Scilight

Journal of Hazards, Risk and Resilience
https://www.sciltp.com/journals/jhrr



Article

Risk Finance for a Disaster-Resilient Society: Ex-ante Investments in Japan and a Hybrid SFDRR–ISO 37116 Framework

Yoshiki Hiruma [1,2,*], Kenji Omi [3], Satoru Nishikawa [4,5] and Kimiro Meguro [2,6]

[1] Development Bank of Japan Inc., Otemachi Financial City South Tower, 9-6 Otemachi 1-Chome, Chiyoda-ku, Tokyo 100-8178, Japan
[2] Institute of Industrial Science, The University of Tokyo, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8505, Japan
[3] Overseas Research Division, Industrial Department, DBJ Institute, Inc., Otemachi Financial City Grand Cube, 9-2 Otemachi 1-Chome, Chiyoda-ku, Tokyo, 100-0004, Japan
[4] International Research Institute of Disaster Science (IRIDeS), Tohoku University, 468-1 Aoba, Aramaki, Aoba-ku, Sendai 980-8572, Japan
[5] Japan International Cooperation Agency, 5-25 Niban-cho, Chiyoda-ku, Tokyo 102-8012, Japan
[6] Interfaculty Initiative in Information Studies, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan
* Correspondence: yohirum@dbj.jp

How To Cite: Hiruma, Y.; Omi, K.; Nishikawa, S.; et al. Risk Finance for a Disaster-Resilient Society: Ex-ante Investments in Japan and a Hybrid SFDRR–ISO 37116 Framework. *Journal of Hazards, Risk and Resilience* **2026**, *1*(1), 31. https://doi.org/10.53941/jhrr.2026.100031

Received: 30 April 2026
Revised: 9 September 2026
Accepted: 5 October 2026
Published: 19 November 2026

Abstract: Approximately 96% of global disaster expenditures still flow to ex-post response, despite policy arguments—notably Sendai Framework (SFDRR) Priority 3—for redirecting capital toward ex-ante investment. This paper asks: (RQ1) what structural limitations make this shift imperative; (RQ2) whether company-level ex-ante investment in Japan yields financial benefits; and (RQ3) how SFDRR macro indicators can be integrated with the micro-level process requirements of ISO 37116:2026. Answering RQ1, probabilistic, expected-annual-damage-based benefit-cost analysis, extended by recovery-curve and spatial-CGE frameworks, emerges as the most suitable evaluation approach. We combine a historical review of international risk-finance policy with a within-industry case study of Alps Electric against six non-rated Japanese electronics peers affected by the 2011 Great East Japan Earthquake. Answering RQ2, the rated company's extraordinary losses (≈USD 17 million) fell below both the peer median (≈USD 86 million) and mean (≈USD 200 million), and its quarterly revenue recovered above baseline by Q2 FY2011, while peers remained below baseline through Q3 FY2012. Given the single-treated-unit design, these patterns are descriptive evidence consistent with—not a causal test of—the Tatano–Tsuchiya recovery-curve mechanisms (attenuated $\Delta Y0$, higher γ). Answering RQ3, to scale ex-ante investment internationally, we propose a hybrid SFDRR × ISO 37116 framework with five implementation pathways—blended finance, sovereign finance, critical infrastructure, corporate and retail finance, and (re)insurance—offering common measurement infrastructure to narrow the Asia-Pacific protection gap. Together, these answers point to long-term measures for both sectors: governments embedding verified ex-ante investment into fiscal and regulatory conditionality, and companies and financial institutions translating resilience into financing terms. Large-sample econometric validation remains a priority. Importantly, ex-ante investment reduces and reshapes—but does not eliminate—disaster risk; the proposed framework is therefore designed to complement, rather than replace, the layered instruments that finance residual risk, including reserves, insurance, reinsurance, contingent credit, and sovereign backstops.

Copyright: © 2026 by the authors. This is an open access article under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).
Publisher's Note: Scilight stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Keywords: disaster risk finance; ex-ante investment; pre-arranged financing; Sendai Framework for Disaster Risk Reduction; ISO 37116:2026; business continuity management; DBJ DRR-BCM rating; protection gap; residual risk

1. Introduction

Between 2000 and 2024, disasters generated average annual economic losses of approximately USD 324 billion globally, of which the Asia-Pacific region alone accounted for about USD 126 billion—roughly 40% of the world total [1–3]. Yet despite a quarter-century of accumulating evidence on the superior cost-effectiveness of ex-ante risk reduction, an estimated 96% of global disaster-related expenditures continue to flow toward ex-post response, recovery, and indemnity-based insurance payouts, while only a marginal share is allocated to proactive risk mitigation [1]. The precise share varies across accounting frameworks—depending on whether household-level insurance premiums, reinsurance recoveries, and in-kind humanitarian assistance are included—but the broad asymmetry between ex-post and ex-ante finance is consistently documented across OECD DAC and World Bank GFDRR datasets. Underscoring the increasingly systemic character of this risk landscape, the most recent United Nations global assessment counts 350–500 medium- to large-scale disasters per year over the past two decades and projects that this figure will reach approximately 560 events per year—1.5 disasters a day—by 2030 [4].

This imbalance is increasingly incompatible with a world in which climate change, rapid urbanization, and asset concentration in hazard-exposed areas are compounding disaster risk faster than ex-post fiscal and insurance mechanisms can absorb. Over the past decade, international policy has converged toward a fundamental reorientation of disaster-related finance—from ex-post compensation toward ex-ante investment. Three recent instruments illustrate this convergence (Table 1): Priority 3 of the Sendai Framework for Disaster Risk Reduction (SFDRR, 2015) [5], which calls for "investing in disaster risk reduction for resilience"; Paragraph 18 of the G20 DRR Working Group Ministerial Declaration (2025) [6], which explicitly promotes pre-arranged financing for ex-ante DRR and preparedness; and ISO 37116:2026 [7], which codifies principles and general requirements for finance directed at ex-ante investment in risk reduction in cities and communities. Taken together, these instruments signal that ex-ante investment has moved from aspirational language to an operational expectation embedded in global standards. Throughout this paper, we define "disaster risk finance" as ex-ante investment contributing to disaster risk reduction, in line with the ISO 37116 conceptualization. Importantly, ex-ante investment is understood throughout this paper as reducing and reshaping—rather than eliminating—disaster risk: a residual layer of risk necessarily remains after cost-effective mitigation and must continue to be financed through complementary instruments such as reserves, insurance, reinsurance, contingent credit, and sovereign backstops, consistent with the risk-layering principle reviewed in Section 2.2 and revisited in Section 6.

Table 1. Evolution of the Concept and Definition of Disaster Risk Finance in International Policy Instruments.

Document/Declaration	Section	Concept/Definition	Year
UN SFDRR	Priority 3	Investing in disaster risk reduction for resilience	2015
G20 Disaster Risk Reduction Ministerial Declaration	Paragraph 18	We encourage the scaling up and greater use of affordable, inclusive pre-arranged financing, to facilitate ex-ante DRR and preparedness for rapid, flexible, comprehensive and equitable disaster response and recovery.	2025
ISO 37116 Risk Finance	Risk finance, Definition	This document provides organizations seeking or providing finance with principles and general requirements for finance for ex-ante investment in risk reduction, including preparedness for disasters, in cities and communities.	2026

Three research gaps remain, however, despite this policy convergence. First, company-level empirical evidence on the financial return of ex-ante disaster-risk investment is scarce; most of the existing literature operates at macro-economic or national scales, or remains confined to qualitative case reports. Second, although the SFDRR and ISO 37116 share a common orientation toward ex-ante investment, no prior study has systematically examined their operational integration—that is, how the macro-level monitoring indicators of the SFDRR can be coupled with the micro-level process requirements of ISO 37116 to yield a workable evaluation framework for practitioners and financiers. Third, although the Asia-Pacific region accounts for roughly 40% of global disaster losses, it remains comparatively underrepresented in the disaster-risk-finance literature, which has historically been shaped by Euro-Atlantic case evidence [2].

