

Does external debt reduce climate risk? Evidence from a global perspective

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History

- Received: 18-05-2025
- Revised: 04-02-2026
- Accepted: 04-09-2026
- Published Online: 13-10-2026

DOI : <https://doi.org/10.32508/vnuhcmj-ebl.v10i4.1636>



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ABSTRACT

Climate change poses growing threats to economic stability, social welfare, and long-term development, particularly in countries with high exposure to climate-related risks and limited fiscal and institutional capacity. At the same time, climate adaptation remains underfinanced, especially in low- and middle-income economies that struggle to mobilize sufficient domestic resources. This study examines whether external debt can function as an effective instrument for reducing climate vulnerability by supporting climate adaptation and resilience-infrastructure investments. Using a panel dataset of 174 countries spanning the period from 2004 to 2022, the analysis investigates the relationship between external debt and climate risk, measured by the Climate Risk Index (CRI), which captures countries' exposure and sensitivity to extreme weather events. The empirical strategy employs a fixed-effects panel regression framework based on the STIRPAT model to control for country-specific heterogeneity as well as key socioeconomic and environmental factors. The results indicate that higher levels of external debt are significantly associated with lower climate risk, suggesting that external borrowing, when appropriately managed, can enhance adaptive capacity and reduce vulnerability to climate shocks. Decomposition analyses further show that long-term external debt and public external debt are particularly effective in lowering climate risk, as these forms of borrowing are better aligned with the long-term nature of climate adaptation investments and public resilience infrastructure, while also reducing refinancing pressures. Additional heterogeneity analyses reveal that the beneficial effects of external debt are strongest in countries with low GDP levels and limited progress toward the Sustainable Development Goals, where domestic financing constraints and weaker institutional frameworks restrict adaptation efforts. Overall, the findings emphasize the importance of debt structure, maturity, and governance in shaping climate outcomes and contribute to the climate finance literature by providing empirical evidence that well-designed and targeted external debt can play a constructive role in advancing climate resilience and sustainable development.

Key words: Climate risk, External debt, Climate mitigation, Fiscal policy

INTRODUCTION

Climate change is one of the most pressing global challenges of the 21st century. Its impacts, including rising sea levels, desertification, and increasingly frequent and intense natural disasters, pose serious threats to ecological systems, human well-being, and economic stability. In 2021 alone, more than 430 major climate-related disasters caused over 10,000 deaths and economic losses exceeding US\$250 billion (Emergency Events Database (EM-DAT))¹. The accelerating frequency and severity of these events, largely driven by anthropogenic greenhouse gas emissions, underscore the urgency of effective mitigation and adaptation strategies worldwide.

In response, international institutions and national governments have adopted a range of policies to address climate change, most notably the Paris Agreement. While mitigation efforts have attracted sub-

stantial political attention and financial resources, climate adaptation, particularly in low, and middle-income countries, remains chronically underfunded. Developing countries face significant financial and institutional constraints that limit their ability to implement adaptation strategies at scale. Recent estimates indicate that adaptation financing needs in developing countries will reach US\$215–387 billion annually by 2030, yet international public adaptation finance amounted to only US\$21 billion in 2021 and US\$32.4 billion in 2022 (UNEP)^{2,3}. This leaves an annual financing shortfall of approximately US\$187–359 billion, with the burden falling most heavily on least developed countries and small island developing states. In these economies, adaptation costs already exceed 1% of GDP in roughly 50 low-income countries and can rise to as much as 20% of GDP in regions highly exposed to tropical cyclones and sea-level rise (UNEP)².

Cite this article : Nguyen L H, Nguyen T H. Does external debt reduce climate risk? Evidence from a global perspective. *VNUHCM J. Econ. Bus. Law.* 2026; 10(4):7098-7113.

A central driver of this persistent financing gap is the limited capacity of vulnerable countries to mobilize domestic resources. Many low, and middle-income economies face narrow tax bases, large informal sectors, and weak fiscal institutions, constraining revenue generation for climate investment (OECD)⁴. High borrowing costs, restricted access to international capital markets, and competing social expenditure needs further limit fiscal space (IMF)⁵. For the most climate-exposed countries, particularly small island states and least developed economies, domestic finance alone is insufficient to meet rapidly rising adaptation needs.

Against this backdrop, external debt has emerged as a potential instrument for financing climate adaptation and long-term resilience. External debt, defined as liabilities owed by a country to foreign creditors, has traditionally been viewed as a source of fiscal vulnerability, especially when mismanaged (Bhattacharya et al.)⁶. More recent development finance literature, however, indicates that when appropriately structured and aligned with sustainability objectives, external borrowing can enable investments in climate-resilient infrastructure, disaster risk reduction, and institutional capacity building. Instruments such as concessional loans, green bonds, and debt-for-climate swaps illustrate how sovereign borrowing can be leveraged to support adaptation goals (Volz; Wade; Luu et al.)⁷⁻⁹.

Despite this growing policy relevance, the relationship between external debt and climate risk remains insufficiently understood. Existing studies have largely focused on how climate shocks affect macroeconomic outcomes, corporate access to finance, and sovereign credit risk (Volz; Wade; Luu et al.; Kling et al.; Ciccarelli & Marotta)⁷⁻¹¹. A more limited literature examines innovative financing mechanisms, such as debt-for-climate swaps or climate funds, primarily through case studies that highlight their potential to alleviate fiscal pressure while financing adaptation (Essers and Prowse; Stoll et al.; Jain et al.)¹²⁻¹⁴. What remains largely absent is large-scale, quantitative evidence on how the composition of external debt—across maturity structures and borrower types, shapes countries' vulnerability to climate-related hazards.

This omission is consequential. On the one hand, excessive or poorly structured debt can crowd out adaptation spending and constrain post-disaster responses. On the other hand, long-term, concessional, and well-targeted borrowing may help countries overcome domestic financing constraints and strengthen adaptive capacity. This duality makes external debt a potentially powerful yet controversial policy tool.

