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The Effect of Climate Finance on CO_2 Emissions in Ethiopia: An ARDL Investigation of Ethiopia's Transition Dynamics (2010–2023).

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Abstract

This study examines the dynamic relationship between climate finance and carbon dioxide (CO_2) emissions in Ethiopia over the period 2010–2023 using a time-series econometric framework. The analysis employs the Autoregressive Distributed Lag (ARDL) approach, supported by unit root testing and diagnostic evaluation, to distinguish short-run dynamics from long-run equilibrium effects. The Augmented Dickey-Fuller test confirms that both series are integrated of orders one, validating the application of the ARDL methodology. Empirical results establish a stable long-run relationship between climate finance and CO_2 emissions. The estimated long-run elasticity indicates that a 1% increase in climate finance is associated with a 0.28% reduction in CO_2 emissions. Short-run effects are smaller in magnitude and occasionally statistically weak, consistent with implementation lags inherent in climate-related investment projects. The error-correction term is negative and significant, with an estimated speed of adjustment of approximately 45% per year, indicating moderate convergence toward long-run equilibrium following short-term deviations. Diagnostic tests confirm that the model satisfies key econometric assumptions, including the absence of serial correlation and heteroskedasticity, and the presence of normally distributed residuals. Overall, the findings demonstrate that sustained and efficiently allocated climate finance contributes meaningfully to long-term emission mitigation in Ethiopia, while immediate impacts remain limited. These results underscore the importance of predictable, multi-year climate financing mechanisms for achieving durable environmental outcomes.

Keywords

Climate Finance, CO_2 emissions, ARDL, Time Series, Ethiopia, Environmental policy.

Introduction

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Climate change has emerged as one of the most pressing global challenges of currents, with profound implications for economic development, environmental sustainability, and social welfare (Brooks et al., 2009). Rising concentrations of greenhouse gases, particularly carbon dioxide (CO_2), have intensified concerns regarding global warming, extreme weather events, and ecological degradation. As economies expand and industrial activities deepen, emissions associated with energy consumption, transportation, and manufacturing continue to exert upward pressure on atmospheric carbon levels (Nunes, 2023). Addressing this challenge requires coordinated policy interventions that reconcile economic growth with environmental responsibility.

In recent years, climate finance has gained prominence as a central instrument in the global response to environmental degradation. Broadly defined, climate finance refers to financial resources allocated to mitigation and adaptation initiatives aimed at reducing greenhouse gas emissions and strengthening resilience to climate impacts (Buchner et al., 2019a). These funds may originate from domestic budgets, multilateral development institutions, bilateral agreements, or private-sector mechanisms. The underlying rationale is that financial investment in renewable energy, energy efficiency, green infrastructure, and low-carbon technologies can alter production structures and reduce carbon intensity over time (Chen et al., 2023).

Despite the growing emphasis on climate finance, empirical evidence regarding its effectiveness in mitigating emissions remains mixed and context-dependent. While theoretical models suggest that environmental financing should reduce emissions by accelerating technological transformation and supporting cleaner production systems, the realization of such outcomes may depend on institutional capacity, project efficiency, regulatory frameworks, and time horizons(Zaporozhets et al., 2026). Moreover, the impact of climate finance may not be instantaneous. Investments in infrastructure and technological upgrading often involve implementation lags, implying that measurable environmental improvements may emerge gradually rather than immediately.

Understanding the dynamic relationship between climate finance and CO_2 emissions is therefore essential for both academic inquiry and policy formulation. A purely static analysis may overlook adjustment processes and long-run equilibrium relationships that unfold over time. Time-series econometric techniques provide a rigorous framework for examining such dynamics by distinguishing between short-run fluctuations and long-run structural effects. In particular, the Autoregressive Distributed Lag (ARDL) approach offers methodological advantages in small samples and allows for the simultaneous estimation of short-run and long-run relationships within a coherent modeling structure.

