“Climate disasters and the resilient design of public-private partnerships: Evidence from developing and emerging economies”

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CLIMATE DISASTERS AND THE RESILIENT DESIGN OF PUBLIC-PRIVATE PARTNERSHIPS: EVIDENCE FROM DEVELOPING AND EMERGING ECONOMIES

Abstract

Climate disasters increasingly damage infrastructure financed through public-private partnerships (PPPs), yet little is known about how such shocks reshape PPP markets. This paper aims to determine how climate disasters and national adaptation readiness affect PPP activity and design in developing and emerging economies. The analysis uses a balanced panel of 129 economies (2000–2024) with 8,213 PPP financial closures from the World Bank PPI Database merged with the Notre Dame Global Adaptation Initiative index, the EM-DAT international disaster database, and World Bank governance and development indicators, and estimates two-way fixed-effects linear and Poisson pseudo-maximum-likelihood models, with damage and GDP in current US dollars. Neither average damage nor major disasters (damage of at least 1% of GDP) show a robust association with the number of closures; post-event coefficients are negative but mostly insignificant, no pre-event decline is detected, and placebo event dates yield estimates of similar size. A positive coefficient at catastrophic levels (at least 5% of GDP) rests on a single episode and is not read as a reconstruction surge. Project composition does respond. After major disasters, the number of non-renewable closures falls by about 38% ($p < 0.001$), and by more where readiness is low, while renewable closures are unchanged. A one-standard-deviation improvement in regulatory quality is associated with a 12.6-percentage-point higher probability of a PPP closure ($p < 0.01$) and roughly 131% larger investment ($p < 0.001$). Case profiles of Armenia, Kazakhstan, and Ukraine reflect the same dominance of institutions. Regulatory strengthening and standby pipelines that keep conventional deals alive through disaster windows are the main levers for disaster-proofing PPP programs.

Keywords public-private partnerships, climate disasters, adaptation readiness, infrastructure investment, renewable energy, regulatory quality, transition economies

JEL Classification Q54, H54, L32, C23

INTRODUCTION

Natural catastrophes caused global economic losses of about USD 320 billion in 2024 and USD 220–224 billion in 2025, roughly nine-tenths of them weather-related (Munich Re, 2025, 2026; Swiss Re Institute, 2026). In emerging economies, 80–90% of catastrophe losses are typically uninsured (Swiss Re Institute, 2026), so reconstruction falls largely on strained public budgets.

These losses add to global infrastructure investment needs estimated at USD 94 trillion to 2040, with a financing gap of about USD 15 trillion (Global Infrastructure Hub, 2018; World Economic Forum, 2019). Public-private partnerships (PPPs) are therefore a key financing channel, and well-structured partnerships are increasingly viewed as instruments for expanding fiscal space in transition economies

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(Prokopenko et al., 2026). Private-participation commitments in low- and middle-income countries reached USD 100.7 billion in 2024, above the USD 100 billion mark for the first time since the pandemic, and shifted toward low-carbon projects (World Bank, n.d.). Reconstruction adds urgency. Ukraine's recovery needs alone are assessed at USD 588 billion over the next decade, with explicit emphasis on private-sector-led recovery (World Bank et al., 2026).

Yet little systematic evidence exists on how climate disasters reshape PPP markets. Disasters may deter investors, delay deals under preparation, redirect design toward resilient technologies, or trigger reconstruction-driven surges in new contracts, and national adaptation readiness may condition which response dominates.

1. LITERATURE REVIEW

The determinants of private participation in infrastructure have been studied since the first waves of PPP programs in developing economies. Cross-country evidence based on the World Bank PPI database shows that PPP activity concentrates in large markets with heavy public debt burdens and that control of corruption raises both the number of projects and the degree of commercial risk that private partners are willing to assume (Hammami et al., 2006). Panel estimates for 1990–2008 confirm that market size, income, macroeconomic stability, and regulatory quality are significant drivers of PPP deal flow, whereas political factors and fiscal constraints receive weaker support (Sharma, 2012). Infrastructure investment is, in turn, consistently linked to development outcomes, with gross capital formation raising real GDP per capita across developing Asia ($\beta \approx 0.048$, $p < 0.05$) (Budhathoki et al., 2026) and infrastructure exhibiting a long-run cointegrating relationship with growth in SAARC economies (FMOLS coefficient 0.04) (Khandelwal et al., 2024). Comparative governance research adds a design perspective, showing that PPPs revitalize traditional industries when adaptive governance and community engagement are built into contracts (Oe et al., 2025), while statistical assessments of social infrastructure in Ukraine's border regions illustrate how exposure to security shocks reshapes territorial infrastructure needs (Vakhovych et al., 2026). What this strand leaves largely unexamined is how climate shocks interact with the determinants it identifies.

A second strand quantifies the macroeconomic footprint of climate disasters and the channels of resilience. Local-projection estimates on EM-DAT data show that major natural disasters depress real investment on impact ($\beta = -3.295$ in the global sample) and that scarce fiscal space deepens the downturn in developing economies (Nguyen et al., 2025). Because public budgets absorb most reconstruction costs, unlocking private adaptation finance in emerging market and developing economies has become a central policy concern (Gautam et al., 2024). War-related shocks display similar macro-financial signatures, disrupting trade structures and economic security (Tsymbal & Demediuk, 2025), which has motivated forecasting frameworks for national financial security under conditions of change (Klochan & Filipov, 2023), while retraining and lifelong learning act as anti-crisis tools that preserve human capital through prolonged conflict (Yeremenko, 2026). Micro-level evidence highlights the financial infrastructure of resilience, showing that regional banks that maintain liquidity, cash access, and unbureaucratic emergency lending sustain local activity during natural hazards (Guhl & Heidemann, 2025) and that the capacity of insurance markets conditions how much risk households and firms can transfer (Shmygol et al., 2024). Organizational research reaches parallel conclusions for supply chains, tracing how health systems rebuilt adaptive capacity after COVID-19 (Hobbs, 2026). In agriculture, income-stabilizing instruments such as CAP eco-schemes cushion energy and weather shocks (Pimenow et al., 2026), and the adoption of climate-smart technologies depends more on social influence ($\beta = 0.395$) and perceived ease of use than on calculated usefulness (Aziz et al., 2024). Whether losses and coping mechanisms of this kind translate into investment decisions ultimately depends on the institutional environment.

Institutional quality is among the most consistent correlates of investment climates, with governance-quality criteria formalized for sustainable-development tasks (Masyk et al., 2023), yet its effects are neither linear nor universal. System-GMM estimates for Sub-Saharan Africa show that conventional institutional indicators can carry a negative coefficient for real GDP ($\beta \approx -0.18$), cautioning against mechanical readiness proxies (Marozva et al., 2026). Structural-equation evidence from Ukraine's recovery indicates that digital government maturity converts into reconstruction only through institutional trust and governance effectiveness (mediated effect $\beta = 0.44$, $p = 0.029$) (Topazly et al., 2026). Enterprise-level models likewise tie the sustainability payoff of digital transformation projects to their implementation outcomes (Bashynska et al., 2023). Moreover, canonical correlation analysis attributes 86.4% of the variation in corruption reduction to innovation and technology diffusion (Yefimenko et al., 2025), and anti-corruption audits offer a complementary safeguard (Bezverkhyi et al., 2024). Governance scholarship further ties the rule of law to equitable public administration (Crowley & Mujtaba, 2026) and shows that policy design determines whether corporate social responsibility supports sustainable regional development (Taliouris & Trihas, 2026), with sustainability reporting and its assurance as the instruments that make such responsibility verifiable (Shygun & Bezverkhyi, 2026; Bezverkhyi et al., 2025). Institutional commitment also shapes public spending, since government health expenditure gaps reflect economic and institutional factors rather than declared international obligations (Megbowon & Zerihun, 2025), and corporate commitment is similarly uneven, as ESG practice in Kazakhstan's telecommunications sector shows (Maralov et al., 2024). Within financial intermediaries, board governance effectiveness raises carbon disclosure in ASEAN banks, and disclosure behavior is highly persistent (system-GMM lag coefficient 0.518) (Mansour et al., 2026), whereas city-level estimates reveal a small inverse association between smart-city rankings and startup ecosystems in random-effects specifications, a reminder that composite governance indices do not automatically translate into private dynamism (Kuzior et al., 2025). The same institutional filters govern whether green capital actually flows.

Research on green investment and climate finance identifies both powerful catalysts and sobering frictions. The 2022 energy security shock accelerated renewable deployment across Europe ($\beta = 0.55$, $p < 0.001$), with the strongest response in fast-deployment solar technologies (Vasylieva et al., 2025a), extending earlier evidence that renewables support EU economic development (Ksonzhyk et al., 2021). Sustainable finance is expanding under the European Green Deal even though environmental spending and growth remain only partially decoupled (Streimikiene et al., 2024). Green financial instruments beyond environmental taxation are needed for cleaner production (Koval et al., 2022). Composite assessments for BRICS economies indicate that energy security and environmental sustainability are best evaluated jointly rather than in isolation (Nihal et al., 2024), while comparative analysis documents the gap between Ukrainian and EU fuel-and-energy innovation strategies (Redko et al., 2023). De-risking matters at the investor level, as feed-in tariffs significantly strengthen the effect of insurance-sector assets on renewable energy consumption (interaction $\beta = 0.051$, $p < 0.05$) (Lyeonov et al., 2025a), and renewable investment and R&D raise the profitability of leading renewable companies (Prokopenko et al., 2023). Frictions are equally well documented, starting with the economic and environmental limits of Europe's energy transition (Prokopenko et al., 2024). Matched secondary-market comparisons in the Nordic countries find no significant green bond premium (mean –5.93 basis points), implying that green labels alone do not lower capital costs once ESG investing becomes mainstream (Aleknevičienė et al., 2025), and decarbonization policy confronts a highly inertial shadow economy (lagged coefficient 0.9679) that blunts short-run reform (Lyeonov et al., 2025b). Complementary engineering and behavioral work addresses implementation, from the monitoring and forecasting challenges of ecological microgrids (Wojciechowski et al., 2025) and AI-driven waste management (Kajda & Karwot, 2026) to behavioral incentives for sustainable practices (Burrell et al., 2025) and supply chain efficiency in electric vehicle markets (Sarasi et al., 2025). How much of this capital reaches developing economies depends on private investment channels and on the organizations that deploy it.

Evidence on foreign and private investment in developing economies underscores heterogeneity and the organizational preconditions of resilience. FDI does not automatically green host economies,

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raising renewable energy consumption in Japan (R^2 = 0.52) while reducing it in Turkey and Colombia, in line with pollution haven concerns under weak regulation (Mursalov et al., 2025), even though inward FDI correlates strongly with domestic capital formation in host industry ($r \approx 0.67$) (Manaf et al., 2025). Technology-enabled business models can steer private activity toward sustainability, as nature-based tourism development in Tanzania illustrates (Mshana & Postrzednik-Lotko, 2026), and cluster analysis of EU member states shows that inclusive growth depends on country-specific institutional and social configurations (Saher et al., 2025). Energy price shocks transmit to inflation primarily through producer prices (pass-through $\beta = 0.0597$, $p < 0.001$), placing public governance of energy markets at the center of macroeconomic stabilization (Vasylieva et al., 2025b). At the organizational level, artificial intelligence integration raises sustainability and business resilience indices ($\beta = 0.452$ and 0.398) (Koldovskyi et al., 2025). Leadership, learning, and knowledge management anchor organizational transformation in public health systems (Tessema, 2025), sustainable leadership steers circular-economy innovation (Bashynska et al., 2024), and job crafting with organizational resilience mediates the payoff from technological capabilities (Prayogi et al., 2025). Human factors complete the picture, as family motivation shapes well-being in remote knowledge work (Sarwar et al., 2026), psychological safety underpins mission-driven leadership (Eke, 2026), and inclusive employment strengthens social security (Zahorodnia et al., 2026). None of these strands, however, connects climate shocks to the contractual vehicles that actually deliver infrastructure.