Corresponding to These Gaps, This Paper Addresses Three Research Questions

- RQ1 (structural): What historical dynamics of international policy and global financial markets produced the structural limitations of the prevailing ex-post compensation model, and which cost-effectiveness methodologies are best suited to evaluate ex-ante alternatives?
- RQ2 (empirical): Does company-level ex-ante DRR-BCM investment generate measurable financial benefits in the form of contained post-event losses and accelerated revenue recovery, as illustrated by DRR-BCM-rated Japanese enterprises during the 2011 Great East Japan Earthquake?
- RQ3 (normative): How can the SFDRR evaluation indicators be integrated with the requirements of ISO 37116 to form a coherent measurement infrastructure, and what concrete funding mechanisms can translate such a framework into mobilized capital flowing from international cooperation into private financial markets?

Our contribution is threefold. (i) We provide one of the first company-level empirical analyses of the DBJ DRR-BCM program, using publicly disclosed extraordinary losses and quarterly revenue trajectories to document—for the case of Alps Electric relative to six comparable Japanese electronic-component manufacturers—markedly contained post-event losses (≈USD 17 million, against a peer median of ≈USD 86 million and a peer mean of ≈USD 200 million; full peer range USD 13–596 million) and a faster above-baseline revenue recovery. We acknowledge that one peer (Tokyo Electron, ≈USD 13 million) reported nominally lower losses; we discuss this case, together with the right-skewed peer distribution, explicitly in Section 5.2. (ii) We propose a hybrid SFDRR × ISO 37116 framework that combines the macro-level quantitative indicators of the SFDRR with the micro-level process governance of ISO 37116, thereby establishing a common measurement infrastructure for pricing ex-ante resilience in capital markets. (iii) We translate this framework into five sectoral implementation pathways spanning blended finance, sovereign finance, critical-infrastructure investment, corporate and retail finance, and (re)insurance—with particular attention to the Asia-Pacific protection gap.

The paper is organized as follows. Section 2 reviews the historical evolution of international public policy and global financial markets concerning DRR and disaster risk finance, together with methodologies for evaluating cost-effectiveness. Section 3 analyses the structural limitations of the ex-post compensation model. Section 4 reviews the cost-effectiveness literature on ex-ante investments. Section 5 presents the empirical company-level findings from the DBJ DRR-BCM program. Section 6 develops the proposed SFDRR × ISO 37116 framework and its five implementation pathways. Section 7 concludes, discusses limitations and a forward research agenda.

2. History of Disaster Risk Finance

The historical evolution of disaster risk finance is divided here into three phases, demarcated by two institutional turning points. The first is the cluster of mega-catastrophes in the early-to-mid 1990s—notably Hurricane Andrew (1992) and the Great Hanshin-Awaji Earthquake (1995)—which exhausted traditional reinsurance capacity and catalyzed the emergence of Alternative Risk Transfer. The second is the adoption of the Sendai Framework (2015), which elevated ex-ante investment to the central organizing principle of global DRR governance.

2.1. Ex-post Financing by Governments (until the 1980s)

Prior to the 1980s, disaster risk financing was dominated by ex-post mobilization of public funds—budget reallocation, temporary taxation, sovereign borrowing, and international aid—committed only after damage had materialized [8]. Although adequate for small and localized events, this reactive model exhibits three critical limitations in catastrophic contexts: a funding time lag that delays emergency response beyond the critical 72-h window; fiscal volatility, as sudden unbudgeted expenditures disrupt national fiscal planning, particularly in developing economies; and the "Samaritan's Dilemma" [9], whereby expectations of ex-post relief function as implicit guarantees that discourage insurance uptake and ex-ante mitigation, allowing systemic risk to accumulate. Japan's own pre-1990s practice illustrates each instrument type in Table 2: recovery from the 1959 Ise Bay Typhoon—the event that prompted the Disaster Countermeasures Basic Act (1961)—was financed almost entirely ex post, through supplementary budgets and budget reallocation, elevated national subsidy shares, local-government bonds, and tax relief. This framework, built on the Disaster Relief Act (1947) and subsequently systematized under the Act on Special Financial Support for Dealing with Severe Disasters (1962), remained essentially intact into the 1980s. The behavioral consequences of this model are empirically visible: at the time of the 1995 Great Hanshin-Awaji Earthquake, household earthquake-insurance penetration in Japan remained below 10% nationwide (9.0% at the end of FY1994)—and reportedly around 3% in Hyogo Prefecture—despite well-documented seismic risk [10], a pattern consistent with expectations of public relief crowding out private ex-ante protection [9,11].

Table 2. Four Types of Ex-Post Financing by the Government.

Types	Ex Post Financing
Budget Reallocation	The redirection of capital from existing public programs and development budgets to cover ex-post recovery and reconstruction expenditures.
Taxation and Surcharges	The levying of temporary surcharges or special reconstruction taxes on citizens and corporations to generate rapid domestic revenue.
Debt Financing (Sovereign/Municipal Bonds)	The issuance of government or municipal debt instruments to secure immediate liquidity, effectively deferring the financial burden of disaster recovery to future generations.
International Donor Assistance	Reliance on bilateral and multilateral emergency aid from international organizations and donor nations, a modality particularly prevalent in developing economies with limited domestic fiscal capacity.

2.2. Integration with Capital Markets and Risk Transfer (1990s–2000s)

Hurricane Andrew (1992) and the Great Hanshin-Awaji Earthquake (1995) generated losses exceeding the capacity of governments and traditional reinsurance markets, catalyzing Alternative Risk Transfer (ART) and the securitization of catastrophe risk. Three innovations defined this era. First, catastrophe (CAT) bonds mobilized institutional investors as risk underwriters—capital raised from investors is forfeited to fund recovery if predefined triggers are met—with Mexico's CatMex bond (2006) and the World Bank's MultiCat Program (2009) establishing the sovereign model. Second, payout structures shifted from indemnity-based to parametric triggers, trading rapid and transparent disbursement against residual "basis risk". Third, multilateral institutions, led by the World Bank, formalized "risk layering" (Table 3), which hierarchically assigns risk retention, insurance and reinsurance, and capital-market instruments to risk strata according to their frequency and severity [12]—a principle to which this paper returns in its treatment of residual risk in Section 6. The significance of ART lies precisely in this transition: disaster risk, hitherto absorbed almost exclusively by government budgets and (re)insurers' balance sheets, could henceforth also be distributed to capital-market investors. Investor appetite rests on two attributes—high coupon payments, and the low correlation of natural-catastrophe risk with conventional financial-market risks—which make CAT bonds a portfolio diversifier for pension funds and other institutional investors. In practice, parametric triggers and thresholds are defined in the bond documentation by the sponsor together with specialized catastrophe-modeling firms and an independent calculation agent, using physical measurements from recognized scientific agencies (e.g., seismic intensity or wind speed); how such trigger design maps onto the actual needs of affected populations in high-risk areas remains an important—and still under-documented—design issue, which we flag here rather than resolve.

Table 3. Risk Layering Theory.

Layer	Item	Description
Bottom	Characteristics	Small-scale, localized events occur frequently, with return periods of one year or less.
	Financing Strategy (Risk Retention)	Financed through internal contingency budgets and national reserves.
	Rationale	Traditional insurance is cost-prohibitive for high-frequency, predictable events because loading costs and administrative fees disproportionately exceed expected payouts.
Middle	Characteristics	Moderate to severe disasters with return periods of approximately 10 to 100 years.
	Financing Strategy (Contingent Financing)	Addressed via ex-ante contingent credit facilities and multilateral standby loans.
	Rationale	Secures rapid liquidity for medium-severity shocks without the continuous premium burden associated with full risk transfer.
Top	Characteristics	Catastrophic, low-probability events with return periods exceeding approximately 100 years, capable of generating systemic macroeconomic impacts.
	Financing Strategy (Risk Transfer)	Managed through sovereign CAT bonds, parametric insurance, and international reinsurance markets.
	Rationale	Transfers extreme exposures that exceed domestic fiscal capacity to international capital markets.