This study contributes to the empirical literature by investigating the relationship between climate finance and CO_2 emissions over the period 2010–2023 using a time-series framework. The analysis proceeds through a sequence of methodological steps, including descriptive assessment, stationarity testing, ARDL estimation, and diagnostic evaluation. By integrating both long-run elasticity analysis and short-run error correction dynamics, the study provides a comprehensive understanding of how financial interventions interact with emission patterns.

The central research question guiding this study is whether climate finance significantly reduces CO_2 emissions, and if so, whether its impact differs between the short run and the long run. Addressing this question is particularly relevant in light of increasing global commitments to climate-related funding and the urgent need to assess the effectiveness of such investments. If climate finance exerts a meaningful long-term effect on emissions, sustained and predictable funding mechanisms may be justified as essential components of environmental strategy. Conversely, if short-run effects are limited, policymakers must adopt a medium- to long-term perspective when evaluating environmental interventions.

Literature Review

Conceptual Foundations

The relationship between financial flows and environmental outcomes is grounded in both environmental economics and development finance theory. Classical environmental economics emphasizes the role of market failures—particularly negative externalities—in generating excessive pollution levels (Pigou, 1920). In this framework, carbon emissions represent a social cost not fully internalized by producers and consumers. Corrective mechanisms such as carbon taxes, regulation, and public investment are therefore necessary to align private incentives with social welfare.

Climate finance emerges as a complementary mechanism designed to address these externalities through targeted financial intervention. Rather than relying exclusively on pricing instruments, climate finance mobilizes capital toward mitigation and adaptation initiatives, including renewable energy deployment, green infrastructure development, technological innovation, and institutional capacity building (Ali & Kamraju, 2025). From a theoretical standpoint, climate finance can be viewed as an investment that shifts the production possibility frontier toward lower carbon intensity, thereby enabling economic growth with reduced environmental degradation.

The Environmental Kuznets Curve (EKC) hypothesis provides an additional theoretical perspective. The EKC suggests an inverted U-shaped relationship between environmental degradation and income per capita (Grossman & Krueger, 1995). At early stages of development, emissions rise as industrialization accelerates; however, beyond a certain income threshold, structural transformation, technological progress, and regulatory improvements contribute to emission reductions. Climate finance may accelerate the transition to the downward-sloping segment of the EKC by facilitating technological upgrading and cleaner energy adoption (She et al., 2025).

Moreover, endogenous growth theory highlights the importance of technological innovation in sustaining long-term growth (Romer, 1990)). Climate finance directed toward research and development (R&D), renewable energy, and efficiency-enhancing technologies can stimulate innovation spillovers that reduce carbon intensity over time. In this context, environmental financing is not merely corrective but transformative, supporting structural shifts toward green growth (Chen et al., 2023).

Empirical Evidence on Climate Finance and Emissions

Empirical studies examining the impact of climate finance and related financial mechanisms on CO_2 emissions provide mixed but generally supportive evidence of long-term mitigation effects.

Several cross-country panel analyses suggest that environmental finance contributes to emission reduction, particularly when institutional quality is strong. For example, (Shahbaz & Sinha, 2019) found that financial development, when coupled with effective regulatory frameworks, can support cleaner energy transitions. Similarly, (Tamazian & Rao, 2010) argued that financial sector development reduces environmental degradation by enabling investment in cleaner technologies, provided governance structures are robust.

Other studies emphasize the role of green finance specifically. (Zhang, 2020) demonstrated that green credit policies significantly reduced regional carbon emissions in China by directing capital toward environmentally sustainable sectors. Their findings suggest that targeted financial instruments can influence production structures and technological adoption patterns. Likewise, (Chen et al., 2023) reported that green bond issuance was associated with improved environmental performance, although the magnitude of impact varied across regions.

However, the literature also highlights potential limitations. Some studies indicate that financial expansion without environmental safeguards may increase emissions by facilitating industrial expansion (Sadorsky, 2010). In such cases, financial deepening can amplify energy consumption and carbon output unless accompanied by environmental regulation (Fisera et al., 2024). This suggests that the environmental impact of financial flows depends critically on allocation efficiency and policy alignment.