Taken together, the literature exhibits a clear gap at the intersection of its strands. Disaster macroeconomics stops at aggregate investment and growth, PPP research models deal flow in an essentially climate-free setting, and studies of climate-oriented partnerships remain largely conceptual or case-based, concentrated on mitigation rather than on how realized disasters reshape partnership activity and technology choice. Large-sample econometric evidence linking observed climate disasters to PPP incidence, investment, and design in developing economies, and testing whether national adaptation readiness conditions these responses, is, to the best of our knowledge, absent.

The present study addresses this gap with a balanced panel of 129 developing and emerging economies for 2000–2024, combining two-way fixed-effects and distributed lead-lag estimates of PPP responses to disasters of increasing severity with interactions of ND-GAIN readiness and vulnerability. In sum, prior research shows that institutions govern infrastructure investment, that disasters depress aggregate capital formation, and that policy de-risking can redirect capital toward resilient technologies. What it has not shown is how these forces operate jointly inside PPP markets.

The aim of the paper is to assess how climate disasters and national adaptation readiness shape PPP activity and design in developing and emerging economies.

2. METHOD

The study relies on an annual country-level panel of 129 developing and emerging economies observed over 2000–2024 (N = 3,225 country-years). The project-level backbone is the World Bank Private Participation in Infrastructure (PPI) Database (2024 release), which records 11,640 infrastructure projects with private participation; the year of financial closure assigns each project to a country-year, leaving 8,213 projects within the sample window. Aggregating closures to the country-year level yields a balanced grid in which country-years without any closure are coded as genuine zeros rather than treated as missing; the 1,191 country-years with at least one closure (36.9%) form the subsample on which project-design shares are defined. Climate resilience is measured with the ND-GAIN Country Index (2026 release), whose vulnerability and readiness scores cover 1995–2024. Climate shocks come from the EM-DAT database maintained by the Centre for Research on the Epidemiology of Disasters (CRED), restricted to climatological, hydrological, and meteorological disasters; country-years without a recorded event are assigned zero damage. Governance controls are taken from the Worldwide Governance Indicators (2025 release), and macroeconomic controls originate from the World Development Indicators. All sources are harmonized to ISO3 country codes and merged on the country-year key; the full country list is provided in Appendix A.

Table 1 defines the variables and their sources. Five outcomes capture the activity and design margins of PPP markets. They comprise an indicator of any financial closure, the number of closures, the log of one plus total investment, and, on the project-year subsample, the shares of closures using renewable generation technologies and receiving direct or indirect government support. Investment values are missing for 61 project-years (5.1% of the subsample); these are excluded from investment aggregates rather than zero-filled.

The baseline specification is a two-way fixed-effects model:

$$y_{it} = \alpha_i + \delta_t + \beta \ln\left(1 + Damage_{i,t-1}\right) + \gamma_1 Read_{it} + \gamma_2 Vuln_{it} + \theta' X_{it} + \varepsilon_{it}, \quad (1)$$

where y_{it} denotes, in turn, the closure indicator (a linear probability model), the log of one plus investment, or a design share for country i in year t; α_i and δ_t are country and year fixed effects that absorb time-invariant national characteristics and global shocks; β is the coefficient on lagged log damage $Damage_{i,t-1}$; γ_1 and γ_2 are the coefficients on the ND-GAIN readiness ($Read_{it}$) and vulnerability ($Vuln_{it}$) scores; X_{it} is the control vector collecting ln GDP per capita, GDP growth, ln population, regulatory quality, trade openness, and FDI inflows, with coefficient vector θ; and ε_{it} is the idiosyncratic error term. Because the closure count is a non-negative integer with many zeros, the count margin is estimated by Poisson pseudo-maximum likelihood (Santos Silva & Tenreyro, 2006):

Table 1. Variables, definitions, and data sources

Variable	Definition	Source
Dependent variables		
Any PPP closure	= 1 if at least one PPP financial closure in the country-year	World Bank PPI Database (World Bank, 2024)
Number of closures	Count of PPP financial closures	World Bank PPI Database (World Bank, 2024)
PPP investment	ln(1 + total investment, USD million)	World Bank PPI Database (World Bank, 2024)
Renewable share	Share of closures using renewable generation technologies	World Bank PPI Database (World Bank, 2024)
Gov. support share	Share of closures with direct or indirect government support	World Bank PPI Database (World Bank, 2024)
Climate variables		
Readiness	ND-GAIN readiness score (0–1)	ND-GAIN Country Index (2026 release) (ND-GAIN, 2026)
Vulnerability	ND-GAIN vulnerability score (0–1)	ND-GAIN Country Index (2026 release) (ND-GAIN, 2026)
Disaster damage	ln(1 + damage from climate-related disasters, thousand USD)	EM-DAT (CRED, 2025)
Major disaster, D(1)	= 1 if annual damage ≥ 1% of GDP, both in current USD	EM-DAT (CRED, 2025); WDI (World Bank, n.d.)
Catastrophic disaster, D(5)	= 1 if annual damage ≥ 5% of GDP, both in current USD	EM-DAT (CRED, 2025); WDI (World Bank, n.d.)
Mortality shock	= 1 if disaster deaths ≥ 100	EM-DAT (CRED, 2025)
Control variables		
ln GDP per capita	Constant-price USD, logarithm	WDI (World Bank, n.d.)
GDP growth	Annual growth of real GDP, %	WDI (World Bank, n.d.)
ln population	Total population, logarithm	WDI (World Bank, n.d.)
Regulatory quality	WGI estimate, approx. −2.5 to +2.5	WGI (2025 release) (Kaufmann & Kraay, 2025)
Trade openness	Exports plus imports, % of GDP	WDI (World Bank, n.d.)
FDI inflows	Net inflows, % of GDP	WDI (World Bank, n.d.)

Note: Panel: 129 economies, 2000–2024. Renewable technologies: solar, wind, hydro, biomass, biogas, geothermal, waste-to-energy, marine and tidal, and technologies labeled renewable in the PPI database. An isolated major disaster is a D(1) event with no D(1) event in the preceding three years.

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$$E\left[N_{it}\middle|\cdot\right] = \exp\left(\begin{array}{l}\alpha_i + \delta_t + \beta \ln\left(1 + Damage_{i,t-1}\right) \\ +\gamma_1 \operatorname{Re}ad_{it} + \gamma_2 Vu\ln_{it} + \theta' X_{it}\end{array}\right), \qquad (2)$$

where $E[N_{it}|\cdot]$ denotes the expected number of PPP closures N_{it} conditional on the regressors and fixed effects, and the remaining terms are as in equation (1). Poisson coefficients are semi-elasticities and are converted into percentage effects when interpreted. To separate large events from the mass of small ones, disaster intensity is scaled by economic size and converted into threshold indicators:

$$D_{it}^{\tau} = 1\left\{100 \cdot \frac{Damage_{it}}{GDP_{it}} \geq \tau\right\}, \tau \in \{1,5\}, \qquad (3)$$

where D_{it}^{τ} is the threshold indicator, 1{} is the indicator function, GDP_{it} is gross domestic product in current US dollars, so that numerator and denominator share the same price basis, following the convention of the disaster-macroeconomics literature (Noy, 2009; Felbermayr & Gröschl, 2014), and the threshold τ equal to one percent defines a major disaster while five percent defines a catastrophic one; 119 country-years (3.7% of the sample) qualify as major and 31 as catastrophic. An event is isolated if no major disaster occurred in the preceding three years (84 events in the panel, of which 46 in 36 countries fall within the event-study window and 39 in 30 countries lie outside micro-states). A mortality-based alternative flags country-years with at least one hundred disaster deaths. The dynamic response is traced with distributed leads and lags of isolated events:

$$E\left[N_{it}\middle|\cdot\right] = \exp\left(\alpha_i + \delta_t + \sum_{k=-2}^{3} \beta_k D_{i,t-k}^{iso} + \theta' X_{it}\right), \qquad (4)$$

where $D_{i,t-k}^{iso}$ is the isolated-event indicator, k indexes event time, and β_k are the corresponding lead and lag coefficients; the two leads (k = –2 and k = –1) test for pre-event differences in PPP activity. Four diagnostics probe the dynamic pattern further. The specification is re-estimated with contemporaneous and lagged damage and disaster counts as additional controls, so that sub-threshold events preceding a major one do not load on the leads. Isolation is tightened to exclude any year with damage of at least 0.5% of GDP in the preceding three years. A Wald test compares the three post-event coefficients jointly with the one-year lead. A placebo exercise reassigns the same number of event years at random within each country 300 times and re-estimates the model to obtain a reference distribution for the lead and lag coefficients. Because catastrophic events are rare, the 5% threshold is examined in a dose-response specification that enters mutually exclusive lagged indicators for damage between 1% and 5% of GDP and for damage of at least 5% of GDP in the same model, and the estimate is re-estimated leaving out each catastrophic event in turn. Whether pre-existing resilience conditions the post-disaster response is examined with interaction models:

$$y_{it} = \alpha_i + \delta_t + \beta_1 D_{i,t-1} + \beta_2 D_{i,t-1} \cdot M_{it} + \beta_3 M_{it} + \theta' X_{it} + \varepsilon_{it}, \qquad (5)$$

where M_{it} is the moderator, namely the readiness or vulnerability score centered at its sample mean, β_2 is the coefficient on the interaction term, and β_3 captures the level effect of the moderator, so β_1, the coefficient on the lagged disaster indicator $D_{i,t-1}$, measures the response at average resilience. Design shares are defined only in country-years with at least one closure, a subsample that disasters may themselves shape, so conditioning on it can create a selection problem. The moderation analysis of project design therefore complements the renewable share with the counts of renewable and non-renewable closures, estimated by Poisson pseudo-maximum likelihood on the full balanced panel, and with a linear probability model for the incidence of at least one renewable closure. If disasters merely remove conventional projects from the pipeline, the non-renewable count falls while the renewable count does not rise. Heterogeneity is assessed by re-estimating the Poisson specification with the lagged major-disaster indicator on subsamples that exclude China, Brazil, and India, exclude micro-states with mean population below one million, split the panel by World Bank income groups, and cover the Europe and Central Asia region separately. Within that region, Armenia, Kazakhstan, and Ukraine are profiled as separate cases, comparing their PPP activity, disaster exposure, readiness, and regulatory quality over 2000–2024 with the ECA and full-sample averages and tracing closures around each country's major disaster. The ECA specification is also re-estimated excluding each of the three countries in turn.

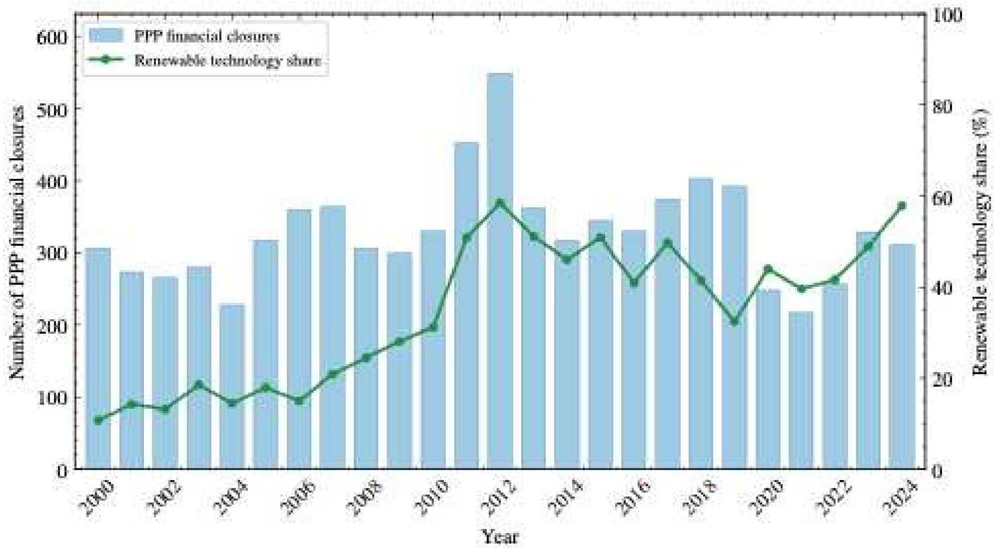
Statistical inference is based on standard errors clustered at the country level, motivated by a Breusch–Pagan test that strongly rejects homoskedasticity (LM = 102.34, $p < 0.001$). A Hausman test rejects random effects in favor of fixed effects ($\chi^2(9) = 58.58$, $p < 0.001$), and variance inflation factors for the baseline regressors remain below 2.5; Appendix B reports the pairwise correlations among the main variables. Poisson estimation drops observations separated by the fixed effects, and singleton fixed effects are removed in the design-share models; the resulting estimation samples comprise 2,348 country-years for the linear probability model, 2,292 for the count model, 2,302 for investment, and 986 project-years for the design outcomes.

