbon development in developing economies, including countries with limited financial markets, fiscal capacity, project pipelines, and high financing costs for

renewables (Njangang et al., 2024). The potential for renewable energy use is significant in many developing countries, but it is necessary to translate this potential into electricity production, requiring high initial capital investment, credible regulation and bankable projects (Borojo et al., 2024; Briera & Lefèvre, 2024). Negative outcomes of these constraints can be mitigated by climate finance, which can lower the perceived investment risk, reduce the cost of capital and mobilize complementary private investment, recent evidence shows. Briera and Lefèvre (2024) find that international climate finance can serve to speed up the deployment of VRE when development finance institutions mitigate financing risks, and that reducing capital costs is crucial for helping developing countries finance the energy transition. Briera and Lefèvre (2024) conclude that international climate finance can help to accelerate the deployment of VRE when development finance institutions lower financing risks, and that reducing capital costs is essential for financing the energy transition in developing countries (Amoah et al., 2025).

The financing channel extends beyond direct funding. Climate finance can assist with project preparation, modernization of the grid, storage, technical assistance and policy implementation for renewables. Aziz and Jahan (2023) indicate that climate policies, public funding, feed-in tariffs and tendering systems have an impact on the flow of IDF, and Borojo et al. (2024) reveals that climate finance influences renewable-energy production and energy efficiency in developing economies. Based on these studies, the performance of renewable electricity is enhanced by climate finance if it is financed in an enabling policy and institutional framework. Accordingly, this study proposes:

- H1: Climate finance is positively associated with renewable-electricity performance in developing economies.

2.2 Climate Finance, Energy Security, Fossil Dependence, and Import Exposure

The concept of energy security is commonly defined by three characteristics: affordability, reliability, and resilience, and minimizing external energy shocks (Zhao et al., 2024). The factors that contribute to energy insecurity in developing economies include fossil-fuel dependence, exposure to imported fuels and fuel-dependent foreign markets, poor electricity infrastructure, and energy-price volatility (Alharbi et al., 2023; Opoku et al., 2025). Climate finance can enhance energy security if it is used for energy efficiency and electricity system diversification, as well as for domestic renewable energy generation and integration into the grid (Thawani et al., 2026; Vo et al., 2025). According to Njangang et al. (2024), climate finance helps to decrease energy vulnerability in developing countries, especially if finance is channeled into mitigation measures. It implies, in consequence, that the evaluation of climate finance should not only be based on emissions reduction, but also on energy system resilience.

One direct path for contributing to a lower-carbon and less import-dependent electricity sector is the potential for climate finance to do so. Renewable electricity can replace coal,

oil and gas generation and domestic clean energy generation can lessen reliance on imported electricity generation (Aslam et al., 2024; Lee et al., 2024a). This transition could be gradual, however, due to the long life span of electricity systems, including policy design and implementation capacity and infrastructure. Galeazzi et al. (2024) indicate that policies to promote renewable energy in developing countries may have delayed and mixed effects, suggesting that this does not necessarily mean that climate finance will lead to immediate fossil energy reduction. However, with finance for electricity-sector transformation, reliance on fossil-electricity is expected to decline, as is net exposure to energy imports. Thus, this study proposes:

- H2a: Climate finance is negatively associated with fossil-electricity dependence in developing economies.
- H2b: Climate finance is negatively associated with net energy-import exposure in developing economies.

2.3 Natural-Resource Dependence and Fossil-Fuel Lock-in

Natural-resource dependence may condition the effectiveness of climate finance because resource rents influence fiscal incentives, energy-sector politics, and infrastructure choices. Resource-rich developing economies may possess revenues that could support transition investment, but they may also face fossil-fuel lock-in, subsidy persistence, rent-seeking, and incumbent resistance. Ahmad et al. (2023) argue that the effect of natural resources on sustainable development depends on institutional and policy conditions, while Liu and Lu (2023) indicate that the resources-energy relationship is heterogeneous across developing economies. Ongo Nkoa et al. (2024) further link natural-resource rents to fragility concerns, suggesting that resource dependence can weaken institutional capacity and long-term transition planning.

In resource-dependent economies, climate finance may therefore face a political-economy constraint. External finance can support renewable projects, but fossil-sector incumbents, rent-distribution systems, and existing fossil infrastructure may reduce the speed at which finance changes the electricity mix (Droste et al., 2024; Rahko et al., 2025). Governments dependent on fossil-resource revenues may also have weaker incentives to reduce fossil-based generation or reform energy subsidies (Chen et al., 2023). As a result, climate finance may remain relevant but less effective where resource rents reinforce carbon-intensive development paths. This leads to the third hypothesis:

- H3: Natural-resource rents weaken the marginal effect of climate finance on energy-security transition outcomes.

2.4 Governance Quality, Absorptive Capacity, and Nonlinear Effects

Governance quality is central to climate-finance effectiveness because external finance must pass through domestic institutions before producing measurable transition outcomes (Ashraf et al., 2025; Wang & Njangang, 2025). Climate finance must be converted into project selection, procurement, regulation, utility coordination, implementation, and

monitoring (Awijen et al., 2025). Weak governance can delay project execution, increase corruption risks, reduce transparency, and weaken investor confidence. Stronger governance, by contrast, can improve regulatory credibility, project appraisal, procurement quality, and implementation capacity (Ashraf et al., 2025; Xu et al., 2023). foreign investment and aid support energy transition more effectively where corruption is lower, reinforcing the view that institutional quality shapes the absorptive capacity of recipient economies (Tawiah et al., 2025).

The climate-finance relationship may also be nonlinear. At lower levels of finance, additional inflows may generate strong gains by supporting readily available renewable projects, technical assistance, and policy reforms (Giganti et al., 2025; Halldén et al., 2025). However, as finance increases, marginal returns may decline if countries face constraints in grid readiness, land access, technical expertise, project pipelines, or administrative capacity (Lee et al., 2024b; Omri & Ben Jabeur, 2024). This means that larger finance volumes do not necessarily produce proportionate transition outcomes. Climate finance must therefore be evaluated through both institutional capacity and nonlinear implementation constraints. Accordingly, this study proposes: This nonlinear logic is also consistent with recent evidence on climate-risk, energy-transition and sustainable-finance spillovers (Mellouli, 2026), and on institutional quality, green technologies and energy diversification (Bergougui & Meziane, 2026).