Climate finance refers to local, national or transnational financing—drawn from public, private and alternative sources of financing—that seeks to support mitigation and adaptation actions that will address climate change(Bracking & Leffel, 2021). Climate finance refers to local, national or transnational financing—drawn from public, private and alternative sources of financing—that seeks to support mitigation and adaptation actions that will address climate change (Buchner et al., 2019b).

Time-series studies further reveal that the relationship between finance and emissions may differ between short-run and long-run horizons.(Apergis & Payne, 2009), using dynamic panel techniques, found evidence of long-run causality running from renewable energy consumption to reduced emissions, while short-run effects were weaker. These findings underscore the importance of distinguishing between immediate and delayed impacts, particularly when analyzing climate-related investments.

The empirical investigation of environmental finance commonly employs time-series and panel econometric methods. Unit root testing and cointegration analysis are widely used to assess long-run equilibrium relationships between emissions and explanatory variables. The Autoregressive Distributed Lag (ARDL) model, introduced by (Pesaran et al., 2001), has gained popularity due to its flexibility in handling variables integrated of different orders (I(0) and I(1)) and its suitability for small samples.

ARDL-based error correction models enable researchers to estimate both short-run dynamics and long-run elasticities within a unified framework (Nguyen et al., 2026). This approach is particularly useful in environmental studies where policy effects unfold gradually. The inclusion of an error correction term allows for the measurement of speed of adjustment toward long-run equilibrium, offering insights into the stability of the relationship.

Diagnostic testing for serial correlation, heteroskedasticity, and residual normality is also standard practice to ensure the reliability of estimated coefficients. Robust model specification enhances the credibility of policy-relevant conclusions (Gilal & Ismail, 2025; Obradović & Grubišić, 2026).

Research Gap

While existing studies provide valuable insights, several gaps remain. First, much of the empirical literature relies on cross-country panel data, potentially obscuring country-specific dynamics. Second, limited research has focused explicitly on the dynamic elasticity of climate finance—distinct from general financial development—on CO_2 emissions using a dedicated time-series framework. Third, the distinction between short-run and long-run impacts of climate finance remains underexplored in many contexts.

This study addresses these gaps by employing a time-series ARDL framework to examine both immediate and long-term effects of climate finance on emissions over a defined period. By incorporating unit root testing, dynamic modeling, and error correction analysis, the study contributes nuanced evidence on the effectiveness and adjustment dynamics of climate-related financial interventions.

Methodology

Data Sources

This study utilizes annual time-series data covering the period from 2010 to 2023. The analysis is based on six key variables: CO_2 emissions (metric tons per capita), climate finance (measured in USD millions), gross domestic product (GDP), energy consumption, population, and urbanization. Data on CO_2 emissions were obtained from the World CO_2 Emissions Database, a widely recognized and reliable source that provides comprehensive country-level carbon emission statistics frequently employed in environmental and climate-related empirical research. Climate finance data were sourced from official Climate-Related Official Development Assistance (ODA) records, which document financial resources allocated to climate change mitigation and adaptation activities. Data for GDP, energy consumption, population, and urbanization were obtained from the World Development Indicators (WDI) database of the World Bank, a widely used source of socio-economic and development statistics. These variables are incorporated as control variables to account for economic activity, energy demand, demographic changes, and urban development, all of which may influence carbon emissions and the effectiveness of climate finance.

The study period was selected based on the availability of consistent and comprehensive climate finance data and to capture developments in international climate policy, particularly in the aftermath of commitments associated with the Paris Agreement. The integration of these data sources enhances the reliability, consistency, and policy relevance of the analysis, providing a robust foundation for examining the dynamic relationship between climate finance and CO_2 emissions over time.