Several limitations follow directly from the design. First, the event-study leads and lags describe how PPP activity evolves around major disasters rather than identify causal effects. Financial closure lags deal preparation by a year or more, disaster-prone periods cluster in time, and the placebo exercise shows that lead and lag coefficients of the observed size arise easily under randomly assigned event dates, so all disaster estimates are interpreted as associations. Second, the ND-GAIN vulnerability score is nearly time-invariant (its within-country standard deviation is 18.5% of the overall one), so its level effect is weakly identified once country effects are included, and its role is examined mainly through interactions. Third, EM-DAT damage is compiled from national and international reports; smaller disasters are known to be under-reported; and the threshold indicators remain sensitive to reporting error near the thresholds. Fourth, the catastrophic-threshold estimate rests on twelve treated country-years in the full estimation sample, seven of them outside microstates, and is driven by a single episode, so it is reported as a fragile estimate rather than as a finding. Finally, the PPI database covers projects with private participation that reached financial closure and is thinner for low-income economies, which limits generalization to settings where PPP markets are nascent.

3. RESULTS

The analytical panel covers 129 developing and emerging economies over 2000–2024 (N = 3,225 country-years) and 8,213 public-private partnership (PPP) projects that reached financial closure.

Source: Our calculations based on the World Bank PPI Database (2024 release) (World Bank, 2024).



Note: Bars show the annual number of PPP financial closures (left axis); the line shows the project-weighted share of new closures using renewable generation technologies (right axis).

Figure 1. PPP financial closures and renewable technology share of new closures, 2000–2024

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At least one closure is observed in 1,191 country-years (36.9% of the grid), with a median of six active years per country. PPP activity is heavily concentrated: China (1,875 projects), Brazil (1,254), and India (1,194) jointly account for 52.6% of all closures, while upper-middle-income economies host 65.6% of projects (5,385), compared with 30.7% in lower-middle-income (2,519) and 3.8% in low-income economies (309). The average project mobilizes USD 237.3 million (SD = 374.8). Greenfield schemes dominate contract design (67.1% of projects in the average country-year with closures), direct or indirect government support covers 12.3% of projects, and 3.6% are subsequently canceled or distressed. Energy is the leading sector (56.3% of projects), and the renewable technology share of new closures rises from roughly 11% in 2000 to 58% in 2024 (Figure 1).

The climate environment is far from calm: the average country experiences 1.9 climate-related disasters per year, and 119 country-years (3.7% of the sample) record direct disaster damage of at least 1% of GDP (Table 2).

Table 2. Descriptive statistics

Source: World Bank PPI Database (2024 release) (World Bank, 2024); ND-GAIN Country Index (2026 release) (ND-GAIN, 2026); EM-DAT (CRED, 2025); Worldwide Governance Indicators (2025 release) (Kaufmann & Kraay, 2025); World Development Indicators (World Bank, 2026).

Variable	N	Mean	SD	Min	Max
Panel A. PPP activity (balanced panel)					
Any PPP project (0/1)	3,225	0.369	0.483	0.000	1.000
Number of PPP projects	3,225	2.547	10.068	0.000	143.000
PPP investment, USD mln	3,164	594.928	2,894.558	0.000	49,778.770
Panel B. PPP design (project-years)					
Investment per project, USD mln	1,130	237.328	374.793	0.500	5,018.850
Gov. support share	1,191	0.123	0.282	0.000	1.000
Greenfield share	1,191	0.671	0.405	0.000	1.000
Cancelled/distressed share	1,191	0.036	0.161	0.000	1.000
Energy sector share	1,191	0.563	0.419	0.000	1.000
Transport sector share	1,191	0.214	0.342	0.000	1.000
Water sector share	1,191	0.082	0.224	0.000	1.000
Renewable technology share	1,191	0.363	0.411	0.000	1.000
Panel C. Climate variables (balanced panel)					
ND-GAIN vulnerability	3,150	0.494	0.075	0.308	0.679
ND-GAIN readiness	3,150	0.343	0.078	0.147	0.620
ND-GAIN index	3,150	42.479	6.570	26.036	64.310
Climate disasters, count	3,225	1.901	3.261	0.000	34.000
Disaster deaths, persons	3,225	149.193	2,681.982	0.000	138,366.000
Disaster-affected, thsd	3,225	1,377.292	12,617.328	0.000	346,557.559
Disaster damage, USD mln	3,225	285.291	2,067.569	0.000	44,717.160
CO2 per capita, t	3,100	2.819	8.694	0.024	202.865
Renewable energy cons., %	2,838	40.443	30.503	0.000	98.300
Forest area, %	3,036	33.789	25.446	0.045	95.577
Panel D. Institutions and macro (balanced panel)					
WGI regulatory quality	3,048	–0.527	0.632	–2.581	1.287
WGI rule of law	3,086	–0.583	0.662	–2.508	1.352
WGI gov. effectiveness	3,049	–0.537	0.633	–2.462	1.269
GDP per capita, const USD	3,082	3,891.835	3,702.299	233.032	33,034.958
GDP growth, %	3,079	3.884	6.138	–50.339	86.827
Inflation, %	2,908	8.942	24.460	–16.860	557.202
Trade openness, % GDP	2,645	74.734	37.021	1.995	347.720
FDI inflows, % GDP	3,027	4.061	6.128	–20.362	103.337
Population, mln	3,150	47.379	166.911	0.018	1,450.936
Internet users, %	2,995	27.207	26.938	0.000	98.021

Note: Balanced panel: 129 economies × 25 years (2000–2024). Project-year subsample: country-years with at least one PPP financial closure. Population reported in millions; disaster-affected in thousands; disaster damage converted from thousands of USD to millions of USD.

Table 3 reports baseline two-way fixed-effects estimates with standard errors clustered by country. The average lagged disaster-damage term is statistically indistinguishable from zero in all five specifications (β = –0.000, SE = 0.002 for the probability of any closure; β = 0.003, SE = 0.008 in the Poisson count model), indicating no unconditional short-run response of PPP activity to climate damage. Institutional quality, in contrast, is a robust correlate of PPP markets. A one-standard-deviation improvement in regulatory quality (0.63 points) is associated with a 12.6-percentage-point higher probability of observing at least one closure (β = 0.200, p < 0.01) and with approximately 131% larger investment volumes (β = 1.324, p < 0.001). Market size matters as well (ln population: β = 0.381, p < 0.01 for closure probability; β = 2.073, p < 0.01 for log investment). Neither ND-GAIN readiness nor vulnerability is significant at the country level. The results indicate that the specification is well behaved: the Hausman test rejects random effects ($\chi^2(9)$ = 58.58, p < 0.001), all variance inflation factors remain below 2.5 (maximum 2.44), and the Breusch–Pagan test confirms heteroskedasticity (LM = 102.34, p < 0.001), justifying the clustered standard errors. Estimation samples comprise 2,348 country-years for the linear probability model (R^2 = 0.397), 2,292 for the Poisson model, 2,302 for investment (R^2 = 0.559), and 986 project-year observations for the design outcomes.

Table 4 traces PPP closures around major climate disasters, defined as country-years with direct damage of at least 1% of GDP, using distributed leads and lags, and Figure 2 plots the event-study coefficients for isolated events with their 95% confidence intervals. Among the large events in the sample are well-known catastrophes such as the 2005 floods in Guyana (damage equal to 56.4% of GDP), Cyclone Pam in Vanuatu (2015, 52.5%), and Hurricane Matthew in Haiti (2016, 14.8%). Point estimates are negative from the event year onward and correspond to 25–34% fewer closures in the three years after an isolated major disaster (t + 1: β = –0.285, SE = 0.185; t+2: β = –0.408, SE = 0.217; t + 3: β = –0.323, p < 0.05). The pattern is essentially unchanged when micro-states with fewer than

Table 3. Baseline fixed-effects estimates of PPP activity and design

Variable	(1) Any PPP	(2) N projects (PPML)	(3) ln Investment	(4) Renewable share	(5) Support share
ln damage (t – 1)	–0.000	0.003	0.003	0.001	–0.001
	(0.002)	(0.008)	(0.012)	(0.003)	(0.002)
ND-GAIN readiness	0.100	1.081	1.250	0.273	–0.057
	(0.279)	(1.094)	(2.029)	(0.261)	(0.305)
ND-GAIN vulnerability	0.700	8.960	–0.269	3.407	–0.148
	(1.150)	(5.020)	(5.630)	(1.862)	(1.105)
ln GDP per capita	0.015	–0.338	0.230	–0.038	0.095
	(0.062)	(0.231)	(0.393)	(0.149)	(0.055)
GDP growth	0.003	0.008	0.010	–0.006	–0.005
	(0.002)	(0.010)	(0.008)	(0.004)	(0.003)
ln population	0.381**	1.305*	2.073**	0.260	0.181
	(0.145)	(0.573)	(0.749)	(0.241)	(0.118)
WGI regulatory quality	0.200**	0.509	1.324***	0.008	–0.003
	(0.060)	(0.352)	(0.356)	(0.076)	(0.053)
Trade openness	0.002*	0.006	0.007	0.001	–0.000
	(0.001)	(0.004)	(0.004)	(0.001)	(0.001)
FDI, % GDP	0.002	0.011	0.027*	0.005	0.001
	(0.002)	(0.008)	(0.013)	(0.005)	(0.004)
Country & year FE	yes	Yes	yes	yes	yes
Observations	2,348	2,292	2,302	986	986
R^2	0.397	–	0.559	0.375	0.335

Note: Two-way fixed-effects estimates; standard errors clustered by country in parentheses. * p < 0.05, ** p < 0.01, *** p < 0.001. Columns (1-3): balanced panel; columns (4-5): project-years. Column (2): Poisson pseudo-maximum likelihood (PPML); 56 observations dropped due to separation. Columns (4-5): 10 singleton fixed effects dropped. Dependent variables: (1) indicator of any closure; (2) number of closures; (3) ln(1 + investment); (4) renewable technology share; (5) government support share.

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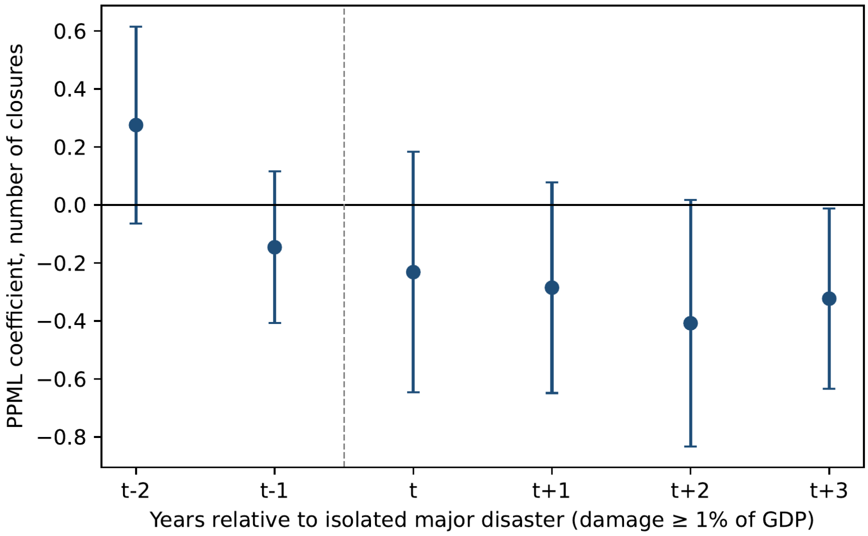
Source: Our calculations based on EM-DAT (CRED, 2025), WDI (World Bank, n.d.), and the World Bank PPI Database (World Bank, 2024).