- H4: The climate-finance relationship is nonlinear, with diminishing marginal returns where absorptive-capacity constraints bind.
- H5: Governance quality strengthens the conversion of climate finance into measurable energy-security transition outcomes.

Although climate-finance research has expanded, notable gaps remain. Most studies examine climate finance through carbon emissions, environmental sustainability, renewable-energy production, energy efficiency, or climate vulnerability (Njangang et al., 2024; Zhao et al., 2024; Zhang et al., 2025). These outcomes are valuable, but they do not fully capture whether climate finance contributes to energy-security transitions. Energy security requires structural changes in renewable electricity, fossil-electricity dependence, and net energy-import exposure. Moreover, prior studies often examine single outcomes separately, even though renewable expansion, fossil displacement, and import-risk reduction are related but distinct dimensions of transition.

This study addresses these gaps in three ways. First, it reframes climate finance as an energy-security instrument rather than only a mitigation or environmental-quality tool. Second, it integrates natural-resource dependence as a boundary condition, testing whether resource rents weaken the marginal effect of climate finance on transition outcomes. Third, it incorporates governance quality and nonlinear effects to capture absorptive capacity and diminishing returns (Halldén et al., 2025; Nepal et al., 2024). By combining fixed-effects

estimates, moderation analysis, marginal effects, and response-surface evidence, the study provides a more comprehensive framework for understanding how climate finance supports, or fails to support, energy-security transitions in developing economies.

3. Data and Methodology

3.1 Data and Sample

This study examines the relationship between climate finance and energy-security transitions in developing economies using country-year panel data. The merged dataset covers up to 118 developing economies over the period 2000–2023, yielding a maximum of 3,144 country-year observations. Because the panel is unbalanced and data availability differs across climate-finance, electricity-sector, energy-import, governance, and macroeconomic variables, the estimation sample varies across specifications; therefore, model-specific country and observation counts are reported in the relevant results tables. The dataset combines information on climate-related development finance, electricity-sector outcomes, energy-import exposure, natural-resource dependence, governance quality, and macroeconomic controls. Climate finance data are obtained from the OECD climate-related development finance database and expressed in constant 2023 US dollars. Energy-sector variables, including renewable electricity, fossil electricity, energy imports, energy use, electricity consumption, and natural-resource rents, are drawn from the World Development Indicators and Our World in Data. Governance indicators are obtained from the Worldwide Governance Indicators database.

The sample includes developing economies with adequate country-year observations across the main variables. The use of an unbalanced panel allows the study to retain the maximum available information while accounting for country-specific data availability. In addition to the full developing-economy sample, a resource-rich developing-economy subsample is used in robustness analysis to examine whether the climate-finance relationship differs in countries where resource rents and fossil-fuel lock-in are more relevant. This sample design is appropriate for testing whether climate finance contributes to renewable-electricity expansion, fossil-electricity reduction, and lower energy-import exposure under different structural and institutional conditions.

3.2 Variable Measurement

The dependent variables capture three dimensions of energy-security transition. Renewable electricity is measured as the share of electricity generated from renewable sources in total electricity generation. Fossil electricity is measured as the share of electricity generated from coal, oil, and gas in total electricity generation. Energy-import exposure is measured as net energy imports as a percentage of energy use. These three outcomes represent complementary dimensions of transition because a secure low-carbon energy system requires not only renewable expansion, but also fossil displacement and reduced exposure to imported energy.

The study also constructs a composite energy-transition index. The index is designed so that higher values indicate stronger transition performance. Renewable-electricity share enters positively, while fossil-electricity share and net energy-import exposure are reverse-coded before aggregation. To reduce potential structural measurement bias, RELEC, FOELEC, and ENIM are treated as the main dependent variables, while ETI is used only as a supplementary robustness indicator. All components are standardized before constructing the index to ensure comparability across variables with different units. The key explanatory variable is climate finance, measured as OECD climate-related development finance in constant 2023 US dollars. Because climate-finance flows are highly skewed and may include zero values, the variable is transformed using the natural logarithm of one plus climate finance. Climate finance per capita is also used as an alternative measure in robustness checks. Natural-resource dependence is measured by total natural-resource rents as a percentage of GDP. Governance quality is measured as the average of the six Worldwide Governance Indicators. The control variables include GDP per capita, population, trade openness, greenhouse-gas emissions, energy use per capita, and electric-power consumption. Table 1 lists definitions and sources of all variables.

Table 1: Variable Definitions and Data Sources

Variable	Definition	Source
Renewable electricity (RELEC)	Renewable electricity output as a share of total electricity generation.	(Şanal et al., 2026) WDI / OWID
Fossil electricity (FOELEC)	Electricity generated from coal, oil, and gas as a share of total electricity generation.	(Vinay et al., 2025) WDI / OWID
Energy imports (ENIM)	Net energy imports as a percentage of energy use; this broader WDI energy-security exposure measure is denoted ENIM.	(Zhang & Usman, 2025) WDI
Energy transition index (ETI)	Higher-is-better composite transition outcome combining renewable performance, reverse-coded fossil dependence, and reverse-coded net energy-import exposure.	Author's calculations
Climate finance (CF)	Natural logarithm of one plus OECD climate-related development finance, expressed in constant 2023 US dollars; denoted CF.	(Ren et al., 2025) OECD
Climate finance per capita (CFPC)	Climate finance scaled by population and used as an alternative finance measure in robustness checks; denoted CFPC.	(Lee & Fang, 2025) OECD
Natural resource rents (NRR)	Total natural resource rents as a percentage of GDP.	(Mohan & Morris, 2025) WDI
Governance quality (GOV)	Average of six Worldwide Governance Indicators.	(Saba et al., 2025) WGI
Controls (X)	Control vector (X): log GDP per capita (LGDPPC), population (POP), trade openness (TRADE), greenhouse-gas emissions (GHG), energy use per capita (ENUSEPC), and electric-power consumption (EPC).	WDI / OWID

Note: Variables are selected to capture climate-finance exposure, electricity-sector transition outcomes, energy-security exposure, resource dependence, governance, and macroeconomic controls. OECD climate-related development finance is expressed in constant 2023 US dollars before transformation; WDI, OWID, and WGI indicators are harmonized at the country-year level. The energy-import measure refers to net energy imports, not net electricity imports.