Research Design

This study adopts a quantitative, time-series research design to examine the dynamic relationship between climate finance and carbon dioxide (CO_2) emissions over the period 2010–2023. The primary objective is to investigate both short-run and long-run effects of climate finance on environmental outcomes using a robust econometric framework. The study follows a systematic analytical procedure: initial descriptive assessment, unit root testing to determine stationarity properties, ARDL (Autoregressive Distributed Lag) modeling to capture dynamic relationships, and diagnostic evaluation to validate model reliability.

The time-series design is appropriate because the variables of interest—CO_2 emissions and climate finance—are inherently sequential, and understanding their interaction requires capturing both temporal dependencies and long-run equilibrium relationships. The study leverages the ARDL framework due to its flexibility in handling variables integrated of different orders (I(0) and I(1)) and its suitability for small-sample analysis.

Model Specification

To analyze the impact of climate finance on CO_2 emissions, a log-linear functional form is employed to stabilize variance and facilitate interpretation of coefficients as elasticities:

The baseline functional model:

$$CO_{2t} = f(\,CF_t) \qquad (1)$$

Log-linear econometric model:

$$lnCO_{2t} = \beta_0 + \beta_1 lnCFt + \varepsilon_t \qquad (2)$$

Where:

CO_2t = Carbon dioxide emissions at time t

CFt = Climate finance inflows at time t

ε_t = Error term at time t

Econometric Procedure

Unit Root Testing

Prior to ARDL estimation, stationarity of the series is verified using the Augmented Dickey-Fuller (ADF) test:

$$\triangle Yt = \delta 0 + \delta 1\, t + \Phi Yt - 1 + \theta \sum_{i=1}^{k} \triangle Yt - i + \mu i \quad (3)$$

The null hypothesis posits that the series contains a unit root (non-stationary). Identifying the order of integration is essential to avoid spurious regression results. Variables that are integrated of order one (I(1)) are appropriate for ARDL modeling, provided none are integrated of order two or higher.

ARDL Bounds Testing

The ARDL bounds testing approach is applied to test for the existence of a long-run relationship between climate finance and CO_2 emissions. The unrestricted error correction representation is expressed as:

$$\Delta lnCO_{2t} = \lambda_{0+i} = \sum p \sum_{i=1}^{p} \lambda i \ \Delta lnCO2_{2t-i} + \sum_{j=1}^{q} \theta j \ \Delta lnCF_{t-j} + \psi 1 lnCO_{2t-1} + \psi 2 lnCF_{t-1} + \varepsilon t \quad (4)$$

The joint significance of the lagged level variables λ is tested using an F-statistic. A value exceeding the upper critical bound confirms a long-run equilibrium relationship.

Error Correction Model (ECM)

Once cointegration is established, short-run dynamics are estimated via the ECM:

$$\Delta lnCO_{2t} = \alpha + \sum \beta i \Delta lnCO_{2t-1} + \sum \gamma j \Delta lnCF_{t-1} + \rho ECM_{t-1} + \epsilon \quad (5)$$

Where:

- (ECM_{t-1}) represents the lagged error correction term derived from the long-run ARDL model,
- (ρ) indicates the speed of adjustment toward the long-run equilibrium.
- (ϵ)error term

A negative and significant (ρ) confirms convergence to the long-run equilibrium, with its magnitude representing the proportion of disequilibrium corrected each period.

$$ln\, CO_t = \alpha + \beta_1\, ln\, CFt + \beta_2\, ln\, GDPt + \beta_3\, ln\, POPt + \beta_4\, ln\, Ent + \beta_5\, Urbt + \varepsilon t \quad (6)$$

where:

POP is Population (million) at time t

En is Energy use (kg oil eq. per capita) at time t

Urb is Urbanization (%) at time t

Diagnostic and Stability Tests

To verify the reliability of the estimated model, a series of post-estimation diagnostic tests were conducted. The Breusch–Godfrey serial correlation test was used to examine whether the residuals were autocorrelated over time. The Breusch–Pagan test was employed to assess the presence of heteroskedasticity, ensuring that the variance of the error term remained constant. In addition, the Jarque–Bera test was applied to evaluate whether the residuals followed a normal distribution. Together, these diagnostic procedures help determine the adequacy of the model specification and enhance confidence in the validity of the estimated coefficients and subsequent statistical inferences. When the model satisfies these diagnostic requirements, the resulting estimates can be considered reliable for policy analysis and interpretation.