Note: Poisson pseudo-maximum-likelihood coefficients on leads and lags of an isolated major disaster (damage of at least 1% of GDP, with no major disaster in the preceding three years). Whiskers show 95% confidence intervals; standard errors are clustered by country.

Figure 2. Event-study estimates of PPP closures around isolated major climate disasters

one million inhabitants are excluded (39 isolated events across 30 countries). Only the third lag is significant at the 5% level, however, and the same holds in the linear probability model for the closure indicator (t + 3: β = −0.131, SE = 0.065).

The leads provide no evidence of a pre-event decline. Closures are statistically indistinguishable from their baseline in the year preceding the event (t−1: β = −0.146, SE = 0.133) and, if anything, elevated two years before it (t − 2: β = 0.275, SE = 0.173). A Wald test cannot reject equality of the three post-event coefficients with the one-year lead ($\chi^2(3)$ = 1.91, p = 0.59), and the contrast between the first lag and the first lead is small (−0.139, SE = 0.190, p = 0.46). Appendix E reports three further diagnostics. Adding contemporaneous and lagged damage and disaster counts as controls leaves the coefficients unchanged (t + 1: β = −0.295; t+3: β = −0.323, p < 0.05), so sub-threshold events preceding a major one do not drive the estimates. Tightening isolation to exclude any damage of at least 0.5% of GDP in the preceding three years (41 events) reduces the post-event coefficients further (t + 1: β = −0.199, SE = 0.204) and turns the two-year lead positive and significant (β = 0.403, p < 0.01). This finding points to mean reversion in a lumpy flow of deals rather than to a response to the disaster. A placebo exercise that reassigns event years at random within countries 300 times produces lead and lag coefficients with a standard deviation of 0.31, and 36% of the placebo first-lag estimates exceed the observed one in absolute value (65% for the first lead). PPP activity is thus somewhat lower in the years following major disasters, but the association is imprecise and cannot be distinguished from the pattern generated by randomly timed events.

Table 5 examines whether the association changes with the severity of the shock in a dose-response specification that enters mutually exclusive indicators for lagged damage between 1% and 5% of GDP and for damage of at least 5% of GDP. The coefficient on the intermediate band is negative and imprecise (β = −0.129, SE = 0.152), whereas the catastrophic band is positive and sizable (β = 0.806, p < 0.01), corresponding to about 124% more closures in the following year, and the two coefficients differ significantly (p = 0.003). The estimate survives the exclusion of micro-states (β = 0.800, p < 0.01) and the additional exclusion of the three largest PPP markets (β = 0.710, p < 0.05). It does not survive scrutiny of the events behind it. Of the 31 catastrophic country-years, 17 lie outside micro-states, twelve enter the full estimation sample, and

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Table 4. PPP closures around major climate disasters: Distributed leads and lags

Variable	(1) All major events	(2) Isolated events	(3) Isolated, excl. micro-states
Major (t − 2)	0.300	0.275	0.262
	(0.158)	(0.173)	(0.176)
Major (t − 1)	−0.172	−0.146	−0.142
	(0.135)	(0.133)	(0.134)
Major (t)	−0.290	−0.232	−0.230
	(0.182)	(0.211)	(0.212)
Major (t + 1)	−0.078	−0.285	−0.284
	(0.167)	(0.185)	(0.187)
Major (t + 2)	−0.198	−0.408	−0.407
	(0.177)	(0.217)	(0.218)
Major (t + 3)	−0.027	−0.323*	−0.331*
	(0.232)	(0.158)	(0.160)
Controls	yes	Yes	yes
Country & year FE	yes	Yes	yes
Observations	1,951	1,951	1,725

Note: PPML estimates; dependent variable: number of PPP closures. Major disaster: annual climate-related damage ≥ 1% of GDP, both in current USD. Isolated event: no major disaster in the preceding three years (46 events across 36 countries in the estimation window). Column (3) excludes countries with mean population below one million (39 isolated events across 30 countries). Controls: ln GDP per capita, GDP growth, ln population, WGI regulatory quality, trade openness, FDI (% GDP). Standard errors clustered by country. Observations dropped due to separation: 124/124/116. Linear probability models for the closure indicator show no significant leads; among the lags, only the third is significant ($\beta = -0.131$, SE = 0.065). * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

seven enter the specification without micro-states (Appendix D). Leaving out each catastrophic event in turn keeps the coefficient between 0.77 and 0.87 for every event but one; without the 2011 floods in Thailand, which were followed by 22 closures in 2012 against nine in the event year, the coeffi-

Table 5. Dose-response estimates across damage bands and mortality shocks

Variable	(1) Full sample	(2) Excl. micro-states	(3) Excl. micro-states & top-3	(4) Deaths ≥ 100
Major, 1–5% GDP (t − 1)	−0.129	−0.127	−0.065	–
	(0.152)	(0.152)	(0.161)	
Catastrophic, ≥ 5% GDP (t − 1)	0.806**	0.800**	0.710*	–
	(0.279)	(0.296)	(0.283)	
Mortality shock (t − 1)	–	–	–	0.021
				(0.086)
ln GDP per capita	−0.359	−0.358	−0.739*	−0.354
	(0.256)	(0.258)	(0.346)	(0.256)
GDP growth	0.006	0.005	0.027**	0.007
	(0.011)	(0.011)	(0.010)	(0.011)
ln population	1.093*	1.135*	1.519*	1.109*
	(0.534)	(0.542)	(0.610)	(0.534)
WGI regulatory quality	0.562	0.560	0.979**	0.558
	(0.312)	(0.317)	(0.314)	(0.309)
Trade openness	0.006	0.006	0.006*	0.006
	(0.004)	(0.004)	(0.003)	(0.004)
FDI, % GDP	0.007	0.008	0.008	0.007
	(0.009)	(0.010)	(0.009)	(0.009)
Country & year FE	Yes	yes	yes	yes
Observations	2,292	2,035	1,966	2,292

Note: PPML estimates; dependent variable: number of PPP closures. Columns (1-3) enter mutually exclusive lagged indicators for damage between 1% and 5% of GDP and for damage of at least 5% of GDP, with damage below 1% as the reference category. Catastrophic events: 31 country-years, 17 outside micro-states, twelve in the estimation sample of column (1) and seven in that of column (2); Appendix D lists them. Mortality shock: at least 100 disaster deaths. Standard errors clustered by country. Observations dropped due to separation: 83/78/78/83. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

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cient turns negative and insignificant (β = –0.464, SE = 0.616). The catastrophic estimate is therefore a single-episode result and is not interpreted as evidence of reconstruction-driven surges. A mortality-based shock definition (at least 100 disaster deaths) yields a precise null (β = 0.021, SE = 0.086), so PPP activity, where it moves at all, responds to economically scaled damage rather than to human losses as such.

Table 6 turns to project design and asks whether adaptation readiness conditions the composition of closures after major disasters. Because design shares are defined only in country-years with at least one closure, a subsample that disasters may themselves shape, the renewable share is complemented by counts of renewable and non-renewable closures and by the incidence of any renewable closure, all estimated on the full balanced panel. In the share regression, a major disaster is followed by a higher renewable share where readiness is low, but the interaction is imprecise (β = –1.401, SE = 0.943); evaluated at one standard deviation below the mean of readiness, the share is 23.7 percentage points higher, against 1.7 points at one standard deviation above it, relative to a sample mean of 36.3%. The counts show where this compositional change comes from. The number of non-renewable closures falls after a major disaster (β = –0.480, p < 0.001), by about 38% at average readiness and by 54% at one standard deviation below it (interaction β = 3.859, p < 0.05). In contrast, the number of renewable closures (β = 0.306, SE = 0.193) and the probability of at least one renewable closure (β = 0.062, SE = 0.046) do not change significantly. The higher renewable share among realized closures therefore reflects the attrition of conventional projects rather than additional renewable deals. Readiness does not moderate overall activity, and vulnerability moderates neither activity nor design (Appendix C).

Country-group estimates (Table 7) confirm the absence of a robust activity response. The lagged major-disaster coefficient is close to zero in the full sample (β = –0.037, SE = 0.157) and in every subsample, including low- and lower-middle-income

Table 6. Post-disaster composition of PPP closures and adaptation readiness

Variable	(1) Renewable share	(2) N renewable (PPML)	(3) N non-renewable (PPML)	(4) Any renewable closure
Major (t – 1)	0.127	0.306	–0.480***	0.062
	(0.066)	(0.193)	(0.130)	(0.046)
Readiness (centered)	0.345	0.267	2.142	0.663*
	(0.264)	(1.120)	(1.469)	(0.293)
Major (t – 1) × Readiness	–1.401	0.821	3.859*	0.038
	(0.943)	(3.083)	(1.954)	(0.662)
ln GDP per capita	–0.119	–0.841	0.129	0.037
	(0.135)	(0.592)	(0.328)	(0.072)
GDP growth	–0.007	–0.010	0.016	0.000
	(0.004)	(0.016)	(0.011)	(0.001)
ln population	0.257	3.507***	0.294	0.318*
	(0.242)	(1.027)	(0.871)	(0.132)
WGI regulatory quality	0.016	0.829*	0.054	0.023
	(0.073)	(0.399)	(0.446)	(0.051)
Trade openness	0.001	0.011	0.004	0.001
	(0.001)	(0.006)	(0.006)	(0.001)
FDI, % GDP	0.003	–0.021	0.025*	0.003
	(0.005)	(0.025)	(0.012)	(0.002)
Country & year FE	Yes	yes	yes	yes
Observations	986	1,840	2,199	2,348
R^2	0.374	–	–	0.393

Note: Readiness is the ND-GAIN readiness score centered at the sample mean (SD = 0.078). Column (1): project-years; 10 singleton fixed effects dropped. Columns (2-3): Poisson pseudo-maximum likelihood on the balanced panel; renewable and non-renewable counts sum to the number of closures; observations dropped due to separation: 508/149. Column (4): linear probability model on the balanced panel. Interactions of the major-disaster indicator with readiness for overall activity and all vulnerability interactions are reported in Appendix C. Standard errors clustered by country. * p < 0.05, ** p < 0.01, *** p < 0.001.

Table 7. Post-disaster PPP activity across country groups

Variable	(1) Full	(2) Excl. CHN/BRA/IND	(3) Excl. micro	(4) LIC + LMIC	(5) UMIC	(6) ECA
Major (t – 1)	–0.037	0.040	–0.040	0.034	–0.022	–0.353
	(0.157)	(0.157)	(0.159)	(0.147)	(0.465)	(0.275)
ln GDP per capita	–0.352	–0.709*	–0.352	–1.081**	–0.408	–1.948
	(0.257)	(0.341)	(0.259)	(0.408)	(0.268)	(1.360)
GDP growth	0.007	0.029**	0.006	0.027**	0.023**	0.085**
	(0.011)	(0.010)	(0.011)	(0.010)	(0.009)	(0.028)
ln population	1.111*	1.500*	1.155*	2.150**	1.027	3.998
	(0.536)	(0.597)	(0.544)	(0.738)	(1.062)	(2.144)
WGI regulatory quality	0.559	0.970**	0.555	0.267	0.967**	1.612*
	(0.310)	(0.310)	(0.314)	(0.519)	(0.301)	(0.626)
Trade openness	0.006	0.006*	0.006	0.013**	0.002	0.007
	(0.004)	(0.003)	(0.004)	(0.004)	(0.006)	(0.008)
FDI, % GDP	0.007	0.007	0.007	0.008	0.016	–0.027
	(0.009)	(0.008)	(0.009)	(0.016)	(0.009)	(0.020)
Country & year FE	yes	Yes	yes	yes	yes	yes
Observations	2,292	2,223	2,035	1,298	994	385

Note: PPML estimates; dependent variable: number of PPP closures; major disaster defined as damage ≥ 1% of GDP, both in current USD, lagged one year. Micro-states: mean population below one million. LIC/LMIC/UMIC: World Bank income groups; ECA: Europe and Central Asia. Standard errors clustered by country. Observations dropped due to separation: 83/83/78/78/5/23. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

countries (β = 0.034, SE = 0.147) and upper-middle-income ones (β = –0.022, SE = 0.465). In the Europe and Central Asia subsample, which includes transition economies such as Armenia, Kazakhstan, and Ukraine, the coefficient is negative but imprecise (β = –0.353, SE = 0.275), and macroeconomic momentum and institutions dominate; closures rise by about 8.9% per percentage point of GDP growth (β = 0.085, $p < 0.01$), and regulatory quality carries a large positive coefficient (β = 1.612, $p < 0.05$). The institutional result is not driven by the largest markets; excluding China, Brazil, and India, regulatory quality remains positive and significant in the Poisson model (β = 0.970, $p < 0.01$).