2.3. An Integrated Approach to DRR Finance and Ex-ante Investment (2015–Present)

The Sendai Framework for Disaster Risk Reduction 2015–2030 (SFDRR), adopted in 2015, elevated ex-ante investment to a central global imperative under Priority 3, "Investing in disaster risk reduction for resilience" [5]. The World Bank's "Triple Dividend of Resilience" supplied the economic rationale, positing that ex-ante DRR investment yields avoided losses, unlocked economic potential, and development co-benefits regardless of whether a disaster occurs [13], with resilience investments estimated to return roughly four times the anticipated cost of ex-post repair [14]. This framework reframed DRR expenditure from a mere "cost" into a strategic investment essential for sustainable growth. Ten years into SFDRR implementation, stocktaking assessments document

tangible progress alongside persistent gaps in early-warning coverage and in the scale of DRR investment, particularly across the Asia-Pacific region [15–17].

Since the late 2010s, climate change has undermined the "stationarity" assumption underlying conventional risk models [18], and disaster risk finance has expanded into the broader framework of Climate and Disaster Risk Finance and Insurance (CDRFI) [19]. In parallel, a rapidly consolidating climate finance literature documents how physical and transition risks are increasingly measured and priced in sovereign and corporate capital markets and embedded in supervisory measurement methodologies [20–26]. Innovative structures have emerged to channel private capital toward ex-ante investment: Resilience Bonds, whose coupons are structurally reduced when the issuer implements verified risk-reduction measures, and blended finance, in which public first-loss tranches crowd in private capital, increasingly linked to National Adaptation Plans and "Build Back Better" conditionalities. Their coverage nevertheless remains concentrated on hydro-meteorological hazards, and sovereign resilience-bond issuance has yet to reach sustained market scale—a gap that itself illustrates the absence of the common measurement infrastructure addressed in this paper. Resilience Bonds are, in this sense, the financing expression of "no-regret" DRR investment: because safer infrastructure, sustained business continuity, reduced uncertainty, and adaptation co-benefits accrue even when no disaster occurs—the first and second dividends of resilience [13]—verified risk reduction can be monetized independently of hazard realization. Finally, pre-arranged finance—the contingent credit lines, sovereign risk pools, parametric sovereign insurance, and CAT bonds promoted by the 2025 G20 DRR Ministerial Declaration [6]—is contractually structured ex-ante but disbursed only ex-post: it compresses the funding time lag and smooths fiscal volatility, yet does not reduce the physical vulnerability that generates losses, and may even reproduce the Samaritan's Dilemma if deployed without a parallel commitment to ex-ante investment. This distinction motivates this paper's narrower, ISO 37116-based definition of disaster risk finance as ex-ante investment contributing to risk reduction, with pre-arranged finance treated as a complement to—not a substitute for—such investment. The scale of this complementary layer is now substantial: international pre-arranged financing reached a record USD 9.4 billion in 2024, driven mainly by contingent credit from multilateral development banks, although low-income and fragile or conflict-affected states each received less than 7% of the total—reinforcing the case for pairing such instruments with ex-ante investment [27].

2.4. Summary

This section has traced the historical evolution of disaster risk finance across three distinct phases. The first phase was characterized by the systemic limitations of traditional government-reliant ex-post financing. The second witnessed the emergence of innovative risk-transfer instruments—including CAT bonds, parametric triggers, and risk layering frameworks—that integrated disaster risk into global capital markets. The third and current phase reflects a paradigm shift toward proactive ex-ante investment, driven by the Sendai Framework, ESG finance, Resilience Bonds, and blended finance mechanisms. Together, these developments have given rise to a maturing financial ecosystem that increasingly aligns private capital flows with the global imperative of disaster risk reduction.

3. Limitations of the Ex-Post Compensation Model

Whereas Section 2 traced the historical evolution of disaster-risk finance across three phases, this section takes a complementary analytical cut by asking why the ex-post compensation model, which dominated the pre-1980s phase and continues to shape current fiscal practice, is structurally unable to absorb the compound risk profile of the 2020s. We examine three mutually reinforcing dimensions—fiscal sustainability, insurance-market insurability, and behavioral-economic moral hazard—and show how their interaction generates a vicious cycle that can only be broken by a structural shift toward ex-ante finance.

3.1. The Current Risk Landscape and Financial Dynamics in the Asia-Pacific Region

The Asia-Pacific region is recognized as one of the world's most hazard-exposed regions. Large-scale catastrophic events have historically inflicted severe economic and social disruptions across various nations. Notable examples include the 2004 Sumatra earthquake in Indonesia, which claimed over 220,000 lives, and Typhoon Yolanda in the Philippines in 2013, resulting in approximately 9000 fatalities and missing persons. More recently, the aggregate damage caused by disasters has intensified due to the compounding effects of climate change and rapid urbanization. This escalating vulnerability is evidenced by Typhoon Yagi in Laos (September 2024), the magnitude 7.3 earthquake in Vanuatu (December 2024), and the magnitude 7.7 earthquake centered in Myanmar (March 2025). Between 2000 and 2024, annual economic losses from disasters averaged USD 324 billion globally, with the Asia-Pacific region accounting for a disproportionately large share at USD 126 billion [2,3].

Despite bearing roughly 40% of global disaster losses, the region remains structurally underserved by risk-transfer markets: CAT bond issuance covering Asia-Pacific exposures represents less than 3% of the roughly USD 50 billion global market outstanding, is concentrated in a handful of mature markets (Japan, Australia, mainland China, the Taiwan market, and New Zealand, with the 2019 Philippine sovereign issuance a rare exception), is denominated almost exclusively in U.S. dollars, and relies predominantly on Western investors and Singapore- or Hong Kong-domiciled issuance vehicles [2,3].

This structural underdevelopment is starkly reflected in the region's insurance protection gap: of the USD 74 billion in economic losses inflicted by Asia-Pacific disasters in 2024, only USD 4 billion were insured—a far larger uninsured share than even the global natural-catastrophe protection gap of roughly 56% discussed in Section 3.3 [2,3,28]. The gap is, moreover, twofold: alongside the insurance protection gap, the region faces an ex-ante investment gap. Consistent with the global pattern in which an estimated 96% of disaster-related expenditure flows to ex-post response and only a marginal share to risk reduction [1], regional investment in risk reduction remains small relative to the scale of annual losses—so that neither the losses themselves nor the investments that would prevent them are adequately financed. Documented aid flows corroborate this asymmetry: only around 0.4% of total international development assistance between 1991 and 2010 was allocated to disaster risk reduction, as against relief and reconstruction [29]. Comparative research on "protection gap entities" in 49 countries reaches a similar conclusion: closing gaps of this magnitude typically requires hybrid, mission-driven insurance arrangements that deliberately blend public and private capacities rather than relying on conventional markets alone [30].

Four systemic bottlenecks hinder deeper market penetration: sovereign prioritization of ex-post recovery financing over ex-ante risk transfer; the limited scale and immaturity of primary insurance markets; deficits in data infrastructure and actuarial loss-assessment capacity; and the substantial structuring and issuance costs of CAT bonds. Together, the region's acute hazard exposure, its outsized and largely uninsured losses, and these structural bottlenecks define the problem space to which the measurement infrastructure proposed in Section 6 responds. For countries that lack the actuarial data and technical infrastructure required for indemnity-based instruments, alternative entry points already exist: parametric sovereign insurance and regional risk pools (e.g., SEADRIF in Southeast Asia and PCRAFI in the Pacific, following the model pioneered by CCRIF in the Caribbean), World Bank-intermediated issuance platforms, and contingent credit lines substantially reduce data requirements, actuarial burden, and fixed issuance costs, and can serve as transitional instruments while domestic data infrastructure and actuarial capacity are progressively built [2].