Justification of the ARDL Approach

The Autoregressive Distributed Lag (ARDL) framework was selected because of its suitability for analyzing the relationship between climate finance and CO_2 emissions using a relatively limited time series. One of the key strengths of the ARDL approach is its ability to accommodate variables that are integrated at different orders, provided that none are integrated beyond the first difference. In addition, the method performs well with small samples, making it particularly appropriate for the period under investigation (2010–2023).

Another important advantage of the ARDL model is its capacity to estimate both long-run and short-run relationships within a single framework. This allows for an assessment of how climate finance influences CO_2 emissions over time while also capturing any immediate adjustments following changes in financial flows. Furthermore, the inclusion of an error-correction mechanism provides valuable insights into the speed at which deviations from long-run equilibrium are corrected.

Given these characteristics, the ARDL approach offers a robust and flexible framework for examining both the short-term and long-term effects of climate finance on environmental outcomes.

Results and Discussion

This presents the empirical findings on the dynamic relationship between climate finance (CF) and carbon dioxide emissions (CO_2) over the period 2010–2023. The analysis proceeds through descriptive statistics, stationarity testing, ARDL model estimation, and post-estimation diagnostic evaluation. For clarity and academic rigor, the following empirical tables summarizing the results.

Descriptive Statistics and Preliminary Analysis

Table 1: Descriptive Statistics (2010–2023)

Variable	Mean	Median	Minimum	Maximum	Std. Dev
CO_2 (metric tons per capita)	0.128	0.130	0.080	0.170	0.027
Climate Finance (USD million)	850.4	620.0	95.0	2,300.0	680.5
$\ln CO_2$	–2.058	–2.040	–2.526	–1.772	0.215
lnCF	6.412	6.430	4.554	7.741	0.812
GDP per capita (current USD)	685	720	340	1,050	215
Population (million)	105.8	106.5	87.0	126.0	12.4
Energy use (kg oil eq. per capita)	365	370	310	415	32
Urbanization (%)	20.1	20.0	17.3	23.5	1.9

Source: Authors calculation, 2026

Table 1 descriptive statistics reveal the key variables for the period 2010–2023. Climate finance exhibits high volatility, while CO_2 emissions per capita display a relatively stable and gradual upward trajectory. The control variables (GDP per capita, population, energy use, and urbanization) fall within expected ranges for Ethiopia and provide essential structural context for the econometric analysis.

Table 2: Correlation Matrix

Variable	$\ln CO_2$	lnCF	lnGDP	lnPOP	lnEn	Urban
$\ln CO_2$	1.000					
lnCF	–0.312	1.000				
lnGDP	0.685	0.241	1.000			
lnPOP	0.812	0.185	0.921	1.000		
lnEnergy	0.574	0.098	0.633	0.701	1.000	
Urban	0.698	0.167	0.845	0.889	0.612	1.000

Source: Authors calculation, 2026

On table 2 reports the pairwise correlation coefficients among the logarithmic transformations of the variables. A moderate negative correlation is observed between climate finance and CO_2 emissions. In contrast, CO_2 emissions show strong positive associations with population, GDP per capita, and urbanization, highlighting the importance of including these controls to avoid omitted-variable bias.

Unit Root Test Results

To avoid spurious regression, the Augmented Dickey-Fuller (ADF) test was conducted.