Table 8 profiles Armenia, Kazakhstan, and Ukraine as separate cases within the ECA subsample. The three economies differ sharply in market size and disaster exposure. Ukraine recorded 108 closures in 16 active years and no year in which damage reached 1% of GDP, although its largest annual damage (2012, 0.9% of GDP) falls just below the threshold. Armenia recorded 34 closures and one event in the first panel year (2000, 5.2% of GDP, above the catastrophic threshold). Kazakhstan showed 27 closures, with the largest annual damage of 0.1% of GDP. All three raised ND-GAIN readiness by 0.08–0.11 points between 2000 and 2024, roughly five to seven times the full-sample gain, and regulatory quality rose from –0.73 to 0.14 in Armenia, from –0.77 to 0.05 in Kazakhstan, and from –0.90 to –0.30 in Ukraine. The case trajectories are consistent with the panel estimates without adding to their identification. Armenia's twelve closures in the three years after its 2000 event coincide with the utility privatizations and concessions of the early 2000s and cannot be attributed to the disaster. Kazakhstan's closures cluster in 2017–2024 (22 of 27), after regulatory quality turned positive, with renewables making up 64% of new projects since 2015, in line with the regulatory-quality association. Armenia is the counter-case, since its period-average regulatory quality is the highest of the three (0.19), yet 28 of its 34 closures fall in 2000–2008 and none in 2009–2014, illustrating that regulatory quality is necessary rather than sufficient in a small market where population, the other robust correlate, is limited. The ECA estimates of Table 7 do not hinge on any single case country either. Re-estimating the ECA specification without Armenia, Kazakhstan, or Ukraine in turn (N = 362 in each case) leaves the lagged major-disaster coefficient negative and insignificant (β between –0.434 and –0.310) and regulatory quality positive and significant (β = 1.667, $p < 0.05$ without Armenia; β = 1.498, $p < 0.05$ without Kazakhstan; β = 2.114, $p < 0.001$ without Ukraine), with the GDP-growth association likewise preserved (β = 0.073 to 0.107, $p < 0.01$).

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Table 8. Case profiles of Armenia, Kazakhstan, and Ukraine, 2000–2024

Source: World Bank PPI Database (2024 release) (World Bank, 2024); ND-GAIN Country Index (2026 release) (ND-GAIN, 2026); EM-DAT (CRED, 2025); Worldwide Governance Indicators (2025 release) (Kaufmann & Kraay, 2025); World Development Indicators (World Bank, n.d.).

Indicator	Armenia	Kazakhstan	Ukraine	ECA (19)	Full sample (129)
Panel A. PPP activity, 2000–2024					
PPP closures, number	34	27	108	49.3 per country	63.7 per country
Years with at least one closure	15	10	16	10.3	9.2
Total PPP investment, USD mln	2,685.5	3,264.2	8,208.0	14,695.3 per country	14,591.9 per country
Renewable share of closures, 2000–2024, %	11.8	51.9	38.0	41.6	36.0
Renewable share of closures, 2015–2024, %	50.0	63.6	89.7	59.2	44.7
Energy sector share of closures, %	47.1	63.0	91.7	72.1	55.9
Panel B. Climate exposure					
Climate disasters per year	0.40	0.76	1.20	1.05	1.90
Major disasters, D(1), country-years	1 (2000)	0	0	16 (0.84 per country)	119 (0.92 per country)
Largest annual damage, % of GDP (year)	5.23 (2000)	0.10 (2008)	0.93 (2012)	0.86	0.72
Panel C. Readiness and institutions					
ND-GAIN readiness, 2000	0.374	0.372	0.364	0.354	0.331
ND-GAIN readiness, 2024	0.457	0.484	0.455	0.446	0.346
ND-GAIN vulnerability, 2000	0.426	0.379	0.429	0.428	0.510
ND-GAIN vulnerability, 2024	0.394	0.355	0.385	0.392	0.480
WGI regulatory quality, 2000	−0.73	−0.77	−0.90	−0.81	−0.67
WGI regulatory quality, 2024	0.14	0.05	−0.30	−0.18	−0.51
WGI regulatory quality, period mean	0.19	−0.29	−0.52	−0.29	−0.53
GDP growth, period mean, %	6.3	5.8	1.1	4.5	3.9
Panel D. PPP closures around the major disaster					
Three years before the event	n/a	–	–	–	–
Event year	1	–	–	–	–
Three years after the event	12	–	–	–	–

Note: Shares are project-weighted. For the ECA and full-sample columns, counts are per-country averages, levels are cross-country means of the first and last available values (2000, or the first available year, and 2024), and the largest annual damage is the median of country maxima. Major disaster: damage ≥ 1% of GDP, both in current USD. Panel D counts closures in the three years before and after the country's major disaster; Armenia's event falls in the first panel year, so its pre-event window is unobserved (n/a); Kazakhstan and Ukraine have no major disaster (–).

4. DISCUSSION

With disaster intensity scaled by GDP in the same price basis, the level of PPP deal flow shows no robust response to major climate disasters, and no pre-event decline is detected, so anticipation effects do not complicate the reading. This null result is informative for risk-centered accounts of climate impacts on infrastructure finance. Natural hazards impose direct damages on power, transport, and water assets in low- and middle-income countries and make infrastructure less attractive to private investors, even though resilient design remains cost-effective (Hallegatte et al., 2019), and climate risk curtails private-sector credit supply globally, pointing to a repricing channel (Li et al., 2024). The present estimates suggest that any such repricing operates on the composition of deals rather than on their number. Conventional projects become scarcer after major disasters, especially where adaptation readiness is weak, while renewable projects continue to reach closure, which is consistent with reviews of low-carbon, climate-resilient PPPs in which unresolved risk allocation and contingent liabilities stall the preparation of exposed conventional assets (Casady et al., 2024). The null effects of average damage and mortality-based shocks support an economic-damage interpretation, consistent with sponsors responding to balance-sheet exposure rather than humanitarian severity.

The findings also qualify the creative destruction reading of catastrophes. A reconstruction surge appears in the estimates only as a single-episode artifact, so the evidence does not support the view that the largest disasters open windows of accelerated private investment. It is closer to the two-earthquake comparison in which institutions decide whether reconstruction windows become development or waste (Barone & Mocetti, 2014), since regulatory quality dominates the disaster terms throughout. This mirrors evidence from Poland that institutional quality drives renewable transitions (Mukhtarov et al., 2023) and cross-country results showing that lower corruption, rather than climate-finance volumes, raises the likelihood of emission reductions (Lyeonov et al., 2023). The greater resilience of renewable closures after disasters does not contradict these findings but suggests that where pre-disaster institutional capacity is weakest, the projects that survive a shock may be those with shorter preparation cycles and more standardized risk allocation, features that increasingly characterize renewable generation.

The results also bear on financial regulation and project preparation. Debates on integrating climate risk into central bank mandates concern the repricing channel suggested here, and macroprudential de-risking would operate on the same margin as PPP guarantees (Omeir & Vasiliauskaite, 2025). At the firm level, readiness for green infrastructure finance depends on organizational characteristics and coordinated government support, so sponsor-side capacity building complements sovereign-level readiness (Patnaik & Hedau, 2026). Three levers follow for developing and transition economies. Regulatory quality should be the first-order instrument for mobilizing private capital, standby pipelines and guarantees should keep conventional infrastructure deals alive through disaster-prone windows, and reconstruction frameworks should treat renewable procurement as the more robust component of the pipeline rather than as a substitute for the conventional projects that disasters displace. These implications are associations rather than causal prescriptions and are strongest for the Europe and Central Asia subsample, where the regulatory-quality association is largest among the country groups and where the case profiles of Armenia, Kazakhstan, and Ukraine trace the same interplay of institutions and market size.

CONCLUSION

The paper examined whether climate disasters and national adaptation readiness reshape PPP activity and design across developing economies. A balanced panel of 129 economies for 2000–2024 with 8,213 PPP closures was analyzed with two-way fixed-effects linear and Poisson models and clustered standard errors, with disaster intensity measured as damage relative to GDP, both in current US dollars.

Neither average damage nor major disasters (damage of at least 1% of GDP) are robustly associated with the number of new closures; post-event coefficients are negative but mostly insignificant, no pre-event decline is detected; and placebo event dates reproduce estimates of similar size, so the estimates are associations, not causal effects. At catastrophic levels (at least 5% of GDP), the positive coefficient rests on a single episode and is not read as a reconstruction surge. Composition does respond; after a major disaster, the number of non-renewable closures falls by about 38%, and by more where readiness is low, while renewable closures are unchanged, so the renewable share of realized projects rises through attrition. Institutions dominate the disaster terms; a one-standard-deviation improvement in regulatory quality is associated with a 12.6-percentage-point higher probability of observing a PPP closure and roughly 131% larger investment, with the association strongest in Europe and Central Asia.

For transition economies such as Armenia, Kazakhstan, and Ukraine, examined here as separate cases, regulatory quality is the first-order lever; independent regulators, transparent tariffs, and predictable contract enforcement mobilize private capital more reliably than disaster-specific incentives. Standby pipelines, guarantees, and risk-sharing instruments should stay active through disaster-prone periods, with particular attention to the conventional projects that are most likely to drop out of the pipeline.

Finally, the resilience of renewable closures after disasters argues for treating renewable procurement as a stable component of reconstruction frameworks and for pre-committing build-back-better standards, so that the projects that do reach closure deliver resilient, low-carbon infrastructure; by analogy rather than direct transfer, it bears on Ukraine's post-war rebuilding.

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DATA AVAILABILITY STATEMENT

The study relies exclusively on publicly accessible databases. PPP project data come from the World Bank Private Participation in Infrastructure (PPI) Database (World Bank, 2024); climate disaster records from EM-DAT, the international disaster database of the Centre for Research on the Epidemiology of Disasters (CRED, 2025); adaptation readiness and vulnerability scores from the ND-GAIN Country Index (ND-GAIN, 2026); governance indicators from the Worldwide Governance Indicators (Kaufmann & Kraay, 2025); and macroeconomic controls from the World Development Indicators (World Bank, n.d.). EM-DAT is available free of charge for non-commercial use upon registration.