3.3 Model Specification

The baseline empirical strategy uses a two-way fixed-effects model to estimate the relationship between climate finance and energy-security transition outcomes. Country fixed effects control for time-invariant country characteristics such as geography, long-run institutional history, resource endowments, and structural development patterns. Year fixed effects control for common global shocks, including international energy-price changes, global financial conditions, renewable-technology cost trends, and international climate-policy momentum.

The baseline model is specified as follows:

$$Y_{it} = \alpha_i + \lambda_t + \beta_1 CF_{it} + \beta_2 NRR_{it} + \gamma' X_{it} + \varepsilon_{it} \quad (1)$$

In Equation (1), the dependent variable represents the energy-security transition outcome for country i in year t, including renewable electricity, fossil electricity, net energy imports, or the energy-transition index. The climate-finance variable denotes climate finance, the natural-resource-rents variable represents natural-resource rents, and the control vector includes the macroeconomic and energy controls. Country fixed effects capture time-invariant country characteristics, year fixed effects capture common time shocks, and the error term captures unexplained variation. Standard errors are clustered at the country level to account for serial correlation and heteroskedasticity within countries. The climate-finance coefficient captures the average within-country association between climate finance and the selected transition outcome, conditional on controls and fixed effects.

3.3.1 Energy Transition Index Construction

Given that renewable electricity enters positively while fossil electricity and energy imports are reverse-coded, the index is specified as:

Equation (2) ETI construction:

$$ETI_{it} = z(RELEC_{it}) - z(FOELEC_{it}) - z(ENIM_{it}) \quad (2)$$

where z(.) denotes standardized values. The negative signs indicate that fossil-electricity dependence and net energy-import exposure are reverse-coded so that higher energy-transition-index values represent stronger transition performance.

3.4 Moderation and Nonlinear Models

To test whether natural-resource dependence conditions the effectiveness of climate finance, the study estimates an interaction model between climate finance and natural-resource rents:

Equation (3) tests the moderating role of natural-resource rents:

$$Y_{it} = \alpha_i + \lambda_t + \beta_1 CF_{it} + \beta_2 NRR_{it} + \beta_3 (\mathrm{CF}_{it} \times \mathrm{NRR}_{it}) + \gamma' X_{it} + \varepsilon_{it} \quad (3)$$

The interaction coefficient indicates whether natural-resource rents alter the marginal effect of climate finance. For renewable electricity and the energy-transition index, a negative interaction suggests that resource rents weaken the positive effect of climate finance. For fossil electricity and net energy imports, a positive interaction suggests that resource rents weaken the negative effect of climate finance, meaning that fossil-fuel lock-in and rent dependence reduce the transition benefits of external finance.

The governance moderation model is specified as follows:

Equation (4) tests the moderating role of governance quality:

$$Y_{it} = \alpha_i + \lambda_t + \beta_1 CF_{it} + \beta_2 GOV_{it} + \beta_3 (\mathrm{CF}_{it} \times \mathrm{GOV}_{it}) + \gamma' X_{it} + \varepsilon_{it} \qquad (4)$$

In Equation (4), governance quality is the moderating variable. Since the energy-transition index is coded so that higher values indicate stronger transition performance, Hypothesis 5 would be supported in the energy-transition-index model only if the climate finance by governance-quality interaction is positive. A negative climate finance by governance-quality interaction coefficient implies that governance is associated with a weaker marginal finance effect in that specification. For fossil electricity and net energy imports, by contrast, a negative interaction would be consistent with governance strengthening the fossil-reduction or import-reduction effect of finance.

To examine nonlinear effects, the study includes a squared climate-finance term:

Equation (5) tests the nonlinear climate-finance specification:

$$Y_{it} = \alpha_i + \lambda_t + \beta_1 CF_{it} + \beta_2 CF_{it}^2 + \gamma' X_{it} + \varepsilon_{it} \qquad (5)$$

A negative squared-finance coefficient in the renewable-electricity or energy-transition-index model indicates diminishing marginal returns, while a positive squared-finance coefficient in the fossil-electricity or net-energy-imports model indicates that the beneficial fossil-reducing or import-reducing effect weakens at higher levels of finance.

3.5 Marginal Effects and Response Surfaces

Because interaction and nonlinear terms cannot be interpreted solely from the main coefficients, the study calculates marginal effects. For the natural-resource moderation model, the marginal effect of climate finance is calculated as:

From Equation (3), the marginal effect of climate finance conditional on natural-resource rents is:

$$\frac{\partial Y_{it}}{\partial CF_{it}} = \beta_1 + \beta_3 NRR_{it} \qquad (6)$$

This expression shows how the effect of climate finance changes across different levels of natural-resource dependence. For the governance model, the marginal effect is calculated as:

From Equation (4), the governance-conditioned marginal effect is:

$$\frac{\partial Y_{it}}{\partial CF_{it}} = \beta_1 + \beta_3 GOV_{it} \qquad (7)$$

For the nonlinear model, the marginal effect is calculated as:

From Equation (5), the nonlinear marginal effect is:

$$\frac{\partial Y_{it}}{\partial CF_{it}} = \beta_1 + \beta_3 GOV_{it} \qquad (8)$$

These marginal effects are evaluated across substantive values of the moderator, such as low, mean, and high levels of natural-resource rents and governance quality. The study also presents three-dimensional response surfaces to visually examine how climate finance and resource dependence jointly shape renewable electricity, fossil electricity, and energy-import exposure. These graphical analyses help interpret the conditional and nonlinear nature of climate-finance effectiveness.

3.6 Robustness and Endogeneity Strategy

Although the two-way fixed-effects framework reduces bias from time-invariant country characteristics and common global shocks, potential endogeneity concerns may remain. Climate finance may be allocated to countries with greater energy insecurity, stronger climate-policy commitment, or better institutional capacity. Reverse causality may also arise if countries with changing renewable-energy performance attract more climate finance. In addition, omitted time-varying factors may influence both climate-finance allocation and transition outcomes.