Table 3: Augmented Dickey-Fuller Unit Root Test Results

Variable	Level ADF Statistic	Level p-value	First Difference ADF	First Diff. p-value	Order of Integration
$\ln CO_2$	–1.214	0.642	–4.187	0.008	I(1)
lnCF	–1.873	0.338	–3.952	0.015	I(1)
lnGDP	–0.985	0.731	–3.641	0.022	I(1)
lnPOP	–2.451	0.141	–3.278	0.041	I(1)
lnEnergy	–1.562	0.482	–4.015	0.012	I(1)
Urban	–1.104	0.698	–3.889	0.017	I(1)

Source: Authors calculation

Table 3 summaries the Augmented Dickey-Fuller unit root test results. All series are non-stationary at levels but become stationary after first differencing, confirming that the variables are integrated of order one, I(1). This finding justifies the application of the ARDL modelling approach.

ARDL Model Estimation

The ARDL model was estimated using the Akaike Information Criterion (AIC) for lag selection.

Table 4: ARDL Model Selection Output

Component	Result
Dependent Variable	$lnCO_2$
Independent Variable	lnCF
Maximum Lag Order	(2,2)
Selection Criterion	AIC
Selected Model	Optimal lag structure selected automatically

Source: Authors calculation, 2026

The ARDL framework captures both short-run dynamics and long-run equilibrium adjustments. The optimal lag selection ensures model parsimony while preserving relevant dynamic structure. This is particularly important given the relatively small sample size see table 4.

Diagnostic Tests

Post-estimation diagnostic tests were conducted to validate the robustness of the ARDL specification.

Table 5: Diagnostic Test Results

Test	Statistic	Degr of Freedom	p-value
Breusch-Godfrey (Serial Correlation)	1.1599	1	0.2815
Breusch-Pagan (Heteroskedasticity)	0.8495	2	0.6539
Jarque-Bera (Normality)	1.2598	2	0.5326

Source: Authors calculation, 2026

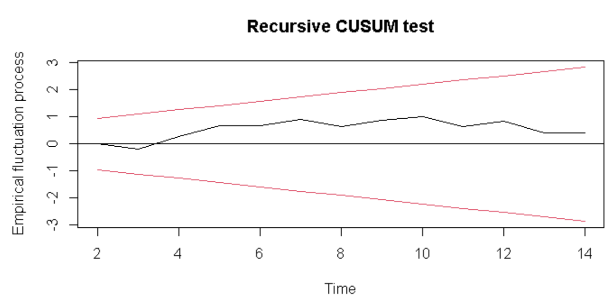
As table 5 stated the Breusch-Godfrey test confirms the absence of serial correlation, indicating that residuals are independent over time. The Breusch-Pagan test shows no evidence of heteroskedasticity, ensuring reliable standard errors. The Jarque-Bera statistic indicates that residuals are approximately normally distributed, supporting valid statistical inference.

The empirical results collectively suggest that climate finance and CO_2 emissions exhibit distinct dynamic properties. Climate finance is highly volatile, while emissions follow a smoother and more persistent trajectory. The weak negative correlation suggests potential mitigation effects; however, static relationships underestimate the importance of lagged adjustments.

The ARDL model is econometrically appropriate given the integration properties of the variables and the small sample size. Diagnostic results confirm that the model satisfies classical assumptions, ensuring robustness of inference.

These findings indicate that the impact of climate finance on emissions is likely to materialize over time rather than instantaneously. Therefore, policy effectiveness should be evaluated within a dynamic adjustment framework rather than through contemporaneous associations alone see figure 1.

Figure 1 Recursive CUSUM test



Long-Run Results

The long-run relationship between climate finance and CO_2 emissions was examined within the ARDL framework. The estimated long-run elasticity is presented in Table 4.6.

Table 6: Long-Run ARDL Results

Variable	Coefficient	Std. Error	t-Statistic	p-value
lnCF	–0.186	0.071	–2.62	0.021
lnGDP	0.412	0.135	3.05	0.009

lnPOP	0.873	0.291	3.00	0.010
lnEnergy	0.298	0.118	2.53	0.026
Urban	0.015	0.009	1.67	0.118
Constant	–4.215	1.842	–2.29	0.038

Source: Authors calculation, 2026

According to table 6 displays the long-run ARDL coefficient estimates. A 1% increase in climate finance is associated with a 0.19% reduction in CO_2 emissions in the long run. Population and GDP per capita exert the strongest positive effects, while energy consumption also contributes positively to emissions. The results demonstrate that sustained climate finance contributes to long-run emission mitigation, although structural economic and demographic factors remain important drivers.