REFERENCES

1. Aleknevičienė, V., Kazilionienė, A., & Bendoraitytė, A. (2025). Does the green bond premium exist in the secondary market? Evidence from Nordic countries. *Equilibrium. Quarterly Journal of Economics and Economic Policy, 20*(1), 327-355. https://doi.org/10.24136/eq.3389
2. Aziz, M. A., Ayob, N. H., Ayob, N. A., Ahmad, Y., & Abdulsomad, K. (2024). Factors influencing farmer adoption of climate-smart agriculture technologies: Evidence from Malaysia. *Human Technology, 20*(1), 70-92. https://doi.org/10.14254/1795-6889.2024.20-1.4
3. Barone, G., & Mocetti, S. (2014). Natural disasters, growth and institutions: A tale of two earthquakes. *Journal of Urban Economics, 84*, 52-66. https://doi.org/10.1016/j.jue.2014.09.002
4. Bashynska, I., Malynovska, Y., Kolinko, N., Bielialov, T., Järvis, M., Kovalska, K., & Saiensus, M. (2024). Performance assessment of sustainable leadership of enterprise's circular economy-driven innovative activities. *Sustainability, 16*(2), Article 558. https://doi.org/10.3390/su16020558
5. Bashynska, I., Mukhamejanuly, S., Malynovska, Y., Bortnikova, M., Saiensus, M., & Malynovskyy, Y. (2023). Assessing the outcomes of digital transformation smartization projects in industrial

enterprises: A model for enabling sustainability. *Sustainability, 15*(19), Article 14075. https://doi.org/10.3390/su151914075

6. Bezverkhyi, K., Parasii-Verhunenko, I., Pylypenko, O., Yurchenko, O., Matiukha, M., & Poddubna, N. (2025). Features of audit of sustainability reporting: Empirical experience of the European Union countries. *Financial and Credit Activity: Problems of Theory and Practice, 3*(62), 79-94. https://doi.org/10.55643/fcaptp.3.62.2025.4735
7. Bezverkhyi, K., Parasii-Verhunenko, I., Yurchenko, O., Kazak, O., Zhytar, M., & Poddubna, N. (2024). Conceptual basis of anti-corruption audit. *Financial and Credit Activity: Problems of Theory and Practice, 6*(59), 77-89. https://doi.org/10.55643/fcaptp.6.59.2024.4482
8. Budhathoki, P. B., Lama, P. B., & Ghimire, S. R. (2026). Addressing socioeconomic challenges in developing Asia: The role of international tourism, financial development, trade openness, and capital formation in economic growth. *SocioEconomic Challenges, 10*(1), 170-186. https://doi.org/10.61093/sec.10(1).170-186.2026
9. Burrell, D. N., Wansi, T., Morin, S. L., Rahim, E., Tessema, D. B., Alemu, B. A., Harris, N., & Conley, L. (2025). Harnessing behavioral economics, green promotions, and financial incentives as catalysts for sustainable practices. *Green Transition and Sustainable Development, 1*(1), 1-16. https://doi.org/10.61093/gtsd.1(1).1-16.2025
10. Casady, C. B., Cepparulo, A., & Giuriato, L. (2024). Public-private partnerships for low-carbon, climate-resilient infrastructure: Insights from the literature. *Journal of Cleaner Production, 470,* Article 143338. https://doi.org/10.1016/j.jclepro.2024.143338
11. Centre for Research on the Epidemiology of Disasters (CRED). (2025). *EM-DAT: The international disaster database* [Data set]. UCLouvain. Retrieved from https://www.emdat.be
12. Crowley, R. W., & Mujtaba, B. G. (2026). Human rights and the rule of law in public governance: The transformation of Black entertainment and athletic excellence in the United States. *Public Governance, Regulation and Law, 2*(1), 1-19. https://doi.org/10.61093/pgrl.2(1).1-19.2026
13. Eke, H. (2026). Psychological safety of nonprofit executives: Attributional insights into the human burden of mission-driven leadership, work-life balance, stress, and burnout. *Safety and Security Advances, 2*(1), 53-62. https://doi.org/10.61093/ssa.2(1).53-62.2026
14. Felbermayr, G., & Gröschl, J. (2014). Naturally negative: The growth effects of natural disasters. *Journal of Development Economics, 111,* 92-106. https://doi.org/10.1016/j.jdeveco.2014.07.004
15. Gautam, D., Gratcheva, E., Natalucci, F. M., & Prasad, A. (2024). Unlocking adaptation finance in emerging market and developing economies. *IMF Staff Climate Notes, 2024*(007). https://doi.org/10.5089/9798400293290.066
16. Global Infrastructure Hub. (2018). *Global infrastructure outlook: Infrastructure investment needs, 56 countries, 7 sectors to 2040*. Oxford Economics. Retrieved from https://cdn.gihub.org/outlook/live/methodology/Global+Infrastructure+Outlook+factsheet+-+June+2018.pdf
17. Guhl, M., & Heidemann, J. (2025). Preventive measures by regional banks to increase the resilience of the local population against natural hazards in Germany. *Financial Markets, Institutions and Risks, 9*(1), 110-122. https://doi.org/10.61093/fmir.9(1).110-122.2025
18. Hallegatte, S., Rentschler, J., & Rozenberg, J. (2019). *Lifelines: The resilient infrastructure opportunity*. World Bank. https://doi.org/10.1596/978-1-4648-1430-3
19. Hammami, M., Ruhashyankiko, J.-F., & Yehoue, E. B. (2006). Determinants of public-private partnerships in infrastructure. *IMF Working Papers, 2006*(099). https://doi.org/10.5089/9781451863598.001
20. Hobbs, S. M. (2026). From crisis to resilience: Building adaptive healthcare supply chains after COVID-19. *Health Economics and Management Review, 7*(1), 133-153. https://doi.org/10.61093/hem.7(1).133-153.2026
21. Kajda, K., & Karwot, J. (2026). AI-driven waste classification and smart management in Poland's Industry 4.0 framework: CNN-based solutions for sustainable municipal systems. *Green Transition and Sustainable Development, 2*(1), 65-87. https://doi.org/10.61093/gtsd.2(1).65-87.2026
22. Kaufmann, D., & Kraay, A. (2025). *Worldwide Governance Indicators, 2025 update* [Data set]. World Bank. Retrieved from https://www.govindicators.org
23. Khandelwal, V., Chotia, V., Sharma, P., Soni, S., & Kalyani, S. (2024). Examining the nexus of infrastructure development and economic growth: Evidence from SAARC countries. *Problems and Perspectives in Management, 22*(4), 649-657. https://doi.org/10.21511/ppm.22(4).2024.49
24. Klochan, I., & Filipov, D. (2023). Design of assessment and forecasting of a country's financial security in change management conditions. *Smart Economy, Entrepreneurship and Security, 1*(1), 31-42. https://doi.org/10.60022/sis.1.(01).3
25. Koldovskyi, A., Babenko, K., Shafranova, K., & Dyvynska, Y. (2025). The role of AI in enhancing sustainable business leadership and organizational resilience. *Business Ethics and Leadership, 9*(2), 188-199. https://doi.org/10.61093/bel.9(2).188-199.2025
26. Koval, V., Laktionova, O., Atstāja, D., Grasis, J., Lomachynska, I., & Shchur, R. (2022). Green financial instruments of cleaner production technologies. *Sustainability, 14*(17), Article 10536. https://doi.org/10.3390/su141710536
27. Ksonzhyk, I., Lavrushchenko, Y., Oleksiuk, M., Saienko, V., & Buryk, Z. (2021). Influence of renewable "green" energy on the economic development of the EU states. *Environment and Ecology Research, 9*(5), 271-281. https://doi.org/10.13189/eer.2021.090507

28. Kuzior, A., Marhasova, V., Zozuľakova, V., Kočnerova, M., Koibichuk, V., Ryabushka, L., & Vasylieva, T. (2025). Smart city rankings and startup ecosystems: An empirical analysis of inverse correlation across 77 smart cities. *Problems and Perspectives in Management, 23*(2), 409-422. https://doi.org/10.21511/ppm.23(2).2025.29

29. Li, S., Li, Q., & Lu, S. (2024). The impact of climate risk on credit supply to private and public sectors: An empirical analysis of 174 countries. *Environment, Development and Sustainability, 26*(1), 2443-2465. https://doi.org/10.1007/s10668-022-02827-0

30. Lyeonov, S., Artyukhov, A., Bokenchina, L., Sitenko, D., Yehorova, Y., Zhytar, M., & Moroz, A. (2025a). The role of feed-in tariffs in encouraging insurance companies to invest in renewables. *Insurance Markets and Companies, 16*(1), 115-130. https://doi.org/10.21511/ins.16(1).2025.10

31. Lyeonov, S., Kulawiecka, E., Krawczyk, D., & Oláh, J. (2025b). Decarbonisation and informality: Empirical evidence on the shadow economy response to climate policy mix. *Economics and Sociology, 18*(3), 274-295. https://doi.org/10.14254/2071-789X.2025/18-3/15

32. Lyeonov, S., Toušek, Z., Bozhenko, V., & Kérmárki-Gally, S. E. (2023). The impact of corruption in climate finance on achieving net zero emissions. *Journal of International Studies, 16*(1), 142-159. https://doi.org/10.14254/2071-8330.2023/16-1/10

33. Manaf, B., Djakons, D., & Bilokon, D. (2025). The impact of Chinese foreign direct investment on US industry. *Financial Markets, Institutions and Risks, 9*(2), 1-34. https://doi.org/10.61093/fmir.9(2).1-34.2025

34. Mansour, M., Albawwat, A., Marei, A., Mujahed, M., & Nofal, M. (2026). The impact of board governance effectiveness on carbon disclosure in the banking sector. *Banks and Bank Systems, 21*(1), 97-109. https://doi.org/10.21511/bbs.21(1).2026.08

35. Maralov, A., Kurmanov, N., Kirichok, O., Amerkhanova, A., Moldakenova, Y., Shayakhmetova, S., & Karimbayeva, G. (2024). Environmental, social, and governance (ESG) practice and company performance: Evidence from telecommunication sector. *Journal of Infrastructure, Policy and Development, 8*(8), Article 7519. https://doi.org/10.24294/jipd.v8i8.7519

36. Marozva, G., Makoni, P. L., & Golpet, M. K. (2026). Addressing socioeconomic challenges in Sub-Saharan Africa: Insights from the financial inclusion, institutional quality, and economic growth nexus. *SocioEconomic Challenges, 10*(1), 140-156. https://doi.org/10.61093/sec.10(1).140-156.2026

37. Masyk, M., Buryk, Z., Radchenko, O., Saienko, V., & Dziurakh, Y. (2023). Criteria for governance institutional effectiveness and quality in the context of sustainable development tasks. *International Journal for Quality Research, 17*(2), 501-514. https://doi.org/10.24874/IJQR17.02-13

38. Megbowon, E. T., & Zerihun, M. F. (2025). Government health expenditure gap analysis: A study on the commitment to international agreement and the role of economic and institutional factors. *Health Economics and Management Review, 6*(1), 95-109. https://doi.org/10.61093/hem.2025.1-06

39. Mshana, S., & Postrzednik-Lotko, K. (2026). Use of modern technologies for development of sustainable tourism in Tanzania. *Green Transition and Sustainable Development, 2*(1), 40-64. https://doi.org/10.61093/gtsd.2(1).40-64.2026

40. Mukhtarov, S., Aliyev, J., Borowski, P. F., & Disli, M. (2023). Institutional quality and renewable energy transition: Empirical evidence from Poland. *Journal of International Studies, 16*(3), 208-218. https://doi.org/10.14254/2071-8330.2023/16-3/12

41. Munich Re. (2025, January 9). *Climate change is showing its claws: The world is getting hotter, resulting in severe hurricanes, thunderstorms and floods* [Press release]. Retrieved from https://www.munichre.com/en/company/media-relations/media-information-and-corporate-news/media-information/2025/natural-disaster-figures-2024.html

42. Munich Re. (2026, January 13). *Climate change presses on: Devastating wildfires and intense thunderstorms exacerbate losses for insurers* [Press release]. Retrieved from https://www.munichre.com/en/company/media-relations/media-information-and-corporate-news/media-information/2026/natural-disaster-figures-2025.html

43. Mursalov, M., Mammadov, H., & Bulhak, A. (2025). Research on influence of foreign direct investment on sustainable development of a country. *Financial Markets, Institutions and Risks, 9*(3), 171-196. https://doi.org/10.61093/fmir.9(3).171-196.2025

44. Nguyen, H., Feng, A., & Garcia-Escribano, M. (2025). Understanding the macroeconomic effects of natural disasters. *IMF Working Papers, 2025*(046). https://doi.org/10.5089/9798229001939.001

45. Nihal, A., Areche, F. O., Araujo, V. G. O. S., & Ober, J. (2024). Synergistic evaluation of energy security and environmental sustainability in BRICS geo-political entities: An integrated index framework. *Equilibrium. Quarterly Journal of Economics and Economic Policy, 19*(3), 793-839. https://doi.org/10.24136/eq.3088

46. Notre Dame Global Adaptation Initiative (ND-GAIN). (2026). *Country Index* (2026 release). [Data set]. University of Notre Dame. Retrieved from https://gain.nd.edu/our-work/country-index/

47. Noy, I. (2009). The macroeconomic consequences of disasters. *Journal of Development Economics, 88*(2), 221-231. https://doi.org/10.1016/j.jdeveco.2008.02.005

48. Oe, H., Yamaoka, Y., & Weeks, M. (2025). Public-private partnerships in traditional industries: A comparative governance framework for regional revitalization in Japan and Central Europe.