3.2. The Erosion of Fiscal Sustainability

Historically, within traditional disaster response paradigms, sovereign governments have functioned as the ultimate "insurer of last resort". Under this model, capital for ex-post recovery and reconstruction is mobilized through emergency taxation, sovereign debt issuance, or the reallocation of contingency reserves. This inherently reactive methodology remained viable—effectively smoothing macroeconomic volatility—provided that catastrophic events were perceived as infrequent, exogenous shocks.

However, escalating disaster frequency and severity are eroding this premise. Successive disasters now strike before the debt from preceding recoveries is amortized, depleting sovereign "fiscal space" and—particularly for economies with elevated public debt-to-GDP ratios—raising the risk of credit downgrades and surging borrowing costs. Ex-post mobilization is also acutely uncertain: emergency taxation carries prohibitive political coordination costs and procedural time lags, post-disaster borrowing commands exorbitant risk premiums, and, in the extreme case of a disaster coinciding with a global financial downturn, governments may be effectively excluded from capital markets altogether. Capital markets have begun to price this fiscal erosion directly: climate-vulnerable sovereigns already pay measurably higher borrowing costs, and simulations of climate-adjusted credit ratings indicate that, under high-emission trajectories, rising temperatures could trigger sovereign downgrades—and correspondingly higher interest burdens—within the coming decades [31,32].

3.3. The Systemic Limitations of the Insurance Market and the Boundaries of Insurability

While the private insurance market serves as a highly effective mechanism for risk diversification, it possesses inherent structural limitations. Most critically, there is a fundamental threshold of "insurability"—a point beyond which market mechanisms become untenable due to the extreme scale and high correlation of catastrophic risks. The accelerating impacts of climate change increasingly concentrate disasters within specific geographic regions and timeframes. This spatial and temporal concentration severely undermines the "law of large numbers", a foundational actuarial principle that strictly relies on the statistical independence of risk exposures. Recent syntheses of disaster insurance reach the same conclusion from the market side: conventional indemnity products

alone cannot close the widening gap, and complementary instruments—parametric covers, inclusive insurance, and community-based risk-sharing—are required to extend protection as climate change erodes insurability [33].

To mitigate severe tail risks, reinsurers and capital market participants are compelled to either substantially increase premiums to commercially prohibitive levels or entirely withdraw coverage from highly exposed regions. Empirically, the escalating frequency of hurricanes in Florida and wildfires in California has already precipitated a systematic withdrawal of private insurers, ultimately compelling state-backed insurers of last resort to absorb these substantial exposures. The result is a profound structural vulnerability: the rapid expansion of the global "protection gap" (the share of economic losses not covered by private insurance), which systematically shifts the ultimate financial burden back onto sovereign balance sheets [34,35].

Swiss Re Institute (Sigma 1/2025) reports global insured losses from natural catastrophes of approximately USD 140 billion in 2024—the fourth consecutive year above USD 100 billion—against corresponding economic losses of approximately USD 320 billion, implying a natural-catastrophe protection gap of roughly 56%. When man-made events are included, the corresponding all-cause figures (approximately USD 145 billion insured against approximately USD 368 billion in economic losses) are somewhat higher. Either framing implies a persistent gap of above 55% and a structural compression of insurability by climate-driven non-stationarity [28].

3.4. A Behavioral Economics Perspective: Charity Hazard and Systemic Risk Accumulation

While the Samaritan's Dilemma (Section 2.1) supplies the general public-economics framework, "Charity Hazard" operationalizes it for natural hazards, identifying empirically observable channels—reduced insurance uptake, continued construction in high-risk zones, and lower retrofit rates—through which expectations of generous ex-post relief crowd out private risk reduction [9,11]. Once subsidized reconstruction and low-interest emergency lending become institutionalized, households and enterprises rationally underinvest in catastrophe insurance, seismic retrofitting, and relocation; exposure therefore remains concentrated in high-risk areas, entrenching moral hazard at the individual level while driving systemic risk accumulation at the macroeconomic level.

3.5. Summary: The Vicious Cycle and the Strategic Shift to DRR Financing

The preceding analysis elucidates a systemic vicious cycle, visualized in Figure 1 and detailed in its caption: sovereign compensation guarantees disincentivize private risk reduction ((1)–(2)); unmitigated exposure compounds aggregate societal risk ((3)); catastrophic events then convert inflated exposure into inflated damages, public fiscal distress, and insurer withdrawal ((4)); and residual risk is concentrated back onto the public balance sheet ((5)), feeding the next cycle. Once fiscal capacity and insurability erode simultaneously, the cycle reaches a systemic viability failure point at which neither marginal fiscal reform nor marginal insurance-market deepening can restore equilibrium.

To dismantle this vicious cycle, it is imperative to structurally redirect capital flows away from addressing ex-post funding shortfalls toward ex-ante DRR finance, which proactively mitigates and avoids risks. This transition represents more than a fiscal adjustment; it constitutes a fundamental shift in the conceptual logic of national risk governance, one that mobilizes private capital to build societal resilience.

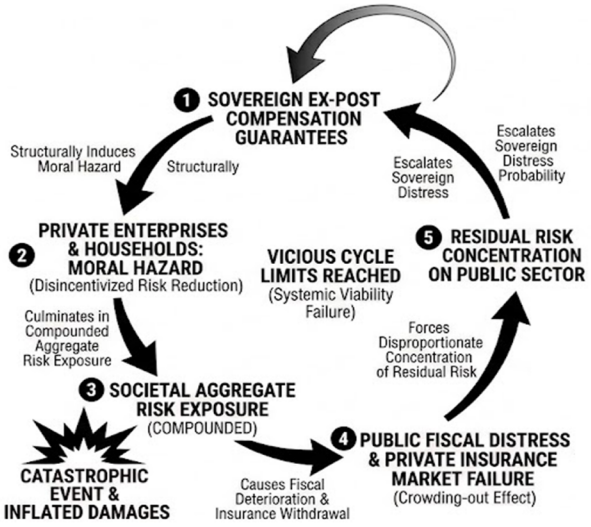


Figure 1. The Vicious Cycle on Ex-post-based Risk Finance.

Sovereign ex-post compensation guarantees (1) structurally disincentivize private-sector ex-ante risk reduction, inducing moral hazard among households and firms (2). Unmitigated exposure compounds aggregate societal risk (3), which manifests as inflated catastrophic damages and concurrent withdrawal of private insurers when an event occurs (4); residual risk is then disproportionately concentrated on the public balance sheet (5), elevating sovereign distress probability and feeding back into (1). Source: authors' synthesis of Sections 2.1, 3.2–3.4.

4. A Review of Cost-Effectiveness Studies on Ex-ante Investments

As the systemic limitations of ex-post compensation models have become increasingly evident, academic and policy discourse regarding the cost-effectiveness of ex-ante investments—designed to mitigate disaster risks prior to their realization—has attracted growing scholarly and policy attention. Macroeconomic modeling reinforces this reorientation: in disaster-prone countries, recurrent weather shocks impose welfare losses equivalent to a permanent 5.3% fall in consumption, and financing resilience before disasters occur is estimated to be more cost-effective for the international community than disbursing aid after they strike [36].

However, the methodological rigor and empirical validation underlying the cost-effectiveness of ex-ante investments remain subjects of ongoing scholarly debate and require further formalization. Accordingly, this section reviews the historical development and current state of quantitative models for cost-benefit analysis (CBA) in disaster risk reduction.