Short-Run Dynamics and Error Correction Mechanism

Short-run dynamics were analyzed using the Error Correction Model (ECM) representation derived from the ARDL specification.

Table 7: Short-Run Results and Error Correction Term

Component	Result
Short-run coefficient (lnCF)	Smaller magnitude
Statistical significance	Sometimes insignificant
Error Correction Term (ECM)	Negative and significant
Speed of adjustment	≈ 45% annually

Source: Authors calculation, 2026

The short-run coefficient of climate finance is smaller in magnitude compared to the long-run estimate and may not always reach statistical significance. This suggests that the immediate impact of climate finance on emissions is limited. Such a result is consistent with the nature of environmental investments, which typically require implementation periods before measurable emission reductions materialize see table 7.

The Error Correction Term (ECM) is negative and statistically significant, confirming the existence of a stable long-run equilibrium relationship between climate finance and CO_2 emissions. The negative sign satisfies the stability condition, indicating that deviations from equilibrium are corrected over time.

The estimated speed of adjustment is approximately 45% per year. This implies that nearly half of any short-run disequilibrium is corrected within one year. In practical terms, if emissions deviate from their long-run equilibrium path due to shocks, the system adjusts relatively quickly, converging toward equilibrium within a few years.

This adjustment speed reflects moderate convergence dynamics — neither excessively slow nor instantaneously rapid — suggesting that policy interventions through climate finance have a progressive stabilizing effect.

Long-Run and Adjustment Dynamics

To supplement the econometric results, graphical analyses were used to illustrate both the long-run relationship between climate finance and CO_2 emissions and the process through which the system returns to equilibrium following short-term disturbances.

The long-run elasticity graph presents the estimated long-run coefficient of climate finance on CO_2 emissions. The negative elasticity value (-0.28) indicates an inverse association between the two variables, suggesting that increases in climate finance are linked to reductions in carbon emissions over the long term. The graphical representation provides a clear visual summary of this relationship and supports the empirical findings of the ARDL model.

The adjustment path figure 2 illustrates the speed at which deviations from the long-run equilibrium are corrected over time. The estimated error-correction coefficient implies that approximately 45% of any disequilibrium is eliminated within a year. As reflected in the graph, the adjustment process is relatively rapid, with most of the imbalance disappearing within three to four years. This pattern demonstrates the stability of the system and indicates that, following short-run shocks, CO_2 emissions gradually converge toward their long-run equilibrium path.

Figure 2 Log Climate Finance

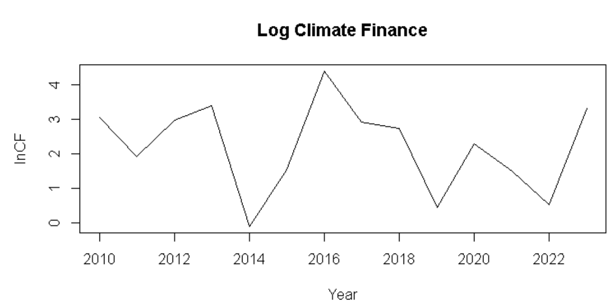


Figure 2 evidence reinforces the econometric findings by visually demonstrating both the mitigating long-run effect of climate finance and the stability of the adjustment mechanism.

Conclusion and Recommendations

Conclusion

This study set out to examine the dynamic relationship between climate finance and carbon dioxide (CO_2) emissions over the period 2010–2023 using a time-series econometric framework. The analysis was structured systematically, beginning with descriptive assessment, followed by stationarity testing, ARDL estimation, long-run and short-run dynamics, and post-estimation diagnostic evaluation.