Public Governance, Regulation and Law, 1(1), 1-15. https://doi.org/10.61093/pgrl.1(1).1-15.2025

49. Omeir, A. K., & Vasiliauskaite, D. (2025). Climate change challenges in central banking: A systematic review with bibliometric and content analysis. *Banks and Bank Systems, 20*(2), 206-222. https://doi.org/10.21511/bbs.20(2).2025.17

50. Patnaik, B., & Hedau, A. (2026). Sustainable infrastructure investment: Financial drivers, policy dynamics and socio-economic challenges. *SocioEconomic Challenges, 10*(1), 27-41. https://doi.org/10.61093/sec.10(1).27-41.2026

51. Pimenow, S., Pimenowa, O., Sitnicki, M. W., Dluhopolskyi, O., & Zieliński, M. (2026). Energy use, costs and economic resilience of EU agriculture: The role and potential of CAP eco-schemes in reducing energy intensity. *Energies, 19*(4), Article 1016. https://doi.org/10.3390/en19041016

52. Prayogi, M. A., Fahmi, M., Zurriah, R., Amaliah, N., & Siagian, A. D. (2025). The mediating job crafting and organizational resilience in linking information technology capabilities with sales performance: An empirical study from Indonesia. *Innovative Marketing, 21*(1), 182-196. https://doi.org/10.21511/im.21(1).2025.15

53. Prokopenko, O., Komarnytska, H., Iankovets, T., Marukhlenko, O., & Protsiuk, N. (2026). Public-private partnership mechanisms in financing smart city projects. *Journal of Applied Economic Sciences, 21*(2), 659-676. https://doi.org/10.57017/jaes.v21.4(92).15

54. Prokopenko, O., Koval, V., Yereshko, J., Kuzkin, O., Skibina, T., & Travin, V. (2024). Economic and environmental limitations of sustainable energy transition in Europe. *Problemy Ekorozwoju, 19*(2), 66-80. https://doi.org/10.35784/preko.5574

55. Prokopenko, O., Kurbatova, T., Khalilova, M., Zerkal, A., Prause, G., Binda, J., Berdiyorov, T., Klapkiv, Y., Sanetra-Półgrabi, S., & Komarnitskyi, I. (2023). Impact of investments and R&D costs in renewable energy technologies on companies' profitability indicators: Assessment and forecast. *Energies, 16*(3), Article 1021. https://doi.org/10.3390/en16031021

56. Redko, K., Borychenko, O., Cherniavskyi, A., Saienko, V., & Dudnikov, S. (2023). Comparative analysis of innovative development strategies of fuel and energy complex of Ukraine and the EU countries: International experience. *International Journal of Energy Economics and Policy, 13*(2), 301-308. https://doi.org/10.32479/ijeep.14035

57. Saher, L., Vakulenko, I., & Oleksich, Z. (2025). What makes growth inclusive? Cluster-based insights for EU member states. *Business Ethics and Leadership, 9*(3), 275-289. https://doi.org/10.61093/bel.9(3).275-289.2025

58. Santos Silva, J. M. C., & Tenreyro, S. (2006). The log of gravity. *The Review of Economics and Statistics, 88*(4), 641-658. https://doi.org/10.1162/rest.88.4.641

59. Sarasi, V., Helmi, A., & Kaltum, U. (2025). Unlocking the nexus of supply chain efficiency in electric vehicle markets: A system thinking approach. *Innovative Marketing, 21*(3), 31-46. https://doi.org/10.21511/im.21(3).2025.03

60. Sarwar, S., Gowindasamy, M., Ashraf, S., & Kashif, I. (2026). Remote work challenges in the knowledge economy: The mediating role of family motivation in well-being and leadership trust dynamics. *Knowledge Economy and Lifelong Learning, 2*(1), 34-47. https://doi.org/10.61093/kell.2(1).34-47.2026

61. Sharma, C. (2012). Determinants of PPP in infrastructure in developing economies. *Transforming Government: People, Process and Policy, 6*(2), 149-166. https://doi.org/10.1108/17506161211246908

62. Shmygol, N., Glushchevsky, V., Cherniavska, O., Sembiyeva, L., Byrskyi, V., Khoroshun, V., & Merzhynskyi, Y. (2024). Determining the leaders of Ukraine's insurance market based on the adaptation of the DEA method. *Insurance Markets and Companies, 15*(2), 14-25. https://doi.org/10.21511/ins.15(2).2024.02

63. Shygun, M., & Bezverkhyi, K. (2026). Sustainability reporting as a tool for corporate social responsibility. *European Journal of Sustainable Development Research, 10*(1), Article em0337. https://doi.org/10.29333/ejosdr/17274

64. Streimikiene, D., Mikalauskas, I., Lėckienė, V., Pisula, T., & Mikalauskiene, A. (2024). The role of sustainable finance in the context of the European Green Course. *Economics and Sociology, 17*(2), 54-79. https://doi.org/10.14254/2071-789X.2024/17-2/3

65. Swiss Re Institute. (2026). *Natural catastrophes in 2025: The persistent rise of wildfire and storm risk* (sigma No. 1/2026). Retrieved from https://www.swissre.com/institute/research/sigma-research/sigma-2026-01-natcat-2025-wildfire-storm-risk.html

66. Taliouris, E., & Trihas, N. (2026). Policy and governance for corporate social responsibility and sustainable tourism: An EU policy analysis and its impact in Greece. *Public Governance, Regulation and Law, 2*(1), 51-65. https://doi.org/10.61093/pgrl.2(1).51-65.2026

67. Tessema, D. B. (2025). Pillars of organizational transformation and sustainability: Leadership, learning, culture, and knowledge management as key success factors in environmental public health. *Health Economics and Management Review, 6*(1), 1-21. https://doi.org/10.61093/hem.2025.1-01

68. Topazly, R., Stadniichuk, R., Liubokhynets, L., Shuprudko, N., Zhosan, H., & Plietnov, M. (2026). Institutional trust and governance effectiveness as mediators in transforming digital maturity into post-war infrastructure recovery. *Business Ethics and Leadership, 10*(1), 188-206. https://doi.org/10.61093/bel.10(1).188-206.2026

69. Tsymbal, L., & Demediuk, A. (2025). Economic security of Ukraine under war: A foreign trade perspective. *Safety and Security Advances, 1*(1), 63-78. https://doi.org/10.61093/ssa.1(1).63-78.2025

http://dx.doi.org/10.21511/ee.17(3).2026.13

70. Vakhovych, I., Pohuliaiko, Y., Al-Shirawi, T., & Smolych, D. (2026). Statistical examination of social infrastructure in Ukraine's border regions. *Journal of Statistics Applications and Probability, 15*(1), 1-9. https://doi.org/10.18576/jsap/150101

71. Vasylieva, T., Derkacz, A., Popp, J., & Horsch, A. (2025a). From energy dependency to energy security: How the war in Ukraine accelerated renewable deployment in Europe. *Economics and Sociology, 18*(3), 229-253. https://doi.org/10.14254/2071-789X.2025/18-3/13

72. Vasylieva, T., Vakulenko, I., & Horsch, A. (2025b). The impact of electricity price shocks triggered by russia's invasion of Ukraine on inflation in European countries: Insights for public governance. *Problems and Perspectives in Management, 23*(4), 486-512. https://doi.org/10.21511/ppm.23(4).2025.35

73. Wojciechowski, W., Niewiadomski, A., & Bilan, Y. (2025). Ecological and secure electricity microgrids-Monitoring and forecasting challenges. *Human Technology, 21*(3), 469-473. https://doi.org/10.14254/1795-6889.2024.21-3.0

74. World Bank, Government of Ukraine, European Commission, & United Nations. (2026). *Ukraine: Fifth rapid damage and needs assessment (RDNA5), February 2022 – December 2025*. World Bank Group. Retrieved from https://www.worldbank.org/en/news/press-release/2026/02/23/updated-ukraine-recovery-and-reconstruction-needs-assessment-released

75. World Bank. (2025). *Private participation in infrastructure (PPI): 2024 annual report*. World Bank Group. Retrieved from https://ppi.worldbank.org/content/dam/PPI/documents/PPI_2024_Annual_Report.pdf

76. World Bank. (2024). *Private Participation in Infrastructure (PPI) Database* (2024 release) [Data set]. Retrieved from https://ppi.worldbank.org

77. World Bank. (n.d.). *World Development Indicators* [Data set]. Retrieved from https://databank.worldbank.org/source/world-development-indicators

78. World Economic Forum. (2019, April 11). *The world is facing a $15 trillion infrastructure gap by 2040. Here's how to bridge it*. Retrieved from https://www.weforum.org/stories/2019/04/infrastructure-gap-heres-how-to-solve-it/

79. Yefimenko, A., Boronos, V., Serpeninova, Y., & Koldovskyi, A. (2025). Innovative and technological determinants of corruption reduction: How do knowledge and technology contribute to public integrity and transparency? *Knowledge Economy and Lifelong Learning, 1*(1), 21-34. https://doi.org/10.61093/kell.1(1).21-34.2025

80. Yeremenko, O. (2026). Retraining and lifelong learning as an anti-crisis tool: Preserving Ukraine's intellectual capital in times of war. *Knowledge Economy and Lifelong Learning, 2*(1), 48-66. https://doi.org/10.61093/kell.2(1).48-66.2026

81. Zahorodnia, K., Uhabakin, O., Titov, E., & Tverdovska, Z. (2026). Inclusive employment as a factor of social security: Enterprise readiness to employ persons with disabilities in Ülemiste City, Estonia. *Safety and Security Advances, 2*(1), 81-107. https://doi.org/10.61093/ssa.2(1).81-107.2026

APPENDIX A. Sample composition: 129 developing and emerging economies

Table A1. Sample composition by country: Income group, PPP closures, and major-disaster country-years, 2000–2024

ISO3	Inc	Proj	Maj	ISO3	Inc	Proj	Maj	ISO3	Inc	Proj	Maj
AFG	LIC	7	0	GUY	UMIC	2	2	PLW	UMIC	1	0
AGO	LMIC	16	0	HND	LMIC	35	2	PNG	LMIC	1	0
ALB	UMIC	30	0	HTI	LIC	5	3	PRK	LIC	1	0
ARG	UMIC	112	0	IDN	LMIC	111	0	PRY	UMIC	5	0
ARM	UMIC	34	1	IND	LMIC	1194	1	PSE	LMIC	2	0
AZE	UMIC	10	1	IRN	UMIC	11	0	RUS	UMIC	168	0
BDI	LIC	4	0	IRQ	UMIC	13	0	RWA	LIC	19	0
BEN	LIC	12	0	JAM	UMIC	17	3	SDN	LMIC	5	0
BFA	LIC	9	1	JOR	UMIC	45	0	SEN	LMIC	32	0
BGD	LMIC	85	2	KAZ	UMIC	27	0	SLB	LMIC	3	1
BGR	UMIC	140	2	KEN	LMIC	37	0	SLE	LIC	7	0
BIH	UMIC	7	3	KGZ	LMIC	6	0	SLV	LMIC	12	3
BLR	UMIC	9	0	KHM	LMIC	33	3	SOM	LIC	8	2
BLZ	UMIC	5	3	KNA	UMIC	1	1	SRB	UMIC	18	1
BOL	LMIC	8	4	LAO	LMIC	33	4	SSD	LIC	2	0
BRA	UMIC	1254	0	LBN	UMIC	7	0	STP	LMIC	2	0
BTN	LMIC	3	0	LBR	LIC	6	0	SUR	UMIC	1	0
BWA	UMIC	8	0	LBY	UMIC	1	1	SWZ	LMIC	1	0
CHN	UMIC	1875	0	LCA	UMIC	1	2	SYC	UMIC	2	0
CIV	LMIC	20	0	LKA	UMIC	76	1	SYR	LIC	6	0
CMR	LMIC	18	0	LSO	LMIC	4	0	TCD	LIC	7	1
COD	LIC	11	0	MAR	LMIC	32	0	TGO	LIC	11	0
COG	LMIC	5	0	MDA	LMIC	7	2	THA	UMIC	135	1
COL	UMIC	155	0	MDG	LIC	12	3	TJK	LIC	6	5
COM	LMIC	2	0	MDV	UMIC	4	0	TLS	LMIC	3	0
CPV	LMIC	4	0	MEX	UMIC	267	0	TON	UMIC	4	3
CRI	UMIC	19	0	MKD	UMIC	9	0	TUN	LMIC	15	0
CUB	UMIC	3	4	MLI	LIC	7	0	TUR	UMIC	279	0
DJI	LMIC	8	0	MMR	LMIC	11	2	TZA	LIC	35	0
DOM	UMIC	49	1	MNE	UMIC	7	0	UGA	LIC	40	0
DZA	UMIC	31	0	MNG	LMIC	5	2	UKR	LMIC	108	0
ECU	UMIC	30	1	MOZ	LIC	22	3	URY	UMIC	6	0
EGY	LMIC	63	0	MRT	LMIC	3	0	UZB	LMIC	24	0
ETH	LIC	7	1	MWI	LIC	5	3	VCT	UMIC	1	7
FJI	UMIC	3	7	MYS	UMIC	87	0	VEN	UMIC	5	0
GAB	UMIC	19	0	NAM	UMIC	9	0	VNM	LMIC	160	5
GEO	UMIC	41	1	NER	LIC	2	2	VUT	LMIC	2	1
GHA	LMIC	29	0	NGA	LMIC	62	0	WSM	UMIC	1	1
GIN	LIC	7	0	NIC	LMIC	25	2	XKX	UMIC	7	0
GMB	LIC	4	0	NPL	LIC	40	1	YEM	LIC	6	1
GNB	LIC	1	0	PAK	LMIC	99	4	ZAF	UMIC	133	0
GNQ	UMIC	1	0	PER	UMIC	177	1	ZMB	LMIC	14	0
GTM	UMIC	23	2	PHL	LMIC	170	1	ZWE	LMIC	7	4