4.1. Previous Research on the Cost-Benefit Ratio of Ex-ante Investments

4.1.1. Quantitative Cost-Benefit Models

The economic viability of ex-ante investments is conventionally quantified by the Benefit-Cost Ratio (BCR), where B_t represents the expected avoided damage in year t, C_t denotes capital expenditure and maintenance costs, r signifies the social discount rate, and T defines the project evaluation period.

$$\mathrm{BCR}=\frac{\sum_{t=0}^{T}\frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T}\frac{C_t}{(1+r)^t}}$$

A significant methodological advancement in contemporary research on ex-ante DRR investments is the transition from deterministic, single-scenario approaches to probabilistic risk assessment (PRA)-based models. Within the PRA framework, the correlation between hazard exceedance probability and resultant economic damage is modeled to compute the Expected Annual Damage (EAD). Mathematically, EAD is expressed as the integral of the product of hazard occurrence probability (p) and the corresponding damage function $D(p)$ over all probability levels.

$$\mathrm{EAD} = \int_0^1 D(p)\ \cdot\ f(p)\,dp$$

$$\Delta EAD\ =\ \mathrm{EAD}_{baseline}\ -\ \mathrm{EAD}_{post-mitigation}$$

The aggregate benefit of an ex-ante investment is fundamentally defined as Δthe reduction in Expected Annual Damage (EAD) before and after the implementation of the mitigation measure. This probabilistic approach is now rigorously applied to evaluate resilience investments in critical infrastructure. For instance, in a recent analysis of ex-ante investments in electrical power systems, He et al. (2024) proposed a sophisticated CBA methodology integrating probabilistic resilience assessments with a life-cycle cost (LCC) model. Their findings empirically demonstrate that optimized ex-ante resource allocation significantly reduces the risk of power grid failures [37].

Furthermore, the "Triple Dividend of Resilience" framework introduced by the World Bank facilitates the comprehensive integration of three critical variables into econometric models: (1) the direct reduction of physical damage, (2) the stimulation of private capital investment via the reduction of background risk, and (3) the generation of concurrent socio-environmental co-benefits during non-disaster periods. This multi-dimensional approach has substantially broadened the analytical scope and applicability of modern CBA frameworks [38].

However favorable the computed benefit-cost ratio, one caveat is fundamental: ex-ante investment reduces expected annual damage but does not drive it to zero. The residual risk that remains after cost-effective mitigation must still be financed through complementary instruments—reserves, insurance, reinsurance, contingent credit, or sovereign backstops—consistent with the layered architecture introduced in Section 2.2 and operationalized in Section 6.5. Benefit-cost analysis of ex-ante investment and the pricing of residual-risk instruments are therefore analytical complements, not substitutes.

4.1.2. Computable General Equilibrium (CGE) Models and the Refinement of Damage Functions in Japan

Within Japan's evaluation practice, damage functions have been progressively refined—from the MLIT flood-control cost-benefit manual [39] to empirical studies of how hazard-map disclosure is capitalized into land prices [40]—while Computable General Equilibrium (CGE) models are increasingly deployed to quantify indirect business-interruption losses and to demonstrate the macroeconomic effects of resilience investments, such as the ex-ante reinforcement of critical road networks and port facilities under Japan's Basic Plan for National Resilience.

4.1.3. Integration of Spatial Computable General Equilibrium (SCGE) Models and Recovery Curves

A notable quantitative methodology integrating Spatial Computable General Equilibrium (SCGE) models with recovery curves has been proposed by Tatano and Tsuchiya [41]. Their framework rigorously models not only the immediate ex-post degradation of capital stock, but also the temporal trajectory of production capacity recovery and the spatial propagation of business interruption losses (BIL) across complex supply chains.

Within this modeling framework, dynamic BIL—specifically focusing on aggregate corporate production—is quantified via an integral equation. Let Y^* denote the ex-ante potential production baseline, $Y(t)$ the actual production output at time t ex-post, and T_R the total duration required for full economic recovery.

$$\text{BIL} = \int_{t_0}^{t_0+T_R} [Y* - Y(t)]\, dt$$

The temporal recovery trajectory of production, $Y(t)$, is characterized by the initial ex-post damage magnitude (ΔY_0) and a defined recovery rate parameter (γ).

$$Y(t) = Y* - \Delta Y_0 \cdot exp(-\gamma(t - t_0)) \quad for\ t \geq t_0$$

The key contribution of Tatano and Tsuchiya [41] lies in their quantitative demonstration that ex-ante investments—specifically, the formulation of robust Business Continuity Plans (BCP) and the establishment of redundant logistical networks—serve a dual function: attenuating the initial ex-post drop in production capacity (ΔY_0) and substantially accelerating the recovery rate (γ) by steepening the trajectory of the recovery curve.

Consequently, the economic value of accelerated recovery—directly attributable to ex-ante measures—is explicitly monetized as avoided indirect damage. This is structurally reflected as enhanced regional production functions and stabilized interregional trade flows within the SCGE architecture. By providing rigorous scientific evidence, this framework substantially elevates the calculated Benefit-Cost Ratios (BCR) for ex-ante investments in non-structural (soft) risk reduction measures and infrastructure redundancy—categories of intervention historically undervalued in traditional analyses. Today, this methodology is increasingly recognized as the standard framework for evaluating macroeconomic resilience in Japan.

4.2. Summary: The Analytical Frontier of Ex-ante Investment Evaluation

However, despite these theoretical advancements, the empirical validation of ex-ante investment efficacy remains incomplete. Broader societal implementation will require the continued accumulation of rigorous empirical evidence. Advancing this domain will require two concurrent efforts: the continuous refinement of quantitative models, and the rigorous empirical verification of their measurable impacts on economic outcomes and financial market behavior.

The following section presents an empirical analysis of ex-ante DRR investment returns, drawing on case studies of Japanese enterprises that have obtained DBJ DRR-BCM ratings.

5. Evaluating the Effectiveness of Ex-ante Investments: The Japanese Case

5.1. DRR and BCM-Rated Financing

5.1.1. Ex-ante Investments in Japan

The DRR and BCM-Rated Loan Program, launched by the Development Bank of Japan (DBJ) in 2006, represents the world's first financing instrument incorporating a disaster preparedness rating methodology [42]. Following the Great East Japan Earthquake of March 2011, the program was substantially expanded to integrate Business Continuity Management (BCM) criteria and rebranded as the DBJ DRR-BCM Rated Loan Program. This framework systematically evaluates enterprises implementing substantive DRR and business continuity initiatives.

A defining characteristic of this program is its comprehensive evaluation architecture. The program extends beyond traditional DRR assessments—which predominantly focus on ex-ante preventative measures—by

integrating BCM criteria, thereby evaluating the capacity for rapid recovery and ex-post operational continuity. Using an internally developed evaluation system, the program quantifies corporate initiatives on a 100-point scale.

Within the DRR category, the primary objective is the preservation of human life and safety. The framework verifies corporate ex-ante risk reduction initiatives, including fire safety protocols, comprehensive disaster mitigation plans, and the execution of rigorous evacuation drills. Specifically, it assesses the efficacy of natural hazard countermeasures, broader initiatives that enhance the disaster resilience of surrounding municipalities beyond the company's direct operational scope, and the systemic implementation of crisis simulations.

Conversely, the BCM category focuses on the formulation and verifiable efficacy of Business Continuity Plans (BCP). It emphasizes the identification of an "all-hazard" risk spectrum and the corresponding strategic frameworks and training regimens. Specifically, the evaluation scrutinizes Enterprise Risk Management (ERM) initiatives, such as the identification, analysis, and assessment of tail risks capable of disrupting medium- to long-term corporate operations and strategic continuity. It further examines the robustness of Business Impact Analyses (BIA), supply chain risk mitigation efforts designed to guarantee the execution of continuity strategies, and the frequency of operational resilience drills.

To maintain global relevance, this evaluation matrix undergoes an annual systematic review. Assessment criteria are dynamically recalibrated—integrating insights from an external Advisory Committee—to align with evolving international policy paradigms. Domestically, the framework calibrates against DRR policies led by the Cabinet Office's Disaster Management Bureau; internationally, it aligns with directives from the United Nations Office for Disaster Risk Reduction (UNDRR), macroeconomic insights from the World Economic Forum's Global Risks Report, and resolutions from the Global Platform for Disaster Risk Reduction.