Clarifying the conditions under which external debt supports or undermines climate resilience is therefore a critical empirical and policy question.

This study addresses this gap by examining the impact of external debt on climate risk across a panel of 174 countries from 2004 to 2022. Using the Climate Risk Index (CRI) as a proxy for climate vulnerability, the analysis employs a fixed-effects panel regression framework grounded in the STIRPAT model. External debt is decomposed by maturity (short-term versus long-term) and by borrower type (public versus private), and heterogeneity is explored across income groups and levels of progress toward the Sustainable Development Goals (SDGs).

The study makes two main contributions. First, it extends the climate adaptation finance literature by conceptualizing external debt as a structural determinant of climate vulnerability rather than solely a fiscal outcome. Second, it offers policy-relevant insights by identifying which forms of external debt are most conducive to building climate resilience, particularly in fiscally constrained and institutionally weaker economies. The novelty of the analysis lies in its detailed decomposition of external debt and its large cross-country panel design, which together allow for a systematic assessment of heterogeneity in debt-climate risk relationships. More broadly, the study offers evidence on how debt strategies can be leveraged to confront climate change, helping ensure that vulnerable countries are not only protected from climate shocks but also better positioned to adapt in an increasingly volatile environment.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature and develops the study's hypotheses. Section 3 outlines the research methodology and variable construction. Section 4 presents the empirical results and discusses their policy implications. Section 5 concludes with a summary of the main findings and directions for future research.

LITERATURE REVIEW AND HYPOTHESES DEVELOPMENT

Climate change adaptation has become a central concern in global development issues, gaining increased attention to the structural, institutional, and financial factors that shape a country's climate vulnerability. While prior literature has extensively analyzed the roles of governance, economic development, and environmental regulation in managing climate risks (Hedlund et al., Mehrabi et al., Cao et al.)¹⁵⁻¹⁷, the relationship between external debt and climate resilience remains relatively underexplored.

Traditional studies of climate vulnerability have focused primarily on natural and socio-economic factors, such as geographic exposure, emissions intensity, macroeconomic dynamics, and distributional impacts (IPCC; Hedlund et al.; Cevik & Jalles; Ciccarelli & Marotta)^{11,15,18,19}. More recent literature has shifted towards the institutional dimension, highlighting that countries with stronger regulatory frameworks, effective governance, and access to public goods are better equipped to manage environmental risks (Adger et al.; Mehrabi et al.)^{16,20}. Prior literature establishes the importance of environmental, economic, and institutional determinants of climate vulnerability, yet it has largely left financial structures, and debt in particular, outside the scope of analysis.

Two competing theoretical perspectives highlight how external debt could influence adaptation capacity. The first emphasizes its enabling capacity, rooted in Development Finance theory (Chenery & Strout)²¹. In this view, external borrowing, especially in the form of concessional loans, allows capital-constrained countries to finance infrastructure and public investment, including in climate adaptation. From the Adaptive capacity framework (IPCC)²², such debt enhances a nation's resilience by expanding its financial and institutional capacity to respond to climate threats. This positive narrative is supported by studies demonstrating how targeted debt can fund flood control systems, drought-resistant agriculture, and early warning systems (Buhr & Volz; Kharas & McArthur)^{23,24}.

In this framework, external debt serves as a developmental tool. Instruments such as green bonds, resilience-linked loans, and debt-for-climate swaps are designed specifically to channel funding into climate mitigation and adaptation efforts. For example, Volz et al. argue that these mechanisms not only help secure fiscal relief but also align financial flows with national environmental goals⁷. Multilateral institutions like the World Bank and the IMF have also promoted concessional financing schemes aimed at reducing climate risk in low- and middle-income countries. This literature indicates that well-structured, long-term, and climate-aligned debt can enhance a country's adaptive capacity and reduce long-run vulnerability to environmental shocks.

In contrast, a second body of literature, grounded in debt overhang theory (Krugman)²⁵, takes a more cautionary view. According to this perspective, high levels of external debt, both public and private debt, weakening fiscal space, straining external balances,

and elevating refinancing risks. For governments, external public debt may constrain budgetary capacity, as debt repayment absorbs resources that could otherwise be allocated to climate-related investment. For the private sector, high external corporate or banking debt can increase vulnerability to exchange rate fluctuations and sudden stops in capital flows, thereby reducing firms' ability to finance green technologies and adaptation measures. In extreme cases, countries may fall into a "climate-debt trap," where repeated climate shocks increase the need for borrowing, but rising debt burdens limit adaptation efforts, thus exacerbating vulnerability over time (Presbitero et al.; Buhr & Volz)^{23,26}.

Beyond theory, empirical evidence remains fragmented. Cross-country analyses provide evidence on how external debt, climate finance, and related fiscal instruments affect development and vulnerability, yet they rarely assess in detail how different types of external debt shape climate risk (Arshed et al.; Luu et al.; Nuta; Coulibaly; Scandurra et al.; Leykun)^{9,27-31}. These studies generally find both enabling and constraining effects, depending on governance quality, debt levels, and institutional context. Case-based research (Alhassan & Kwakwa; Adebayo et al.; Chandia et al.; Benmelech & Dvir)³²⁻³⁵ illustrates contextual mechanisms in Ghana, India, Pakistan, and East Asia, showing how debt and resource dynamics interact with environmental stress. Firm-level analyses highlight how climate risk exposure and uncertainty influence capital costs, access to finance, and corporate debt structures (Kling et al.; Choi; Jawadi et al.)^{10,36,37}. These strands reveal important patterns but also inconsistencies, with limited synthesis across scales and a lack of systematic evidence on the role of debt composition in shaping climate vulnerability.