Note: ISO3 – country codes; Inc – World Bank income group (LIC = low income, LMIC = lower middle income, UMIC = upper middle income); Proj – total PPP financial closures, 2000–2024; Maj – number of country-years with climate-related damage of at least 1% of GDP, both in current USD. Totals: 8,213 projects and 119 major-disaster country-years.

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APPENDIX B. Pairwise correlations of the main variables

Table B1. Pairwise correlations of the main variables, balanced panel, 2000–2024

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1) Vulnerability	1.00															
(2) Readiness	−0.47	1.00														
(3) ND-GAIN index	−0.85	0.86	1.00													
(4) Disasters, count	−0.11	0.08	0.11	1.00												
(5) ln Damage	−0.20	0.12	0.18	0.57	1.00											
(6) Regulatory quality	−0.42	0.63	0.62	0.09	0.10	1.00										
(7) Rule of law	−0.26	0.65	0.54	−0.05	−0.01	0.81	1.00									
(8) Gov. effectiveness	−0.44	0.67	0.65	0.10	0.13	0.84	0.82	1.00								
(9) ln GDP per capita	−0.67	0.60	0.74	−0.00	0.11	0.51	0.48	0.61	1.00							
(10) GDP growth	0.05	−0.00	−0.03	0.07	0.01	0.01	−0.01	−0.01	−0.07	1.00						
(11) Inflation	0.02	−0.13	−0.09	−0.01	−0.01	−0.22	−0.17	−0.17	−0.06	−0.11	1.00					
(12) Trade openness	−0.13	0.23	0.21	−0.19	−0.11	0.17	0.20	0.18	0.24	0.08	−0.09	1.00				
(13) FDI, % GDP	−0.02	0.10	0.07	−0.11	−0.07	0.12	0.15	0.10	0.08	0.10	−0.03	0.34	1.00			
(14) ln Population	−0.11	−0.23	−0.08	0.54	0.40	−0.16	−0.44	−0.19	−0.25	0.07	0.09	−0.43	−0.26	1.00		
(15) Internet users	−0.53	0.50	0.60	0.02	0.06	0.37	0.28	0.49	0.59	−0.14	−0.02	0.17	0.00	−0.05	1.00	
(16) CO2 per capita	−0.17	0.26	0.25	−0.02	−0.00	0.10	0.25	0.12	0.32	−0.06	−0.02	0.17	0.08	−0.22	0.27	1.00

Note: Lower triangle of pairwise Pearson correlations, balanced panel, 2000–2024; coefficients rounded to two decimals. High correlations of the composite ND-GAIN index with its components (−0.85; 0.87) and within the WGI block (0.81–0.84) motivate the use of vulnerability and readiness separately and of a single governance dimension (regulatory quality) in the main specifications.

APPENDIX C. Moderation of post-disaster responses by climate readiness and vulnerability

Table C1. Readiness interactions

Variable	(1) Any PPP	(2) N projects (PPML)	(3) ln Investment	(4) Renewable share
Major (t − 1)	−0.042	−0.066	−0.205	0.127
	(0.045)	(0.122)	(0.241)	(0.066)
Readiness (centered)	0.102	1.421	1.187	0.345
	(0.282)	(1.331)	(2.062)	(0.264)
Major (t − 1) × Readiness	0.482	2.866	1.735	−1.401
	(0.604)	(2.541)	(3.503)	(0.943)
ln GDP per capita	0.000	−0.403	0.233	−0.119
	(0.059)	(0.266)	(0.381)	(0.135)
GDP growth	0.003	0.007	0.010	−0.007
	(0.002)	(0.010)	(0.007)	(0.004)
ln population	0.380**	1.123*	2.070**	0.257
	(0.145)	(0.537)	(0.748)	(0.242)
WGI regulatory quality	0.203**	0.444	1.333***	0.016
	(0.060)	(0.380)	(0.357)	(0.073)
Trade openness	0.002*	0.006	0.007	0.001
	(0.001)	(0.004)	(0.004)	(0.001)
FDI, % GDP	0.002	0.010	0.027*	0.003
	(0.002)	(0.008)	(0.013)	(0.005)
Country & year FE	yes	yes	yes	yes
Observations	2,348	2,292	2,302	986
R^2	0.398	–	0.560	0.374

Note: Readiness is the ND-GAIN readiness score centered at the sample mean (SD = 0.078). Column (2): Poisson pseudo-maximum likelihood; 56 observations dropped due to separation. Column (4): project-years; 10 singleton fixed effects dropped. Standard errors clustered by country in parentheses. * p < 0.05, ** p < 0.01, *** p < 0.001. None of the disaster–readiness interactions is statistically significant.

Table C2. Vulnerability interactions

Variable	(1) Any PPP	(2) N projects (PPML)	(3) ln Investment	(4) Renewable share
Major (t–1)	−0.052	−0.073	−0.231	0.120
	(0.043)	(0.188)	(0.255)	(0.065)
Vulnerability (centered)	0.730	10.850	0.096	3.460
	(1.139)	(6.494)	(5.599)	(1.835)
Major (t–1) × Vulnerability	0.333	1.663	0.586	−0.058
	(0.883)	(2.752)	(3.907)	(0.976)
ln GDP per capita	0.016	−0.286	0.267	−0.036
	(0.061)	(0.220)	(0.375)	(0.149)
GDP growth	0.003	0.008	0.011	−0.007
	(0.002)	(0.010)	(0.008)	(0.004)
ln population	0.374**	1.345*	1.981**	0.245
	(0.142)	(0.586)	(0.716)	(0.245)
WGI regulatory quality	0.207**	0.600*	1.406***	0.026
	(0.063)	(0.294)	(0.386)	(0.075)
Trade openness	0.002*	0.006	0.007	0.001
	(0.001)	(0.004)	(0.004)	(0.001)
FDI, % GDP	0.002	0.011	0.027*	0.004
	(0.002)	(0.008)	(0.013)	(0.005)
Country & year FE	yes	yes	yes	yes
Observations	2,348	2,292	2,302	986
R^2	0.398	–	0.559	0.377

Note: The moderator is the ND-GAIN vulnerability score centered at the sample mean (SD = 0.075). Column (2): Poisson pseudo-maximum likelihood; column (4): project-years. Standard errors clustered by country in parentheses. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. None of the disaster–vulnerability interactions is statistically significant.

APPENDIX D. Catastrophic disasters (damage of at least 5% of GDP) and PPP closures around them

Table D1. Catastrophic disasters and PPP closures in the surrounding years

ISO3	Year	Damage, %	t–1	t	t+1	ISO3	Year	Damage, %	t–1	t	t+1
ARM	2000	5.23	n/a	1	3	NIC	2020	7.22	0	0	0
BLZ†	2000	24.38	n/a	0	1	SLV	2009	5.49	0	0	0
BLZ†	2001	21.33	0	1	1	SOM	2021	10.47	1	0	0
CUB‡	2008	6.34	0	0	0	THA	2011	10.87	7	9	22
FJI†‡	2016	12.17	0	0	1	TJK	2000	6.62	n/a	0	1
GEO	2000	6.54	n/a	8	0	TJK	2008	16.27	0	1	0
GUY†	2005	56.38	0	0	0	TON†	2001	28.32	3	0	0
GUY†	2006	7.10	0	0	0	TON†	2014	7.03	0	0	0
HTI	2016	14.83	0	0	0	TON†	2020	21.91	0	0	0
JAM‡	2004	8.80	1	0	0	VCT†‡	2004	7.27	0	0	0
LBY	2023	14.08	0	1	0	VCT†‡	2010	6.66	0	0	0
MDA‡	2007	9.22	0	0	0	VCT†‡	2013	14.12	0	0	0
MMR‡	2008	12.55	0	0	0	VCT†‡	2024	19.93	0	0	n/a
MNG‡	2000	7.04	n/a	0	0	VUT†	2015	52.54	0	0	0
MOZ	2000	7.09	n/a	0	0	WSM†	2012	17.20	0	0	0
MOZ	2019	14.38	0	1	1						

Note: Damage in percent of GDP, with damage and GDP in current USD. Closures in the year before (t−1), the year of (t), and the year after (t+1) the event; n/a where the year lies outside the panel. † micro-state (mean population below one million); ‡ country without any closure in the estimation window, dropped from the Poisson sample by separation, so the event does not contribute to Table 5.

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APPENDIX E. Pre-trend diagnostics for the event-study specification

Table E1. Event-study estimates with sub-threshold controls and strict isolation

Variable	(1) Isolated events, sub-threshold controls	(2) Strict isolation	(3) Strict isolation, excl. micro-states
Major (t − 2)	0.279	0.403**	0.389**
	(0.171)	(0.127)	(0.128)
Major (t − 1)	−0.142	−0.139	−0.135
	(0.135)	(0.146)	(0.147)
Major (t)	−0.242	−0.052	−0.051
	(0.215)	(0.174)	(0.175)
Major (t + 1)	−0.295	−0.199	−0.198
	(0.202)	(0.204)	(0.205)
Major (t + 2)	−0.408	−0.291	−0.289
	(0.219)	(0.229)	(0.231)
Major (t + 3)	−0.323*	−0.337	−0.347
	(0.158)	(0.183)	(0.185)
ln damage (t)	0.002	–	–
	(0.008)		
Climate disasters, count (t)	0.000	–	–
	(0.004)		
ln damage (t–1)	0.002	–	–
	(0.009)		
Controls	yes	yes	yes
Country & year FE	yes	yes	yes
Observations	1,951	1,951	1,725
Wald test, post-event = t–1 (p-value)	0.565	0.673	0.636
Isolated events in the estimation window	46	41	35

Note: PPML estimates; dependent variable: number of PPP closures. Column (1) adds ln(1 + damage) and the number of climate disasters in the current year and ln(1 + damage) in the previous year to the specification of Table 4, column (2). Columns (2)–(3) define an isolated event as a major disaster with no damage of at least 0.5% of GDP in the preceding three years (41 events; 35 outside micro-states). The Wald test compares the three post-event coefficients jointly with the one-year lead. Placebo inference (300 random reassignments of event years within countries) yields a standard deviation of 0.31 for both the first lead and the first lag; 65% of placebo first-lead and 36% of placebo first-lag estimates exceed the observed coefficients in absolute value. Controls as in Table 4. Standard errors clustered by country. Observations dropped due to separation: 124/124/116. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.