Assessment outcomes are stratified into distinct rating tiers, which determine the applicable loan interest rates. The magnitude of the interest rate incentive varies with prevailing monetary policy conditions. Moreover, post-disbursement, a formal BCM memorandum of understanding is executed. This facilitates ongoing ex-post monitoring from the financial institution's perspective, designed to reinforce the ongoing effectiveness of the borrower's ERM framework.

The DBJ program is not without limitations. As a voluntary, rating-based instrument operated by a single policy bank, its reach is bounded by the bank's client base and by companies' willingness to undergo assessment; systematic evaluation of its causal impact on company-level resilience outcomes—separated from self-selection effects—remains an open research question that Section 5.2 addresses only in illustrative form.

5.1.2. International Recognition and Previous Research

The program has received sustained international recognition as a reference model for private-sector-led ex-ante DRR finance. In addition to its inclusion in the 2013 UNISDR (now UNDRR) publication Business and Disaster Risk Reduction: Good Practices and Case Studies [43], the program was highlighted in the Special Report on the Great East Japan Earthquake in the World Economic Forum's Global Risks 2012 [44], which identifies DBJ as the first lender worldwide to grant preferential borrowing terms to companies that strengthen their emergency resilience and presents this approach as a sign of improving risk recognition. The program's core logic—converting BCM performance into differentiated capital costs—has thus been internationally documented since the immediate aftermath of the 2011 earthquake. Earlier academic treatments of the program by the present authors (Hiruma & Noda, 2012) [45], as well as related empirical work on corporate BCM adoption following the 11 March 2011 Great East Japan Earthquake, have similarly documented its role in shifting corporate disaster-preparedness expenditures from 'costs' to 'investments', but have stopped short of a large-sample causal evaluation. We acknowledge that [45] is co-authored by the first author of the present paper; we cite it here solely to situate the DBJ DRR-BCM program within the prior academic record, and the empirical analysis in Section 5 relies exclusively on publicly disclosed EDINET filings (EDINET (Electronic Disclosure for Investors' NETwork) is the electronic disclosure system operated by Japan's Financial Services Agency (FSA) for documents required under the Financial Instruments and Exchange Act, including annual securities reports (yūka-shōken hōkokusho).) rather than on data presented in [45]. The present paper therefore builds on this accumulated external recognition and academic groundwork, while deliberately reframing the program as a national prototype for the SFDRR × ISO 37116 hybrid framework proposed in Section 6, rather than as a stand-alone object of evaluation. Beyond the program-specific literature, a growing body of empirical research has documented the supply-chain propagation of the 2011 Great East Japan Earthquake's shock—most notably Carvalho et al. (2021), who quantify network-mediated output losses at the company level, and Todo, Nakajima & Matous (2015), who show that diversified supplier networks accelerate post-disaster recovery.

5.1.3. Positioning within This Paper—Treatment as a Prototype for Section 6

Building on the prior literature reviewed above, the present paper does not seek to evaluate the DBJ DRR-BCM program as a stand-alone object of policy analysis. Rather, we use the program—and the case of Alps Electric in particular—as a domestic prototype that motivates and disciplines the international SFDRR × ISO 37116 framework developed in Section 6. Our case study therefore contributes to the supply-chain-shock literature [46,47] by zooming in on a specific, externally rated BCM regime, complementing the network-level findings of those studies with company-level evidence on the financial visibility of ex-ante investment, and by translating that evidence into design implications for cross-border risk-finance instruments rather than into a domestic policy evaluation. The reader should therefore interpret Sections 5.2–5.3 as a single illustrative case calibrating the normative architecture of Section 6, not as a representative sample of the rated population.

5.2. Evaluating the Empirical Effectiveness of Ex-ante Investments by DRR-BCM-Rated Enterprises: The Case of Alps Electric

This section evaluates the empirical effectiveness of ex-ante DRR-BCM investments, drawing on Alps Electric Co., Ltd. (which merged with Alpine Electronics in 2019 to form Alps Alpine Co., Ltd.) as a case study. According to the company's own public disclosures, Alps Electric had been systematically building its Business Continuity Management (BCM) system since 2005, encompassing such measures as seismic isolation and damping of manufacturing facilities, formulation of Business Continuity Plans, multi-sourcing of critical components, and supply-chain visibility systems. These ex-ante investments were therefore substantively in place at the time of the Great East Japan Earthquake on 11 March 2011. The company's DBJ DRR-BCM rating was subsequently announced publicly in August 2011, five months after the earthquake, recognizing the BCM system that the company had developed over the preceding years. For the purposes of this study, the August 2011 public rating is therefore interpreted as an external verification of pre-existing ex-ante investments, rather than as a post-event certification or an intervention contemporaneous with the disaster. The case study is accordingly presented as illustrative and hypothesis-generating rather than as causal evidence: its principal value lies in illustrating the evolution of disaster risk finance and the adaptation of financial mechanisms to increasingly frequent and severe disasters.

The selection of Alps Electric as the single treated unit reflects three considerations rather than an outcome-based sampling decision. First, the company's pre-disaster BCM implementation history—systematically built from 2005 onward and publicly documented by the company itself well before March 2011—provides an ex-ante rather than ex-post basis for identifying the treated status, mitigating the most direct form of selection-on-outcome bias. Second, the company had substantial manufacturing exposure in the Tohoku region, satisfying the same hazard-exposure criterion applied to the comparison group (Appendix A). Third, among DBJ-rated electronic-component manufacturers affected by the 2011 Great East Japan Earthquake, Alps Electric is the only company for which (a) the BCM system was externally verified through a public DBJ DRR-BCM rating announcement within the same fiscal year as the earthquake, and (b) continuous quarterly financial disclosure through Q4 FY2012 is available via EDINET. These conditions permit a clean pre-/post-event comparison at the company level, at the cost of restricting the analysis to a single treated unit.

Focusing on the 2011 Great East Japan Earthquake, we analyze publicly available quantitative financial data—specifically, extraordinary losses and revenue trajectories—across several leading Japanese electronic-component manufacturers to empirically assess the effectiveness of Alps Electric's ex-ante investments. This case study employs a within-industry comparative design and is best interpreted as hypothesis-generating rather than hypothesis-conforming. Beyond the single-treated-unit limitation already discussed in connection with the case selection above, four further methodological caveats deserve explicit acknowledgment. First, with a single treated unit (Alps Electric), we cannot establish statistical causation; the observed differences are consistent with, but do not prove, a causal effect of ex-ante DRR-BCM investment. Second, voluntary participation in the DBJ DRR-BCM program introduces selection on unobservables: companies that pursue a rating may differ systematically from non-rated companies in managerial quality, risk culture, or supply-chain sophistication. Third, the 2011 Great East Japan Earthquake generated highly heterogeneous spatial damage, such that residual differences in plant locations may confound comparisons even among companies with Tohoku exposure. Fourth, the two outcome variables analyzed here—extraordinary losses and revenue trajectories—are financial proxies for damage and recovery rather than direct operational measures of DRR-BCM performance: they do not directly observe actual factory downtime, production-line interruption, relocation costs, or post-disaster supply-chain functionality, and inferences about the operational channel therefore remain indirect. To partially mitigate these concerns, we (i) restrict the comparison set to companies with documented Tohoku-region production exposure and comparable product portfolios (selection criteria detailed in Appendix A), (ii) normalize financial metrics by pre-disaster

revenue scale to control for inter-firm heterogeneity, (iii) triangulate extraordinary-loss figures with physical-damage disclosures from annual securities reports filed with the Japanese Financial Services Agency, and (iv) present revenue trajectories on a common index basis to focus on dynamic patterns rather than absolute levels. A fuller econometric evaluation of the DBJ DRR-BCM program—for instance, a difference-in-differences design exploiting staggered rating adoption across the 473 rated transactions, or a synthetic-control estimator constructed from industry peers—is reserved for future research.