Overall, the literature demonstrates that external debt can act as both an enabler and a constraint for climate adaptation, but cross-country quantitative studies explicitly linking debt composition to climate vulnerability remain almost absent. Moreover, existing work rarely synthesises these perspectives, leaving unresolved the conditions under which debt alleviates versus exacerbates vulnerability. This absence defines the core research gap of the need for systematic, comparative evidence on how different forms of external debt interact with climate risk across diverse national contexts.

To address this gap, this study proposes two competing hypotheses:

H1a: Higher levels of external debt are associated with lower climate risk due to enhanced adaptation capacity.

H1b: Higher levels of external debt are associated with higher climate risk due to fiscal constraints and debt overhang effects.

Beside the general debate on the benefits and risks of external debt, the maturity structure of borrowing plays an important role in shaping climate resilience. Long-term debt offers more stable financing, reduces refinancing pressures, and allows governments to plan and invest in resilient infrastructure, renewable energy, and disaster preparedness. By contrast, short-term debt heightens exposure to refinancing risks, capital flow reversals, and exchange rate fluctuations, diverting resources away from adaptation and increasing systemic vulnerability (Luu et al.,; Alhassan & Kwakwa; Chandia et al.,; Benmelech & Dvir)^{9,32,34,35}.

H2: Long-term external debt is more effective in reducing climate risk than short-term external debt.

Additionally, long-term debt can provide countries with stable financing resources and certainty in planning climate-related investments. With less frequent refinancing, long-term borrowing reduces exposure to sudden liquidity pressures and allows resources to be directed toward projects such as resilient infrastructure, renewable energy systems, or disaster-preparedness programs. In this way, well-managed long-term debt can strengthen adaptive capacity, climate resilience investment, and thus reduce climate risk (Luu et al.,; Alhassan and Kwakwa)^{9,32}.

By contrast, high reliance on short-term external debt increases countries' vulnerability. Short-term obligations expose borrowers to refinancing risks and the possibility of abrupt capital outflows, particularly during periods of global financial stress or climate-related shocks. These dynamics can force governments and firms to divert resources away from adaptation programs in order to meet short-term repayment obligations. Moreover, the need to constantly roll over short-term liabilities enhances exposure to interest rate risk and exchange rate fluctuations, further constraining resilience. For countries already facing frequent climate disasters, the combination of short maturities and climate shocks can quickly deplete fiscal buffers and increase systemic vulnerabilities (Chandia et al.,; Benmelech and Dvir)^{34,35}.

From this perspective, the maturity structure of debt offers an important lens for understanding climate vulnerability.

H2a: Long-term external debt reduces climate risk, as extended maturities offer stable financing for adaptation and reduce refinancing pressures.

H2b: Short-term external debt increases climate risk, as refinancing pressures and exposure to sudden capital flow reversals constrain resilience and adaptation efforts."

Moreover, the type of external debt also matters. Public debt, particularly when concessional and well-targeted, can expand fiscal space and finance adaptation, though excessive levels may still strain budgets. Private external debt, on the other hand, is more exposed to global market volatility, refinancing risks, and currency shocks, which can constrain firms' ability to invest in resilience and amplify vulnerability (Alhassan & Kwakwa; Joy & Panda; Luu et al.,)^{9,32,38}. This leads to the following hypotheses:

H3: Public external debt is more effective in reducing climate risk than private external debt.

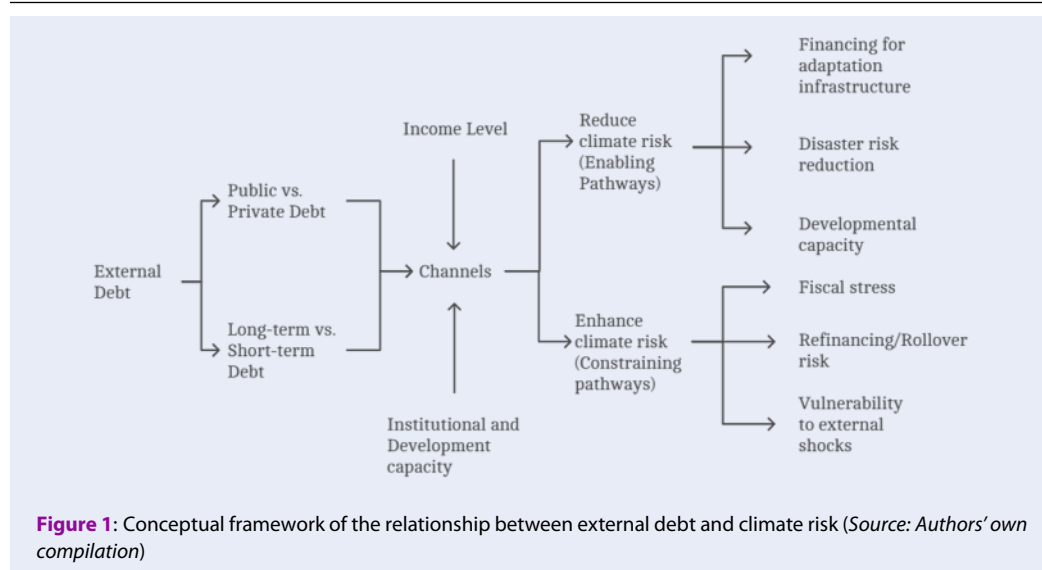
Previous studies highlight that the developmental context strongly shapes whether external debt supports or undermines climate resilience. Countries with lower income levels often face higher financing constraints and rely more heavily on external borrowing to fill gaps in adaptation and development spending. In those countries, external debt can contribute to growth and sustainability when allocated effectively (Alemu et al.,; Qayyum & Haider)^{39,40}. On the other hand, wealthier economies tend to have more budget flexibility and more efficient financial systems, reducing their dependence on external borrowing for climate-related investments (Fernández & Tamayo)⁴¹. Related research on adaptation finance also suggests that private capital flows are less accessible in poorer countries, limiting their ability to diversify financing sources and reinforcing reliance on external public debt (Pauw)⁴². This evidence indicates that income level and development capacity are important in shaping how external debt interacts with climate vulnerability.