To address these concerns, the study applies several robustness checks, each serving a specific diagnostic purpose. Climate finance per capita tests whether results depend on absolute finance volume rather than population-scaled exposure. Lagged-finance models capture implementation delays between commitment, disbursement, project execution, and observed energy-sector outcomes. Resource-rich subsample models test whether the proposed mechanism is stronger where natural-resource rents and fossil-fuel lock-in are more structurally relevant. Shock-year exclusions reduce the influence of crisis years and unusual energy-market disruptions. Panel-corrected standard error (PCSE) models assess whether the main conclusions are sensitive to panel heteroskedasticity, serial correlation, and cross-sectional dependence. PCSE estimates are used only as a diagnostic robustness check, and rounded standard errors are interpreted cautiously against the main fixed-effects evidence.

4. Results

4.1 Descriptive Statistics

Table 2 indicates considerable cross-country and over-time variation in the energy-transition and explanatory variables. Renewable electricity averages 33.937 percent, while fossil electricity averages 62.477 percent, indicating that fossil-based generation remains

dominant in the sample despite wide dispersion across countries. The negative mean and large standard deviation of net energy imports suggest substantial differences between energy exporters and import-dependent economies. Variation in climate finance, resource rents, governance, trade openness, and greenhouse-gas emissions further supports the use of panel methods that account for heterogeneous national conditions.

Table 2: Descriptive Statistics

Variable	Obs.	Mean	SD	Min.	Max.
RELEC	2753	33.937	32.921	0.000	100.000
FOELEC	2958	62.477	34.273	0.000	100.000
ENIM	1929	-57.724	233.792	-3300.15	116.928
ETI	3087	-0.158	0.703	-1.398	2.004
CF	3144	15.145	6.059	0.000	23.408
CFPC	3144	1.834	1.709	0.000	8.794
NRR	2783	8.323	11.295	0.000	88.592
GOV	2958	-0.535	0.624	-2.410	1.100
LGDPPC	3065	7.743	0.940	5.455	9.611

Note: The table reports the available country-year observations after merging finance, energy, governance, and macroeconomic data. Differences in observations reflect source-specific missingness and variation in country-year coverage across indicators.

4.2 Data Analysis

Table 3 indicates that renewable and fossil electricity are strongly inversely correlated, as expected from their competing roles in electricity generation. Climate finance is positively associated with renewable electricity and energy-import exposure and negatively associated with fossil electricity, although these bivariate correlations are modest. The strong negative correlation between natural-resource rents and energy imports, together with the positive association between governance and GDP per capita, highlights structural differences across countries that motivate the multivariate fixed-effects analysis.

Table 3: Correlation Matrix

Variable	RELEC	FOELEC	ENIM	CF	NRR	GOV	GDPPC
RELEC	1.00						
FOELEC	-0.97*	1.00					
ENIM	0.07*	-0.07*	1.00				
CF	0.13*	-0.14*	0.17*	1.00			
NRR	-0.02	0.02	-0.74*	-0.09*	1.00		
GOV	-0.13*	0.12*	0.34*	-0.00	-0.43*	1.00	
GDPPC	-0.31*	0.29*	-0.15*	-0.04*	-0.07*	0.50*	1.00

Note: Pairwise Pearson correlations are descriptive and do not account for fixed effects or controls. Asterisks denote $p<0.05$ and indicate bivariate statistical association only.

The results provide evidence consistent with a conditional climate-finance argument. Climate finance is most consistently associated with outcomes tied directly to electricity-sector transformation, while the magnitude and direction of the association depend on resource rents, governance quality, and nonlinear implementation constraints. Because the main estimates are fixed-effects associations, the findings should be interpreted as conditional within-country relationships rather than definitive causal effects.

The relatively low within R-squared values in several renewable-electricity and fossil-electricity specifications are not unusual in two-way fixed-effects panel models, where identification comes from within-country changes after absorbing country and year effects. Nevertheless, the estimates should be interpreted cautiously and should not be used to claim that climate finance alone explains most variation in electricity-transition outcomes. The low values therefore indicate modest within-country explanatory power after fixed effects, not absence of a theoretically meaningful association.

Table 4 provides the initial empirical evidence for the renewable-electricity channel. The positive climate-finance coefficient in the renewable-electricity model indicates that increases in climate-finance exposure are associated with stronger renewable-electricity performance after controlling for country-specific characteristics, year shocks, and macroeconomic conditions. This result is consistent with the argument that climate finance relaxes investment constraints, supports project preparation, and improves the feasibility of renewable generation in developing economies. The negative interaction between climate finance and natural-resource rents further indicates that this positive association weakens as resource dependence rises. In substantive terms, climate finance appears to support renewable expansion, but its marginal effectiveness is reduced where extractive rents, fossil-sector incumbency, and infrastructure lock-in continue to shape the electricity system.

Table 4: Main Transition Results

Variable	(1)	(2)
Outcome	RELEC	ETI: GOV
CF	0.5884*	-0.0359***
	(0.3328)	(0.0121)
NRR	0.2072**	
	(0.0980)	
GOV		0.2905
		(0.1998)
CF × NRR	-0.0109*	
	(0.0057)	
CF × GOV		-0.0146**
		(0.0063)
CF^2	-0.0232*	0.0010*
	(0.0132)	(0.0006)
LGDPPC	-0.5735	-0.1000
	(3.1345)	(0.1970)
POP	-0.2961	-2.0569***
	(7.1284)	(0.3722)
TRADE	0.0001	0.0027
	(0.0185)	(0.0018)
ENUSEPC		-0.0000
		(0.0001)
EPC		0.0003**
		(0.0001)
Constant	39.6842	34.0233***
	(117.2931)	(5.7365)
Observations	2141	487
Countries	118	26
R-squared	0.0270	0.5897
F statistic	2.587	

Note: Standard errors are clustered by country and reported in parentheses. Country and year fixed effects are included. Significance levels are * p<0.10, ** p<0.05, and *** p<0.01. Coefficients should be read as within-country associations conditional on controls and fixed effects.