We first assess the extent of ex-post physical damage by comparing the extraordinary losses reported by each company. As illustrated in Figure 2, Alps Electric's reported losses were contained to approximately JPY 1.4 billion (approximately USD 17 million at the March 2011 exchange rate of 81 JPY/USD), markedly below the range reported by six comparable Japanese electronic-component manufacturers—Renesas Electronics, Murata Manufacturing, Fujitsu, Furukawa Electric, TDK, and Tokyo Electron—selected on the basis of industry classification, company size, and Tohoku regional exposure. The relatively low loss figure is consistent with the hypothesis that ex-ante structural investments—specifically seismic isolation and damping in manufacturing facilities and anchoring of critical production equipment—mitigated direct physical damage to buildings and production lines.

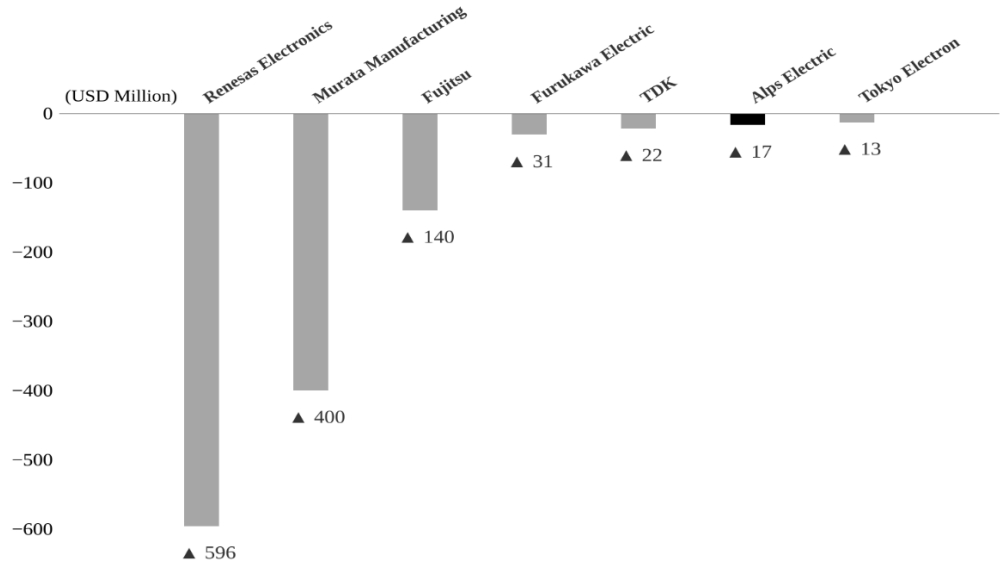


Figure 2. Comparison of Extraordinary Losses (USD million) for the Fiscal Year Ended March 2011. Converted from JPY figures at the March 2011 exchange rate of 81 JPY/USD. Source: Annual securities reports filed with the Japanese Financial Services Agency, retrieved via EDINET.

Subsequently, we analyze how the mitigation of physical damage translated into operational continuity and revenue recovery. Figure 3 presents the relative revenue trajectories for Alps Electric (solid black line), benchmarked against the industry peer average (dashed grey line), normalized to a baseline index of 100 for the first quarter of fiscal year 2011 (April–June 2011). While the peer average remained below the baseline throughout fiscal 2011, experiencing a prolonged downturn (with the index ranging between 80 and 95)—particularly from Q3 FY2011 through Q3 FY2012—Alps Electric consistently outperformed its industry peers from the immediate ex-post period (Q1 FY2011) onward. Notably, Alps Electric's index exceeded 110 by the second quarter of fiscal 2011 (July–September 2011)—exceeding pre-disaster production levels—and rose to approximately 120 by the end of fiscal 2012.

This robust revenue recovery trajectory cannot be attributed solely to the containment of physical damage (i.e., the efficacy of ex-ante structural investments). Rather, it suggests the contribution of strategic ex-ante non-structural investments—specifically, the rigorous formulation of Business Continuity Plans (BCP), the proactive establishment of redundant production networks (multi-sourcing), and enhanced supply chain visibility—which functioned effectively during the ex-post crisis phase. In addition to the rapid reactivation of undamaged facilities, the agile reallocation of production to alternative domestic and international sites ensured the uninterrupted fulfillment of supply obligations, ultimately supporting the preservation of market share during and after the crisis.

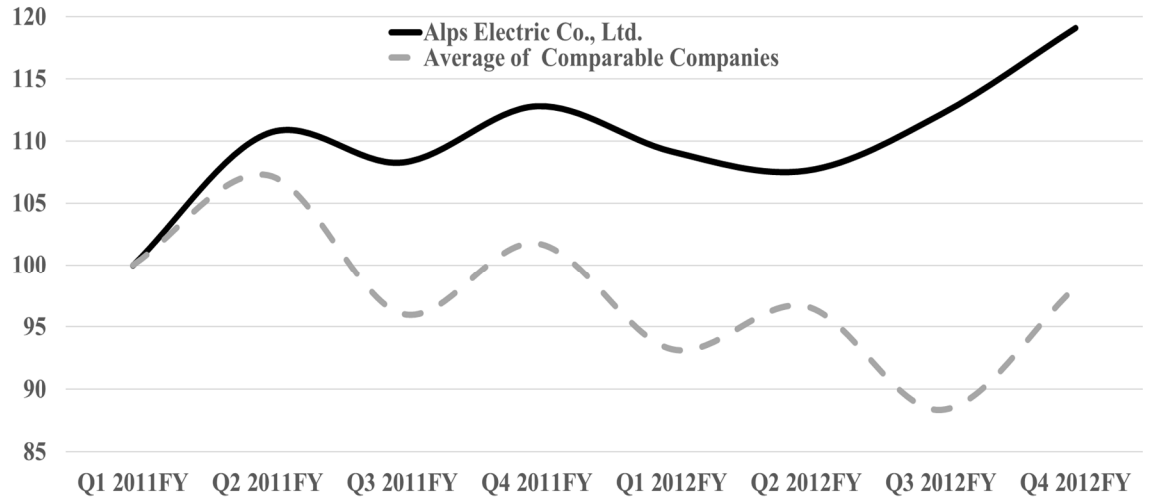


Figure 3. Indexed Quarterly Revenue Trajectories for Alps Electric (solid black line) and the Average of Six Comparable Peer Companies (dashed grey line) following the 2011 Great East Japan Earthquake. Baseline = 100 at Q1 FY2011 (April–June 2011). Peer companies: Renesas Electronics, Murata Manufacturing, Fujitsu, Furukawa Electric, TDK, and Tokyo Electron. Source: Quarterly financial reports retrieved via EDINET.

Two caveats temper the interpretation of Alps Electric's above-baseline revenue trajectory. First, the global supply shortage of electronic components in the second half of 2011 generated a pro-cyclical demand tailwind for companies whose production capacity recovered rapidly; part of Alps Electric's observed outperformance therefore reflects the company's ability to capture market share vacated by more severely damaged peers, rather than a pure BCM effect. Second, product-mix differences among the comparison companies, particularly the exposure of Renesas and TDK to disaster-affected semiconductors and hard-disk-drive fabs—may bias the peer average downward, inflating the apparent comparative advantage. Both mechanisms, however, are themselves consistent with the broader theoretical claim that ex-ante BCM investment allows a company to internalize rather than forgo the market-share reallocation that follows a large supply shock.

Because the peer distribution of extraordinary losses is strongly right-skewed, the comparison should be read primarily against the median rather than the mean. Reported on this basis, Alps Electric's loss containment is consistent with—but more modest than—what a mean-based comparison suggests. The qualitative pattern is robust to the exclusion of Renesas Electronics, whose semiconductor fab damage is an outlier event within the comparison set. Moreover, because plant-level shutdown duration is not directly disclosed in public quarterly filings, the figures reported in the Business Interruption Duration row of Table 4 should be read as indirect, order-of-magnitude estimates rather than precise operational measurements. The estimates are derived from the indexed quarterly revenue trajectories (Figure 3) under the simplifying assumption that production capacity recovered linearly from the Q1 FY2011 trough toward the FY2010 baseline. Specifically, for each company, estimated downtime (days) $\approx 90 \times \max(0, 1 - R_trough/R_baseline)$, where R_trough is the minimum quarterly revenue index in FY2011 Q1–Q2 and R_baseline is the FY2010 Q4 revenue. The figures are reported here to give the reader a qualitative sense of the relative recovery speeds across the treated and comparison companies; a direct measurement would require internal plant-level data that are not publicly disclosed. We therefore place relatively more analytical weight on the extraordinary-loss comparison—which is drawn directly from audited financial statements—than on the duration estimates. The full comparative profile is reported in Table 4.