H4: In low-income countries, higher levels of external debt is more effective in reducing climate risk by filling financing gaps for adaptation and resilience investments.

H5: In countries with low development capacity, external debt is more effective in reducing climate risk by compensating for weak institutional and developmental capacity.

By testing these hypotheses using a global panel dataset, this study contributes to a more comprehensive understanding of how debt dynamics intersect with climate resilience across diverse national contexts.

Figure 1 presents the conceptual framework, illustrating the mechanisms through which external debt, by type and maturity, affects climate risk, with income



level and development capacity conditioning these relationships.

METHODOLOGY

This study investigates the relationship between external debt and climate risk using a panel dataset of 174 countries over the period 2004–2022. The chosen time frame aligns with the availability of data and encompasses key developments in global climate policy and debt governance, including the Paris Agreement and evolving climate finance mechanisms.

The research design is built on the STIRPAT (Stochastic Impacts by Regression on Population, Affluence, and Technology) framework, a widely used empirical model for analyzing environmental impacts driven by macroeconomic and demographic factors. By extending this framework to include financial indicators, particularly external debt, study introduces a novel approach to assessing structural determinants of climate vulnerability.

The dependent variable in this analysis is the Climate Risk Index (CRI), developed by Germanwatch, 2023. The CRI aggregates four dimensions of climate-related disasters: total deaths, deaths per 100,000 inhabitants, absolute economic losses in purchasing power parity (PPP), and economics losses as a percentage of GDP. A higher CRI score reflects greater climate vulnerability. These indicators are normalized and combined using a weighted ranking approach, with greater emphasis placed on relative measures to capture countries' exposure and vulnerability to extreme weather events. A higher CRI score reflects greater realized climate vulnerability. The resulting

CRI is a continuous index derived from normalized relative country rankings across the underlying impact indicators, following the original Germanwatch methodology applied during the study period. The CRI is used as a backward-looking indicator, capturing the observed impacts of climate-related events on countries over time rather than projecting future climate risk.

The key independent variable is external debt, measured as the total external debt (including public, publicly guaranteed, and private nonguaranteed debt, short-term debt, and IMF credit) expressed as a percentage of GDP. To examine the effects of debt composition, the study further decomposes external debt into four subcomponents: long-term vs. short-term debt, and public vs. private debt. This disaggregation allows for a more nuanced understanding of how the structure of borrowing influences climate outcomes.

Control variables are included to capture country-specific factors that may also affect climate vulnerability. *GDP* (log of gross domestic product) controls for economic size, as larger economies may have more resources for adaptation but also higher absolute exposure to damages. *Trade Open* (exports plus imports as a share of GDP) reflects integration with global markets, which may enhance resilience through resource access but also increase exposure to external shocks. *Real Interest Rates* capture the cost of borrowing, higher rates may limit fiscal space for adaptation investment. *Population Growth* reflects demographic pressures, as rapidly growing populations can strain infrastructure and increase exposure to climate

hazards. Finally, the share of renewable energy in total energy consumption (*Renewable Energy Consumption*) accounts for energy transition progress, since greater reliance on renewables may reduce long-term vulnerability. All independent and control variables are lagged by one year to reduce simultaneity bias and to reflect delayed effects on climate risk. The final unbalanced panel includes 1,349 observations after removing missing values. Table 1 reports the summary of the variable measurement.

The empirical specification is estimated using panel fixed-effects regression to control for unobserved time-invariant country characteristics. The model also incorporates year fixed effects to account for global shocks that may simultaneously affect all countries, such as financial crises or major international climate agreements. Robust standard errors clustered at the country level are applied to address heteroskedasticity and autocorrelation issues. The baseline model is specified as:

$$\begin{aligned} CRI_{it-1} = & \beta_0 + \beta_1 Total\ External\ debt_{it-1} \\ & + \beta_2 GDP_{it-1} + \beta_3 Trade\ Open_{it-1} \\ & + \beta_4 Real\ Interest\ Rates_{it-1} \\ & + \beta_5 Population\ Growth_{it-1} \\ & + \beta_6 Renewable\ Energy\ Consumption_{it-1} \\ & + \mu_i + \lambda_t + \varepsilon_{it-1} \end{aligned}$$

Where CRI_{it-1} represents the Climate Risk Index for country i at time t ; $Total\ External\ debt_{it-1}$ is the lagged external debt-to-GDP ratio; μ_i and λ_t are country and year fixed effects, respectively; and ε_{it-1} is the error term. Robust standard errors clustered at the country level are used to ensure valid inference.

RESULTS AND DISCUSSION

Descriptive statistics and Correlation matrix

Table 2 shows descriptive statistics of 1,349 observations from 174 countries between 2004 and 2022. The Climate Risk Index (CRI), the dependent variable, has a mean of 55.23 and ranges from 0 to 126.17, indicating large disparities in climate vulnerability. The main independent variable, total external debt as a share of GDP, has a mean value of 0.497 (equivalent to 49.7% of GDP), with values ranging from 0.012 to over 4.00, reflecting differing fiscal capacities across countries. Control variables also show notable variation: real interest rates range from -19.4% to 39.9% , and renewable energy consumption from 0.1% to 97.3% , indicating diverse financial environments and energy transitions. GDP and trade openness exhibit moderate dispersion, while population growth remains relatively stable.

Table 3 of correlation matrix shows a weak but statistically significant negative relationship between external debt and climate risk, indicating higher debt is slightly associated with lower vulnerability. Other control variables, including GDP, interest rates, population growth, and renewable energy use, show low correlations with CRI, minimizing concerns about multicollinearity. The reported VIF of all the variables are less than 5, illustrating that the multicollinearity problem does not seriously threaten our empirical model (Hair et al.)⁵⁴.