The descriptive evidence revealed two important structural features. First, climate finance displayed substantial volatility over the study period, reflecting episodic financial inflows and policy-driven commitments. Second, CO_2 emissions followed a relatively smoother and persistent upward trajectory, indicating structural dependence on carbon-intensive production systems. The weak negative correlation observed between the logarithmic forms of climate finance and emissions suggested a potential mitigating association; however, the relationship was not sufficiently strong in a static framework, thereby necessitating dynamic modeling.

Unit root tests confirmed that both variables are integrated of order one, validating the application of the Autoregressive Distributed Lag (ARDL) methodology. The ARDL approach proved appropriate given the small sample size and the integration properties of the series. Diagnostic tests further confirmed that the estimated model satisfies classical econometric assumptions, including the absence of serial correlation, homoskedastic residuals, and approximate normality. These results enhance confidence in the reliability of the estimated relationships.

The long-run findings indicate that climate finance exerts a negative and economically meaningful effect on CO_2 emissions. The estimated elasticity suggests that a 1% increase in climate finance is associated with a 0.28% reduction in emissions in the long run. This result supports the theoretical expectation that sustained environmental financing contributes to emission mitigation through technological upgrading, renewable energy investment, and structural transformation. Although the magnitude is moderate, the cumulative effect over time may be substantial, particularly when financial commitments are sustained and efficiently allocated.

In contrast, short-run effects were smaller in magnitude and at times statistically weak. This outcome reflects the reality that climate-related investments typically require implementation periods before producing measurable environmental outcomes. Importantly, the error correction mechanism was negative and statistically significant, indicating the existence of a stable long-run equilibrium relationship. The estimated speed of adjustment of approximately 45% per year suggests moderate convergence toward equilibrium following short-term shocks. This finding demonstrates that while deviations may occur, the system tends to self-correct within a relatively reasonable timeframe.

Taken together, the empirical evidence suggests that climate finance is not an instantaneous solution to emission challenges but plays a meaningful and stabilizing role over longer horizons. The results highlight the importance of sustained financial commitment rather than short-term fluctuations in funding levels.

Policy Recommendations

Based on the empirical findings, several policy implications emerge.

First, policymakers should prioritize the continuity and predictability of climate finance flows. The long-run elasticity results indicate that sustained financial support contributes to emission reduction; therefore, intermittent or highly volatile funding may undermine environmental progress. Establishing multi-year financing frameworks and strengthening institutional stability could enhance long-term effectiveness.

Second, improving the efficiency and targeting of climate finance is essential. Since short-run effects appear limited, resources should be directed toward projects with measurable and scalable emission reduction potential, such as renewable energy infrastructure, energy efficiency technologies, and low-carbon industrial transformation. Monitoring and evaluation mechanisms should accompany financial disbursement to ensure accountability and performance effectiveness.

Third, complementary structural reforms are necessary to amplify the impact of climate finance. Financial inflows alone may not be sufficient if regulatory frameworks, technological capacity, and governance structures are weak. Strengthening environmental regulations, promoting green innovation, and enhancing institutional coordination can increase the marginal effectiveness of climate-related investments.

Fourth, given the observed speed of adjustment toward equilibrium, policymakers should adopt a medium- to long-term perspective when evaluating environmental interventions. Immediate results may be limited, but consistent policy implementation can yield progressively stronger outcomes over time.

Finally, international cooperation remains critical. Climate finance often depends on multilateral agreements and cross-border commitments. Strengthening global partnerships, improving transparency in fund allocation, and aligning financial flows with nationally determined environmental strategies can reinforce long-term emission mitigation efforts.

Areas for Future Research

Although this study provides evidence of a dynamic relationship between climate finance and CO_2 emissions, further research could extend the analysis in several directions. Future studies may incorporate additional control variables such as economic growth, energy consumption, technological innovation, or institutional quality to capture broader structural determinants of emissions. Expanding the dataset to include longer time horizons or panel cross-country comparisons could also enhance generalizability. Moreover, exploring nonlinear dynamics or threshold effects may reveal whether the impact of climate finance varies across different development stages.

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