Table 5 is a further extension of evidence related to renewable expansion and fossil displacement and exposure to imported energy. The negative coefficients of the fossil-electricity and the energy-import models indicate a negative relationship between climate finance and the use of fossil electricity and import of energy. This is important because a transition to energy security is about reducing as well as adding renewable energy generation. Positive interaction terms suggest that the positive effects are less pronounced in resource dependent economies, reflecting the negative effects of fossil-fuel lock-in and rent-seeking political incentives on the security benefits of climate finance. This is therefore consistent with the findings of a transition-security mechanism in which transition (via climate finance) is most important when it affects the electricity mix and

vulnerability to external energy shocks. The common-sample FOELEC specification is reported in column 3, with the stronger coefficient being a check for comparability given that it refers to a smaller sample of 62 countries (with complete data) and not to a complete-sample estimate of the specification.

Table 5: Fossil Dependence and Energy-Security Results

Variable	(1)	(2)	(3)
Outcome	FOELEC	ENIM	Main sample: FOELEC
CF	-0.7801***	-3.0484**	-1.1797**
	(0.2696)	(1.2812)	(0.4831)
NRR	-0.2187	-3.4784***	-0.2408
	(0.1375)	(1.1712)	(0.1871)
CF × NRR	0.0159*	0.1229*	0.0186
	(0.0088)	(0.0650)	(0.0124)
CF^2	0.0325***		0.0323**
	(0.0114)		(0.0146)
LGDPPC	2.1675	-110.7599***	4.1431
	(3.4989)	(27.2763)	(3.8495)
POP	0.2683	24.9683	4.1261
	(6.1332)	(45.5726)	(12.1003)
TRADE	-0.0172	-0.2854	
	(0.0212)	(0.1778)	
Constant	46.3865	466.2469	-31.3904
	(103.2413)	(838.2338)	(187.4252)
Observations	2553	1467	1323
Countries	118	86	62
R-squared	0.0425	0.3271	0.0549
F statistic	3.719	3.925	1.679

Note: Negative climate-finance coefficients indicate lower fossil-electricity dependence or lower net energy-import exposure, depending on the dependent variable. Interaction terms indicate whether natural-resource rents alter the marginal climate-finance effect. Country and year fixed effects are included unless otherwise stated..

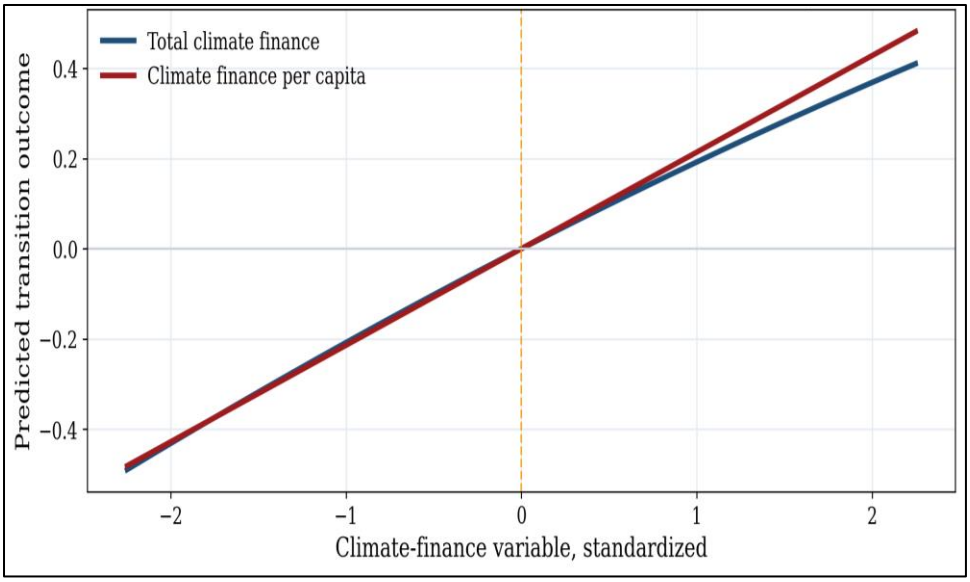


Figure 1: Nonlinear Climate-Finance Transition Relationship

Figure 1 illustrates the nonlinear climate finance transition relationship. The curve suggests that the association between transition and climate finance is stronger at low levels of finance, but becomes weaker at higher levels of finance. This is a standard pattern of diminishing returns: While some initial funding can support high-priority renewable development, policy changes, and technical assistance, additional funding will face constraints on grid capacity, land acquisition, procurement quality, regulatory delays, or a limited pipeline of bankable renewable projects. The figure thus underscores the importance of integrating climate financing with absorptive capacity development, not assuming that higher amounts of money will lead to higher transition gains.

Table 6 demonstrates that the main findings are not driven by a single empirical specification, but the robustness evidence should be interpreted with attention to what each check is designed to test. Across these variants, the most stable evidence remains concentrated in electricity-sector outcomes and in the conditioning role of resource dependence. The governance results are more mixed: the negative climate finance by governance-quality interaction coefficient in the energy-transition-index model suggests that Hypothesis 5 is not supported in that specification as currently reported. Some coefficient magnitudes change across specifications, which is expected in a heterogeneous developing-economy panel, but the overall pattern remains consistent with climate finance being more effective when connected to electricity-sector transformation and when structural barriers are less binding.

Table 6: Robustness Analysis

Variable	(1)	(2)	(3)	(4)	(5)
Outcome	CFPC: RELEC	Resource-rich FOELEC	No-shock FOELEC model	GOV all developing	PCSE FOELEC model
CF	0.6294	-0.6931	-0.7578***	-0.0075***	-0.1437
	(0.4006)	(0.5428)	(0.2617)	(0.0024)	(0.1244)
NRR	0.1459**	-0.2685*	-0.2065		-0.0625**
	(0.0680)	(0.1583)	(0.1304)		(0.0277)
GOV				-0.0517	
				(0.0855)	
CF × NRR	-0.0719**	0.0220**	0.0142*		0.0042**
	(0.0287)	(0.0100)	(0.0082)		(0.0018)
CF × GOV				-0.0054*	
				(0.0031)	
CF^2		0.0145	0.0321***		0.0060
		(0.0239)	(0.0110)		(0.0063)
LGDPPC	-1.3776	4.2947	2.0675	-0.0359	4.7988***
	(3.2570)	(4.0974)	(3.6831)	(0.0988)	(1.4393)
POP	0.6832	-4.1998	0.5913	-0.8496***	-1.6799
	(6.8057)	(18.7502)	(6.4927)	(0.2134)	(4.9576)
TRADE	-0.0017	0.0048	-0.0158	0.0006	-0.0202
	(0.0176)	(0.0436)	(0.0208)	(0.0006)	(0.0221)
GHG		0.0722			
		(0.0705)			
Constant	32.4348	102.5045	41.7283	13.5716***	25.6904
	(111.4311)	(282.5470)	(110.1192)	(3.4384)	(87.4057)
Observations	2141	618	2319	2171	1,392
Countries	118	36	118	116	52
R-squared	0.0277	0.0559	0.0347	0.4482	0.7752
F statistic	2.771	3.171	3.006	20.012	4.019