Baseline results

Table 4 presents baseline regression results across three model specifications to examine the relationship between external debt and climate risk. Column (1) reports a simple OLS regression without controls. Column (2) includes country-fixed effects to account for time-invariant national characteristics. Column (3) adds both country and year-fixed effects, capturing unobserved heterogeneity and global time-specific shocks. Across all three models, total external debt as a percentage of GDP (*ExternalDebt*) consistently shows a negative and statistically significant coefficient, confirming the study's primary hypothesis (H1a) that higher external debt is associated with lower climate risk. In the specification with country and year fixed effects (Column 3), the coefficient of -12.990 indicates that countries with higher levels of external debt relative to GDP tend to experience lower climate risk as measured by the CRI. In practical terms, an increase of 10 percentage points in the external debt-to-GDP ratio is associated with an average reduction of about 1.3 points in the CRI. A reduction of 1.3 CRI points reflects an improvement in a country's relative climate outcomes, corresponding to lower observed human and economic losses from extreme weather events compared to other countries in the sample. The result suggests that external borrowing, when used effectively, can provide governments with additional financial resources to support climate adaptation measures and resilience-building investments, thereby helping to reduce the observed impacts of climate-related disasters.

The results also offer insights into the role of control variables. In the full model (Column 3), GDP is negatively associated with the Climate Risk Index (CRI), indicating that higher levels of economic development are linked to reduced climate vulnerability, consistent with the Environmental Kuznets Curve hypothesis. Trade openness and renewable energy consumption (RE) are positively associated with climate

Table 1: Variable measurements

Variable			Measurement	Source		Supporting studies
Dependent variable						
Climate Risk Index (CRI)			Aggregates total deaths, deaths per 100,000 inhabitants, absolute economic losses (PPP), and losses as % of GDP. Higher score correlates to greater vulnerability.	Germanwatch (2023)		Eckstein et al.; Germanwatch; Gu et al., ^{43–45}
Independent variable						
External Debt			Total external debt as % of GDP	World Development Indicators (WDI)	Development Indicators	Luu et al.; Haughton and Keane ^{9,46}
Long-term Debt			Share of total external debt with maturity over one year, % of GDP.	WDI		Luu et al.; Alhassan and Kwakwa ^{9,32}
Short-term Debt			Share of total external debt with maturity of one year or less, % of GDP.	WDI		Chandia et al.; Benmelech and Dvir ^{34,35}
Public Debt			Public and publicly guaranteed external debt as % of GDP.	WDI		Joy and Panda; Mammadli et al. ^{38,47}
Private Debt			Private nonguaranteed external debt as % of GDP.	WDI		Luu et al.; Arshed et al. ^{9,27}
Control variables						
GDP			Natural logarithm of gross domestic product (constant US\$).	WDI		Khan et al.; Haughton and Keane ^{46,48}
Trade Openness			Sum of exports and imports as % of GDP.	WDI		Adebayo et al.; Luu et al., ^{9,49}
Real Interest Rate			Lending interest rate adjusted for inflation (GDP deflator).	WDI		Ozili; Volz ^{7,50}
Population Growth			Annual population growth rate (%).	WDI		Luu et al.; Stephenson et al. ^{9,51}
Renewable Consumption	Energy		Share of renewable energy in total final energy consumption (%).	WDI		Owusu and Sarkodie; Olabi and Abdelkareem ^{52,53}

Source: Authors' own compilation

Table 2: Descriptive statistics

	N	Mean	SD	Min	p25	Median	p75	Max
CRI	1349	55.234	39.782	0	19.670	55.830	88.330	126.17
ExternalDel	1349	0.497	0.408	0.012	0.244	0.375	0.644	4.121
GDP	1349	23.815	2.063	19.782	22.492	23.474	25.048	30.511
Tradeopen	1349	0.741	0.315	0.172	0.488	0.688	0.946	2.007
Interest	1349	6.833	9.669	-19.442	2.555	6.113	9.893	39.877
Popgrowth	1349	1.539	1.305	-3.218	0.811	1.471	2.417	9.992
RE	1349	40.583	28.914	0.100	14.300	36.600	64.500	97.300

Source: Authors' own compilation

Table 3: Correlationmatrix

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	VIF
(1) CRI	1.000							
(2) ExternalDebt	- 0.059***	1.000						1.19
(3) GDP	0.089***	- 0.242***	1.000					1.37
(4) Tradeopen	0.003	0.304***	-0.138***	1.000				1.50
(5) Interest	0.108***	0.049**	- 0.181***	- 0.093***	1.000			1.05
(6) Popgrowth	0.046***	- 0.081***	- 0.022	- 0.112***	0.101***	1.000		1.33
(7) RE	0.068***	-0.033	- 0.148***	- 0.324***	0.173***	0.290***	1.000	1.64

Source: Authors' own compilation

Note: *, **, *** indicate significance at 10%, 5%, and 1% levels, respectively

Table 4: Baseline regression result

VARIABLES	(1) No Controls	(2) Country Fixed effects	(3) Country Fixed effects and Year Fixed effects
ExternalDebt	-11.319*** (2.305)	-18.782*** (4.054)	-12.990*** (3.002)
GDP		17.623*** (3.192)	-8.962* (4.539)
Tradeopen		40.427*** (8.969)	15.185** (7.021)
Interest		0.921*** (0.175)	0.236* (0.113)
Popgrowth		5.217*** (1.773)	1.357 (1.177)
RE		0.760*** (0.276)	0.445* (0.251)
Constant	57.451*** (1.134)	-430.328*** (84.104)	242.088** (106.161)
Observations	2,223	1,348	1,348
R-squared	0.542	0.217	0.524

Source: Authors' calculation

Notes: This table reports the baseline regression results on the impact of Total external debt on Climaterisk index (CRI). The dependent variable is CRI. The main independent variable is ExternalDebt. Column (1) is the result of regression of the model using no control. Column (2) is the regression of the model using country-fixed effects. Column (3) is the regression of the model using country-fixed effects and year-fixed effects. Robust standard errors are in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1%, respectively.

risk, potentially reflecting transitional exposure to industrial activity or initial stages of energy transition. These findings may imply that greater integration into global trade can increase exposure to external shocks, supply-chain disruptions, and carbon-intensive industries, particularly in developing economies where environmental standards are weaker (Feng and Li; Hassan et al.; Tian et al.)⁵⁵⁻⁵⁷. The positive association between renewable energy consumption and climate risk highlights the presence of transitional risks. In many developing economies, renewable capacity remains insufficient to replace fossil fuels, and the costs and uncertainties of transitioning energy systems may temporarily increase, rather than decrease, climate-related risks (Aall et al.; Stepanov et al.; Khalfaoui et al.)⁵⁸⁻⁶⁰. This implies that both variables capture adjustment processes rather than mature resilience outcomes.

Robustness tests

We test the robustness of our baseline results through a set of alternative specifications. First, to address concerns of endogeneity, we employ the system generalized method of moments (GMM) following Ullah et al.⁶¹. This approach uses lagged levels and differences of external debt as instruments to mitigate simultaneity bias and reverse causality. The results reported in Column (1) of Table 5 remain consistent with the baseline, confirming that higher levels of external debt significantly reduce climate risk, and indicate that the baseline findings are not driven by potential dynamic endogeneity.

Second, in Column (2) we re-estimate the baseline model using Driscoll-Kraay standard errors, which are robust to heteroskedasticity, autocorrelation, and cross-sectional dependence (Hoechle)⁶². The coefficients of external debt and its components remain negative and statistically significant, reinforcing the stability of our results across alternative specifications. Thirdly, in Column (3) we include *InstitutionalQuality* as an additional control to account for the role of governance in shaping climate resilience. Institutional quality is drawn from the World Governance Indicators (WGI), covering six dimensions, control of corruption, government effectiveness, political stability, regulatory quality, rule of law, and voice and accountability, and condensed into a single index using principal component analysis following Bermpel et al., Kamah et al., and Nguyen & Su⁶³⁻⁶⁵. The inclusion of *InstitutionalQuality* does not alter the main findings, reveal that debt structure and institutional strength operate as complementary determinants of climate risk.

Decomposition analysis

Table 6 presents a decomposition of total external debt into four categories, long-term debt, short-term debt, public debt, and private debt, to assess how different debt structures influence climate risk. The results support H2, showing that long-term external debt has a statistically significant negative effect on the Climate Risk Index (CRI). This underscores that longer maturity loans, often used for infrastructure and resilience projects, are effective in reducing climate vulnerability (Beirne et al. Kharas & McArthur)^{24,66}. In contrast, short-term debt shows a positive but statistically insignificant relationship with climate risk, indicating limited relevance for long-term adaptation outcomes. Regarding creditor type, the findings are consistent with H3 in showing that public external debt exhibits the stronger negative association with climate risk, with a substantially larger coefficient magnitude than private external debt. While private external debt is also negatively and statistically significantly associated with climate risk, its effect is considerably smaller, indicating a weaker role in supporting large-scale climate resilience. This pattern implies that public external debt, typically aligned with national development strategies and often provided on concessional terms, is more effective in financing comprehensive climate adaptation initiatives than more fragmented private capital flows (IMF; Combes et al.)^{67,68}. This implies that policymakers should not only monitor overall debt levels but also optimize debt composition, focusing on long-term and public financing instruments that enhance fiscal stability and alignment with climate strategies.

These findings highlight that not all debt contributes equally to climate resilience. The structure and purpose of borrowing matter. From a policy perspective, countries should not only monitor overall debt levels but also optimize debt composition, favoring long-term and public financing instruments that are better suited for climate investment and sustainable development goals.

Additional analysis

Table 7 examines heterogeneity across country contexts, thereby testing H4 and H5 in relation to the general debt-climate relationship outlined in H1a/H1b. In low-GDP countries, external debt has a negative and statistically significant impact on the Climate Risk Index (CRI), supporting H4 and aligning with H1a, indicating that external borrowing helps reduce climate vulnerability by filling critical financing gaps for adaptation. This aligns with the idea that poorer

Table 5: Robustness tests

VARIABLES	(1) GMM	(2) Discoll-Kraay standard errors	(3) Add governance control variable
ExternalDebt	-1.978* (1.124)	-12.990*** (2.791)	-13.000*** (2.951)
GDP	-3.766*** (0.417)	-8.962* (4.674)	-8.888* (4.624)
Tradeopen	5.096 (3.325)	15.185** (6.599)	15.151** (7.208)
Interest	0.151* (0.080)	0.236*** (0.072)	0.236* (0.116)
Popgrowth	1.556*** (0.359)	1.357 (1.166)	1.367 (1.207)
RE	-0.236*** (0.031)	0.445* (0.223)	0.443 (0.264)
InstitutionalQuality			-0.024 (0.345)
Constant	125.858*** (12.450)	225.133** (107.060)	241.521** (105.836)
Observations	1,349	1,349	1,348
Number of countries	86	86	
AR (1)	0.000		
AR(2)	0.599		
R-squared		0.4328	0.524

Source: Authors' calculation

Notes: This table reports the robustness test results for the relationship between external debt and the Climate Risk Index (CRI). The dependent variable is CRI. The key independent variables are total external debt and its components. Column (1) presents the System GMM estimates, addressing potential endogeneity. Column (2) presents the results estimated using Driscoll-Kraay standard errors, which correct for heteroskedasticity, autocorrelation, and cross-sectional dependence. Column (3) adds Institutional Quality as an additional control. Robust standard errors are in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

countries lack domestic fiscal resources and thus rely more on external finance to fund climate-resilient infrastructure (Hallegatte et al.; Bahram & Lauren)^{69,70}. In contrast, the effect is positive but statistically insignificant in high-GDP countries, indicating that wealthier nations are less reliant on external debt for climate action due to stronger internal funding capacities and institutional frameworks. These results underscore that external debt is particularly valuable for enhancing resilience in low-income settings. Renewable energy consumption is negatively associated with climate risk in both GDP groups, suggesting that although countries with higher renewable use may face greater climate exposure in the full sample, increased renewable adoption within similar income groups is linked to stronger climate resilience.