Note: Robustness checks use alternative finance scaling, lagged finance, resource-rich subsamples, shock-year exclusions, governance conditioning, and PCSE estimation. Climate finance per capita tests scaling sensitivity; lagged finance captures implementation delays; the resource-rich subsample tests the rent-dependence mechanism; shock-year exclusion reduces crisis distortion; and PCSE estimation addresses panel heteroskedasticity and cross-sectional dependence. PCSE estimates are retained as a sensitivity check and are interpreted cautiously where rounded standard errors appear in the table.

Table 7 provides an interpretation of the interaction estimates in terms of the moderation mechanism that is substantive. In the case of renewable electricity, the marginal impact of climate finance is positive over the entire range of moderators, and is only slightly

decreasing with increasing resource dependence. The impacts of fossil electricity and energy imports are lower fossil dependence and lower import risk, but become weaker at higher levels of resource rent. The patterns uphold the main thesis that climate finance helps achieve transition outcomes, while also having a negative effect on the marginal effect of climate finance. The table can also aid in the interpretation of policies as it indicates where finance is likely to have more or less of an impact on the transition. These marginal slopes are descriptive translations of the interaction terms and should be read as effect-size guidance rather than formal Delta-method significance tests.

Table 7: Marginal Effects of Climate Finance

Outcome	Moderator -2	Moderator -1	Moderator 0	Moderator +1	Moderator +2	Curvature
RELEC	0.6103	0.5993	0.5884	0.5775	0.5665	-0.0232
FOELEC	-0.8119	-0.7960	-0.7801	-0.7643	-0.7484	0.0325
ENIM	-3.2943	-3.1714	-3.0484	-2.9255	-2.8026	0.0000
ETI	-0.0066	-0.0212	-0.0359	-0.0505	-0.0651	0.0010

Note: Marginal effects are evaluated across standardized moderator values from -2 to +2. The calculations translate interaction coefficients into substantively interpretable changes in the slope of climate finance.

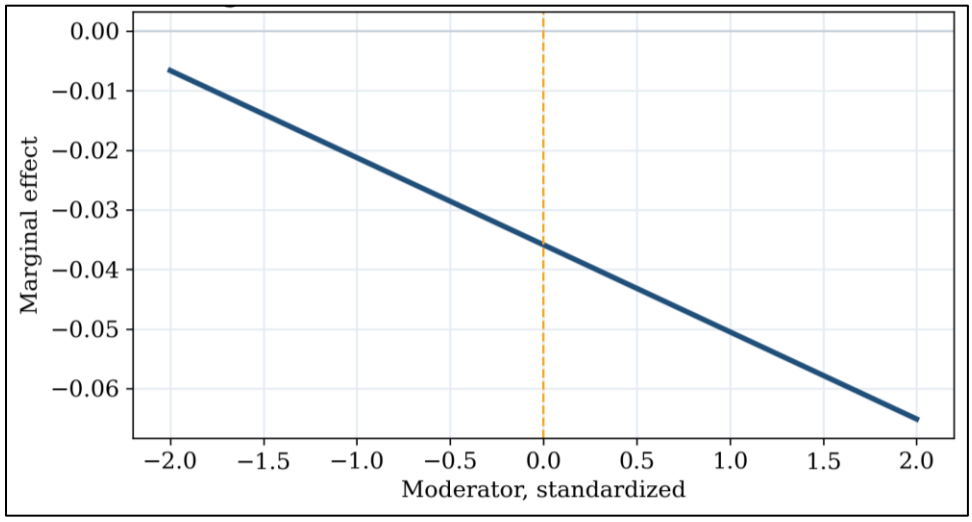


Figure 2: Marginal Effect of Climate Finance on Transition Capacity

The marginal effect of climate finance varies over the moderator distribution as shown in Figure 2. The downward slope suggests that what structural and institutional conditions do is not just to push transition outcomes up or down but to affect the effectiveness of climate finance. The results of the interactions are complemented by this visual evidence, which demonstrates that in different situations of resource dependence and absorptive capacity, the effects of climate finance differ. The figure suggests that in policy terms, the same

amount of financing can result in different types of transition depending on the country in which the finance is received, due to their differing governance systems, resource dependence, and capacity for implementation. Numerically, the RELEC slope declines from 0.6103 at moderator -2 to 0.5665 at moderator +2, indicating a modest weakening rather than a reversal of the finance effect.