Table 7, Column (3) and (4) explores heterogeneity based on countries' development capacity using SDG performance as proxy. In countries with low SDG achievement, external debt significantly reduces climate risk, suggesting that debt plays a compensatory role where institutional and developmental capacity is weak. Conversely, in high-SDG countries, the effect of debt on climate risk is still negative but not statistically significant, likely because these countries already have sufficient domestic mechanisms for climate adaptation. This implies that the effectiveness of external debt in building climate resilience is more pronounced in countries that lag in development and institutional readiness (Hallegatte et al.; Dabla-Norris et al.)^{69,71}.

This result signals for policymakers that external debt is particularly valuable for countries with low income

Table 6: Decomposition result

VARIABLES	(1) Long-term external debt	(2) Short-term external debt	(3) Public external debt	(4) Private external debt
<i>LTDebt</i>	-20.458*** (4.770)			
<i>STDebt</i>		8.189 (31.726)		
<i>PublicDebt</i>			-48.489*** (11.378)	
<i>PrivateDebt</i>				-16.059*** (4.566)
<i>GDP</i>	17.712*** (3.988)	17.496*** (3.889)	12.332*** (3.900)	16.704*** (4.206)
<i>Tradeopen</i>	40.256*** (13.612)	38.393*** (13.611)	32.259** (13.908)	42.016*** (14.346)
<i>Interest</i>	0.919*** (0.216)	0.882*** (0.206)	0.894*** (0.220)	1.136*** (0.243)
<i>Popgrowth</i>	5.247* (3.132)	5.171* (2.983)	4.529 (2.796)	4.874 (3.023)
<i>RE</i>	0.769** (0.339)	0.925*** (0.335)	0.728** (0.329)	0.897** (0.420)
<i>Constant</i>	-433.599*** (107.035)	-441.990*** (104.964)	-291.742*** (106.298)	-426.069*** (114.726)
<i>Observations</i>	1,348	1,348	1,348	1,060
<i>R-squared</i>	0.217	0.203	0.225	0.235

Source: Authors' calculation

Notes: This table reports the decompose tests on the impact of Total external debt on climate risk index (CRI). The dependent variable is CRI. The main independent variable is *totaldebtgdp*. The definitions for all of the variables are shown in Table 3.1. Columns (1) - (4) show the regression model of each external debt component. Includes, long-term external debt, short-term external debt, public external debt and private external debt. Robust standard errors are in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1%, respectively.

and weak development capacity. In these contexts, concessional, long-term, and publicly oriented borrowing can serve as a crucial complement to climate finance, whereas wealthier and higher-SDG countries should prioritize mobilizing domestic resources and crowding in private capital for climate action.

CONCLUSION AND POLICY IMPLICATIONS

This study explores the relationship between external debt and climate risk across 174 countries from 2004 to 2022, using panel regression methods and the Climate Risk Index (CRI) as the key indicator of vulnerability. The findings reveal that higher levels of external debt are significantly associated with lower climate risk, particularly in countries with limited fiscal capacity and weak institutional frameworks. De-

composition analysis shows that long-term and public external debts are the most effective in supporting climate resilience, highlighting the strategic importance of debt structure. Heterogeneity analyses further demonstrate that external debt is more beneficial in low-GDP and low-SDG countries, where it compensates for gaps in domestic financing and institutional readiness.

These findings have several policy implications. Governments, especially in low-income and low-SDG contexts, should integrate climate vulnerability assessments into debt sustainability frameworks and prioritize concessional climate finance. Multilateral institutions must expand access to low-cost, climate-linked lending, while governance systems guiding debt allocation should be strengthened. Policy coherence between debt management and climate goals must be ensured, with differentiated strategies based

Table 7: Heterogeneity analysis on the impact of Externaldebt on Climate risk

VARIABLES	(1) Low GDP	(2) High GDP	(3) Low SDG	(4) High SDG
<i>ExternalDebt</i>	-5.141* (2.751)	1.848 (5.060)	-26.379** (2.708)	-11.434 (4.344)
<i>GDP</i>	0.891 (1.208)	-7.175*** (0.938)	19.892* (5.487)	15.234** (3.505)
<i>Tradeopen</i>	-2.367 (5.221)	-5.454 (4.283)	46.250 (20.983)	34.115 (21.580)
<i>Interest</i>	-0.154 (0.164)	0.242* (0.128)	0.609** (0.103)	1.219*** (0.112)
<i>Popgrowth</i>	-0.298 (1.170)	2.623*** (0.955)	22.737** (2.491)	2.596* (0.678)
<i>RE</i>	-0.212*** (0.064)	-0.282*** (0.047)	0.299 (0.395)	0.902 (0.466)
<i>Constant</i>	56.561** (27.088)	240.250*** (26.505)	-511.692* (155.552)	-368.480** (61.664)
<i>Observations</i>	678	671	544	722
<i>R-squared</i>	0.476	0.404	0.273	0.204

Source: Authors' calculation

Notes: This table reports the additional analysis on the relationship between total external debt and climate risk index (CRI). The dependent variable is CRI. The main independent variable is *totaldebtgdp*. Robust standard errors are in parentheses. *, **, and *** denote statistical significance at the 10%, 5%, and 1%, respectively.

on countries' economic conditions. Specifically, debt management strategies should emphasize long-term borrowing over short-term liabilities to minimize re-financing risks, and prioritize public debt instruments that are better aligned with national adaptation plans. Moreover, for low-income and low-development-capacity countries, external debt should be structured in a way that directly channels resources to resilience investments, while high-income and high-development-capacity countries should complement external borrowing with domestic resource mobilization. Overall, if well-designed and targeted, external debt can serve as a valuable tool for advancing climate resilience and sustainable development.