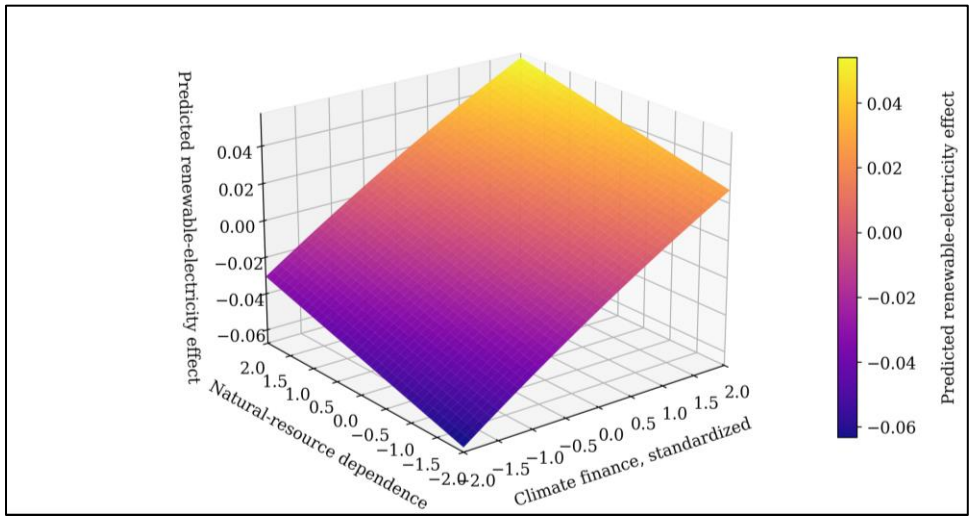


Figure 3: Climate Finance, Resource Dependence, and Renewable Electricity

The joint response of renewable electricity to climate finance and resource dependence is shown in Figure 3. Higher climate finance, the stronger the renewable-electricity performance, as evidenced by the slope of the surface; with greater resource dependence, the slope of the surface flattens. The visual pattern is used to illustrate how climate finance can be used to facilitate the expansion of renewables, but how much it can facilitate such expansion is weaker the more resource-rent dependent the system of the renewables expansion is. The figure is in line with the notion that financing for renewables should go hand in hand with structural change in the extractive sector that lessens its dominance and enhances the opportunities for renewables investment. This visual pattern corresponds to the negative CF x NRR coefficient reported for RELEC (-0.0109, $p < 0.10$).

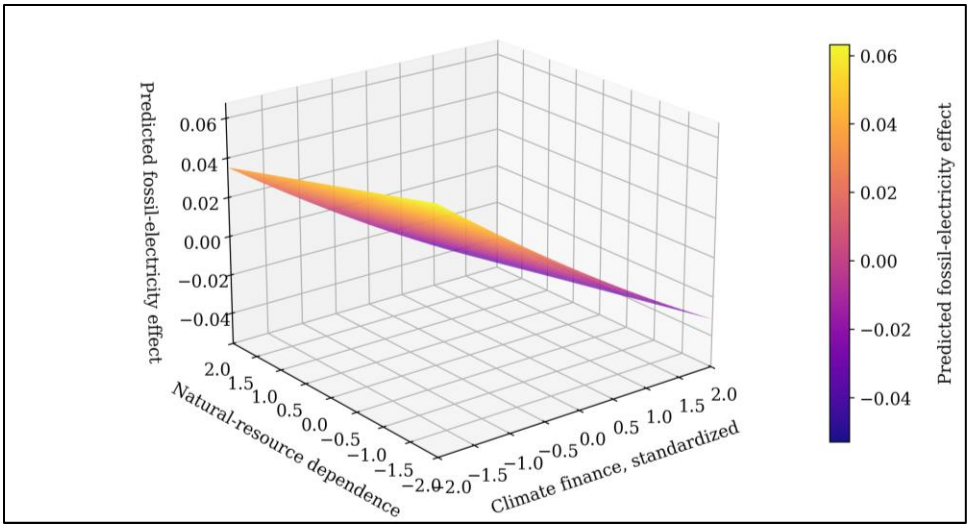


Figure 4: Climate Finance, Fossil Dependence, and Electricity Lock-in

The fossil-electricity displacement channel is shown in figure 4. The surface suggests a linkage between climate finance and reduced reliance on fossil-electricity, but under conditions that are consistent with the fossil-fuel lock-in, the linkage is less pronounced. This indicates that the adoption of climate finance together with a fossil fuel subsidy reduction in recipient countries, grid access of renewable generators and a reduction in resistance from incumbents in the energy sector will be more effective. The figure is meant to support the data in Table 5, and illustrates that fossil displacement is not automatically achieved due to receiving climate finance. The interaction evidence is consistent with a weaker fossil-reduction association at higher resource dependence, as reflected by CF x NRR = 0.0159 ($p < 0.10$).

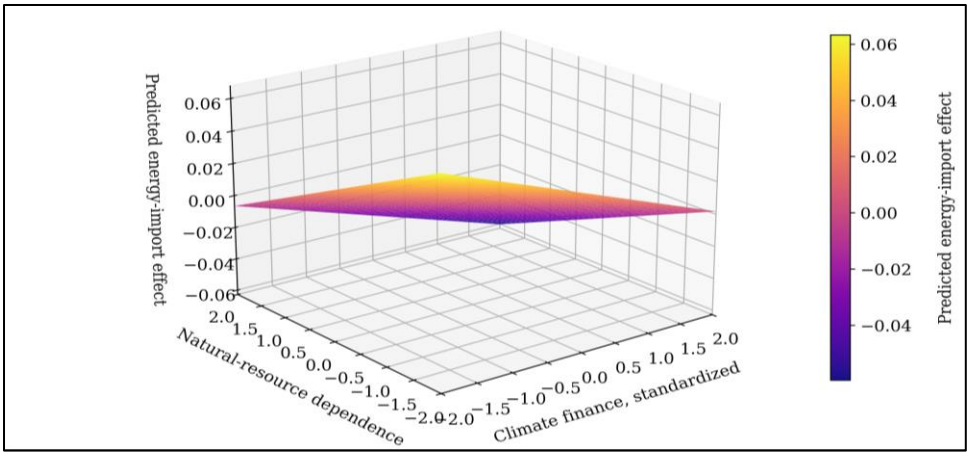


Figure 5: Climate Finance, Resource Dependence, and Energy Imports

In Figure 5, external energy-security exposure is correlated with climate finance. The surface suggests an association in which climate finance may help to decrease energy-import reliance if coupled with domestic renewable energy generation, efficiency measures, and the diversification of the electricity system. But this association varies by levels of resource dependence, suggesting that domestic political-economy conditions influence how effective climate finance is at decreasing vulnerability to international fuel-price shocks and supply disruptions. This puts the finance-transition link into a wider energy-security mechanism.

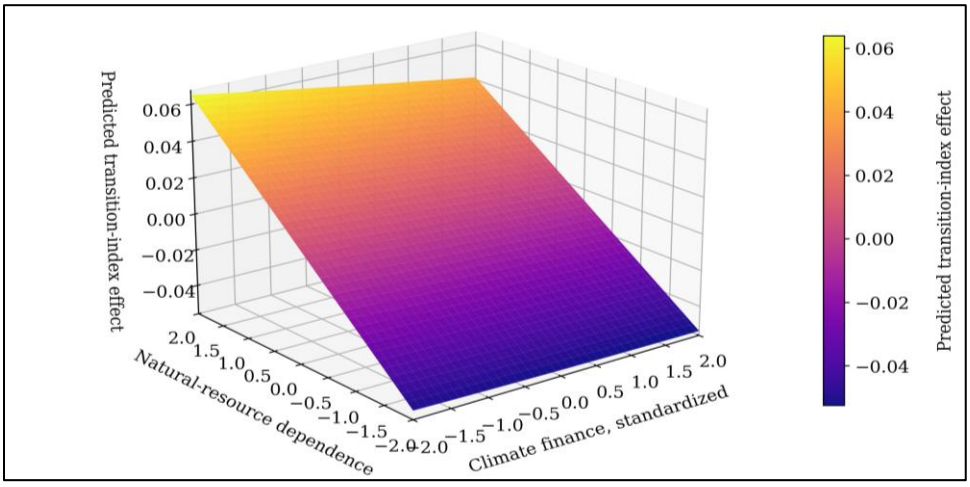


Figure 6: Climate Finance, Governance, and Energy Transition

Caution is warranted when interpreting Figure 6; the coefficient of governance of the energy transition is reported. Given the coding of the energy-transition index, which gives higher scores to countries that have performed better on transition, the negative correlation between energy transition and governance indicates that governance is linked to less rather than more of a marginal finance effect in this specification. Accordingly, the absorptive-capacity interpretation is presented as mixed for the energy-transition-index model rather than as uniformly supportive of Hypothesis 5.

4.3 Discussion

The findings add to ongoing debates about climate finance and "green development" in that they indicate that climate finance is more analytically useful when measured by actual outcomes in the electricity sector. The results corroborate recent research indicating that the financing constraints and cost of capital are still significant impediments to the deployment of renewable energy in developing countries (Briera & Lefèvre, 2024). Moreover, the outcomes transcend the narrow finance-volume debate. They demonstrate positive linkages between climate finance and transition progress where finance is connected to increased renewable electricity, reduced fossil electricity and reduced import exposure. This implies an assessment of climate-finance effectiveness should be conducted using sector-specific transition indicators, rather than only finance commitments.

The resource-dependence results build on the literature by indicating that natural-resource rents are not merely a background variable. They condition climate-finance effectiveness. However, in resource-dependent economies, climate finance can be partly offset by fossil sector rent-distribution structures, fossil-sector incumbency, long-lived infrastructure and subsidy structures (Alsagr & Ozturk, 2024; Olaniyi & Odhiambo, 2025). The finding reinforces the political economy view of the effectiveness of climate finance: external funding can contribute to green investments, but it may not be enough to overcome domestic incentives to maintain fossil-based energy systems. The fossil-sector lock-in and rent capture should be explicitly addressed in packages of climate finance for resource-dependent economies.

Absorptive capacity remains an important policy condition, but the governance evidence should be presented with caution. Climate finance needs to be channeled through institutions to become operational renewable capacity, fossil displacement, or reduced import exposure (Ashraf et al., 2026). Inconsistent procurement, regulatory uncertainty, corruption risks, and insufficient coordination between agencies can impede or diminish the impact of finance. However, the reported negative climate finance by governance-quality interaction coefficient in the higher-is-better energy-transition-index model does not directly support the claim that governance strengthens the marginal effect of finance. The governance result is therefore described as mixed rather than uniformly supportive in the ETI specification.

The policy implication is evident: climate-finance design should be tailored to country contexts. The financing packages needed in resource-dependent developing economies can

include fossil-subsidy reform, investments in the grid, clear procurement processes, support for project pipelines and monitoring systems. Incremental increases in finance commitments may be less effective when institutional and political-economic constraints are not addressed. The central implication for donors and recipient governments is that electricity-sector funding should be tied to tangible results, and to reforms that enhance the credibility of implementation.

5. Conclusion

The results provide evidence consistent with the view that energy-security transition in developing economies is more likely when climate finance is accompanied by enabling structural and institutional conditions. The strongest findings are in electricity-sector outcomes: there are robust associations between climate finance and renewable-electricity outcomes, fossil-electricity outcomes, and energy-import exposure. The results indicate that climate finance should be viewed not only as a climate-mitigation instrument, but also as a potential tool for selected energy-security transition indicators, including reduced exposure to fossil-fuel price volatility and import reliance (Njangang et al., 2024).

The main conclusion of the paper is that climate finance is a catalyst rather than a guarantee. Fossil-fuel lock-in and rent-seeking political incentives reduce the finance-transition nexus, implying that dependence on natural resources can impede the ability of external finance to support the transition. Governance quality is theoretically important because finance must pass through institutions of planning, procurement, regulation, utility systems, and monitoring, and the current energy-transition-index governance interaction is reported cautiously as mixed rather than uniformly positive. Thus, the effectiveness of climate finance is contingent on external financial support combined with domestic capacity, while the exact governance mechanism requires careful interpretation.

For policymakers, this implies additional climate finance is needed, but finance design matters. Future financing should prioritize renewable electricity deployment, integration, fossil displacement, clear procurement, and institutional safeguards. The financing of transitions must be supported by transition-governance reforms that reduce rent capture and reduce lock-in effects within fossil industries in resource-dependent economies. The criteria for assessing climate-finance programs should, therefore, not be limited to the volume of funds disbursed, but include the impact of the program on the shift in electricity mix, reduction of import risk and strengthening of institutions.

The study is subject to several limitations. Project-level implementation, disbursement timing, technology-specific deployment, and regulatory quality in specific sectors cannot be observed with country-year data. Project-level climate-finance data should be linked to solar capacity, wind capacity, storage deployment, transmission expansion, and fossil-plant retirement. Future research should examine how different types of finance, including grants, concessional loans, guarantees, and blended finance, affect transitions. The analysis

provides evidence consistent with natural-resource dependence as a central constraint on climate-finance effectiveness, while the governance mechanism requires additional verification because the reported energy-transition-index interaction does not clearly support a strengthening effect. Future work may also compare multilateral, bilateral, concessional, and private climate-finance channels because these sources may differ in conditionality, implementation speed, and sectoral targeting.

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Declaration of AI Use

During manuscript preparation, AI-assisted editing was used to improve language, structure, and presentation.

Data Availability

The datasets are available from the corresponding author upon reasonable request.

Declaration of Conflict of Interest

The authors declare no conflict of interest / no competing interests.

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