ABBREVIATIONS

Acronym: Definition

CRI: Climate Risk Index

IPCC: Intergovernmental Panel on Climate Change

EM-DAT: Emergency Events Database

UNFCCC: United Nations Framework Convention on Climate Change

UNEP: United Nations Environment Programme

IFIs: International Financial Institutions

SDGs: Sustainable Development Goals

GDP: Gross Domestic Product

GCF: Green Climate Fund

STIRPAT: Stochastic Impacts by Regression on Population, Affluence, and Technology

EKC: Environmental Kuznets Curve

WDI: World Development Indicators

HIPCs: Heavily Indebted Poor Countries

VIF: Variance Inflation Factor

IMF: International Monetary Fund

OLS: Ordinary Least Squares
RERenewable Energy Consumption

SDG 13: Sustainable Development Goal 13 - Climate Action

ADB: Asian Development Bank

UNDP: United Nations Development Programme

PPP: Purchasing Power Parity

EM-DAT: Emergency Event Database

OECD: Organisation for Economic Co-operation and Development

WDI: The World Development Indicators

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflicts of interest - Nhóm tác giả xin cam đoan rằng không có bất kì xung đột lợi ích nào trong công bố bài báo

AUTHOR CONTRIBUTIONS

Luu Hanh Nguyen conceptualized the study, designed the research framework, supervised the overall project, performed the main analyses, and drafted the majority of the manuscript.

Nguyen Thanh Huyen was responsible for data collection and data cleaning, contributed to the development and writing of the methodology and conclusion sections, and handled manuscript formatting and final preparation.

Both authors reviewed and approved the final version of the manuscript.

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Nợ nước ngoài có làm giảm rủi ro khí hậu không? Bằng chứng thực nghiệm trên phạm vi toàn cầu

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Lịch sử

- Ngày nhận: 18-05-2025
- Ngày sửa đổi: 04-02-2026
- Ngày chấp nhận: 04-09-2026
- Ngày đăng: 13-10-2026

DOI: <https://doi.org/10.32508/vnuhcmj-ebl.v10i4.1636>



Bản quyền

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TÓM TẮT

Biến đổi khí hậu đang gây ra những mối đe dọa ngày càng nghiêm trọng đối với sự ổn định kinh tế, phúc lợi xã hội và phát triển dài hạn, đặc biệt tại các quốc gia chịu ảnh hưởng lớn từ rủi ro khí hậu, trong khi năng lực tài khóa và chất lượng thể chế còn hạn chế. Đồng thời, nguồn tài chính hỗ trợ thích ứng với biến đổi khí hậu vẫn còn thiếu hụt nghiêm trọng, đặc biệt ở các nền kinh tế thu nhập thấp và trung bình, nơi gặp nhiều khó khăn trong việc huy động nguồn lực trong nước. Nghiên cứu này xem xét liệu nợ nước ngoài có thể đóng vai trò như một công cụ hiệu quả nhằm giảm thiểu mức độ tổn thương trước biến đổi khí hậu thông qua việc hỗ trợ các khoản đầu tư cho thích ứng khí hậu và cơ sở hạ tầng tăng cường khả năng chống chịu hay không. Sử dụng bộ dữ liệu bảng gồm 174 quốc gia trong giai đoạn 2004–2022, nghiên cứu phân tích mối quan hệ giữa nợ nước ngoài và rủi ro khí hậu, được đo lường bằng Chỉ số Rủi ro Khí hậu (Climate Risk Index – CRI), phản ánh mức độ ảnh hưởng và nhạy cảm của các quốc gia trước các hiện tượng thời tiết cực đoan. Chiến lược thực nghiệm áp dụng mô hình hồi quy bảng tác động cố định dựa trên mô hình STIRPAT nhằm kiểm soát các đặc điểm dị biệt theo quốc gia cũng như các yếu tố kinh tế – xã hội và môi trường then chốt. Kết quả cho thấy mức nợ nước ngoài cao hơn có mối liên hệ có ý nghĩa thống kê với rủi ro khí hậu thấp hơn, hàm ý rằng việc vay nợ từ bên ngoài, nếu được quản lý phù hợp, có thể nâng cao năng lực thích ứng và giảm mức độ dễ tổn thương trước các cú sốc khí hậu. Phân tích sâu hơn cho thấy nợ nước ngoài dài hạn và nợ nước ngoài của khu vực công đặc biệt hiệu quả trong việc làm giảm rủi ro khí hậu, do các hình thức vay này phù hợp hơn với đặc tính dài hạn của các khoản đầu tư thích ứng khí hậu và cơ sở hạ tầng chống chịu, đồng thời giúp giảm áp lực tái cấp vốn. Các phân tích bổ sung chỉ ra rằng tác động tích cực của nợ nước ngoài rõ nét nhất ở các quốc gia có GDP thấp và mức độ hoàn thành các Mục tiêu Phát triển Bền vững còn hạn chế, nơi các ràng buộc về tài chính trong nước và khuôn khổ thể chế yếu kém cản trở nỗ lực thích ứng. Nhìn chung, các phát hiện nhấn mạnh tầm quan trọng của cấu trúc, kỳ hạn và quản trị nợ trong việc tác động đến mức độ chống chịu rủi ro khí hậu của các quốc gia, đồng thời đóng góp cho nghiên cứu về tài chính khí hậu bằng cách cung cấp bằng chứng thực nghiệm cho thấy nợ nước ngoài, khi được thiết kế và định hướng phù hợp có thể đóng vai trò tích cực trong việc thúc đẩy khả năng chống chịu khí hậu và phát triển bền vững.

Từ khoá: Rủi ro khí hậu, Nợ nước ngoài, Giảm thiểu biến đổi khí hậu, Chính sách tài khóa

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