Table 4. Comparative Analysis of Ex-post Outcomes for Alps Electric (Verified by the DBJ DRR-BCM Rating) versus Non-Rated Industry Peers.

Key Performance Indicator	Alps Electric (DBJ DRR-BCM-Rated)	Control Group (Non-Rated Industry Peers)	Comparative Delta
Business Interruption Duration [1]	Approximately 14–21 days	Approximately 45–60 days	Approximately 30-day reduction (~60–65% shorter recovery)
Ex-post Extraordinary Losses	Approximately USD 17 million	Approximately range: USD 13–596 M; mean: USD 200 M [2]	Approximately 91% below peer mean and approximately 80% below peer median [3]

[1]: Business interruption duration is not directly disclosed in public quarterly filings. Figures reported here are indirect, order-of-magnitude estimates derived from the indexed quarterly revenue trajectories under the simplifying assumption that production capacity recovered linearly from the Q1 FY2011 trough toward the FY2010 baseline (days ≈ 90 × max(0, 1 − R_trough/R_baseline)). These estimates are intended to convey relative recovery speed and should not be interpreted as precise operational measurements.; [2]: Note on the USD 200 million peer-average figure. Computed as the arithmetic mean of the six peer-company extraordinary-loss values reported in Figure 2 (USD 596 M, 400 M, 140 M, 31 M, 22 M, 13 M; arithmetic mean ≈ USD 200 M ≈ JPY 16.2 billion at the March 2011 rate of 81 JPY/USD); [3]: Approximately 91% below the peer mean (≈USD 200 M) and approximately 80% below the peer median (≈USD 86 M; median of the six peer values USD 13, 22, 31, 140, 400, and 596 M). Sensitivity check: excluding Renesas Electronics—whose USD 596 M loss reflects an outlier semiconductor-fab event—reduces the peer mean to approximately USD 121 M (5-company mean: USD 596 M dropped; remaining values USD 400, 140, 31, 22, 13 M) and the peer median to USD 31 M. Alps Electric's USD 17 M loss therefore remains approximately 86% below the trimmed peer mean and approximately 45% below the trimmed peer median, indicating that the qualitative pattern is not driven by the Renesas outlier.

5.3. Summary: Hypothesis-Generating Evidence on the Effectiveness of Ex-ante Investments

This section synthesized illustrative, hypothesis-generating evidence on the potential efficacy of ex-ante investments, drawing on enterprises that strategically allocated capital toward ex-ante DRR—specifically, those evaluated under the DBJ DRR-BCM-Rated Loan Program. Two financial metrics anchored the analysis: "extraordinary losses" (as a proxy for the severity of direct financial damage) and "revenue trajectories" (as an indicator of business recovery speed). The findings should not be interpreted as causal estimates but rather as descriptive patterns that motivate the larger-sample empirical agenda set out in Section 7. Both metrics are financial proxies for damage and recovery rather than direct operational measures of DRR-BCM performance (such as factory downtime, production-line interruption, relocation costs, or supply-chain functionality), which reinforces the illustrative, hypothesis-generating status of the evidence.

Containment of Ex-post Extraordinary Losses: A comparative analysis of ex-post extraordinary losses revealed that Alps Electric contained its extraordinary losses to approximately JPY 1.4 billion. This marked containment of financial losses—despite the scale of the physical hazard— is consistent with—though does not by itself establish—the hypothesis that the company's ex-ante DRR investments (e.g., facility decentralization, structural seismic retrofitting, and the establishment of supply-chain redundancies) contributed to substantially contained financial losses despite the magnitude of the physical hazard.

Competitive Advantage via Accelerated Revenue Recovery: Furthermore, an evaluation of the quarterly revenue recovery trajectories throughout fiscal year 2011 (April 2011–March 2012) demonstrated that the company's recovery capacity markedly outpaced that of its industry peers. This recovery pattern is consistent with the activation of redundant production systems, as prescribed in the company's ex-ante Business Continuity Plan (BCP). Although our single-treated-unit design cannot rigorously isolate the BCP contribution from confounding factors (see Section 5.2), the rapid above-baseline recovery is qualitatively aligned with the theoretical mechanism posited in Section 4.1.3. Read through the recovery-curve framework of Section 4 (Tatano–Tsuchiya [41]), the contained extraordinary losses correspond to an attenuated initial production drop (ΔY_0) and the faster above-baseline trajectory to a higher recovery rate (γ); we emphasize that this correspondence is a descriptive pattern consistent with the recovery-curve logic, not causal proof.

This empirical case study suggests that ex-ante DRR-BCM investments extend beyond traditional purely defensive expenditures. Rather, they function as strategic investments that enable enterprises to maintain supply obligations, preserve market share, and support sustained corporate value, while less-prepared competitors face prolonged recovery periods.

6. Proposal for an International Risk Finance Initiative Based on SFDRR and ISO 37116

As established in Sections 2 through 5, the evolution of disaster risk finance requires a fundamental paradigm shift from reactive ex-post responses to proactive ex-ante investments designed to mitigate damages before they materialize. Furthermore, this study has argued, drawing on both theoretical frameworks (Section 4) and an illustrative empirical case (Section 5), that mechanisms capable of translating the qualitative benefits of ex-ante investments into quantifiable financial metrics are gradually emerging. This paradigm shift, moreover, forms part of a broader mainstreaming of ex-ante risk assessment across global finance: nature-related financial risk frameworks now extend the same logic of forward-looking dependency and impact analysis to ecosystems [48–54], quantitative indices increasingly capture geopolitical risk in real time [55,56], and the latest global risk outlook ranks extreme weather and biodiversity loss among the dominant threats of the coming decade [57].

While the single-case design of Section 5 does not permit a formal test of the dual mechanism posited by the Tatano-Tsuchiya recovery-curve literature—attenuation of ΔY_0 combined with acceleration of γ—the observed combination of contained extraordinary losses and rapid above-baseline revenue recovery is qualitatively consistent with that framework, providing a company-level illustration that motivates the normative proposal developed in this section.

In this context, the international standard ISO 37116 (Sustainable cities and communities—Disaster risk finance—Principles and general requirements for financing ex-ante investment in risk reduction) provides a foundational normative framework essential for scaling ex-ante DRR investments globally. This section proposes the conceptual and institutional integration of the macro-level policy imperatives established by the United Nations Sendai Framework for Disaster Risk Reduction (SFDRR 2015-2030) with the operational, micro-level financial protocols delineated in ISO 37116. Building upon the strategic policy coordination promoted by multilateral institutions such as the United Nations, the World Bank, and the G20, this section proposes a theoretical framework to develop this integration into a "multi-tiered capital mobilization mechanism". Ultimately, this integrated approach is designed to promote the development of private-sector-led financial instruments. One scope condition bears emphasis at the outset: the framework mobilizes capital for risk reduction, but ex-ante investment reduces—it does not remove—disaster risk. Residual risk remains and must continue to be managed through the layered instruments detailed in Section 6.5, where the complementarity between residual-risk financing and ex-ante investment is developed.

This section is organized as follows. Section 6.1 outlines the architecture of ISO 37116—its scope, user typology, and core regulatory requirements. Section 6.2 articulates the strategic logic of integrating ISO 37116 with SFDRR macro-indicators and previews the five sectoral implementation pathways. Section 6.3 addresses Asia-Pacific implementation priorities. Section 6.4 elaborates each of the five pathways in turn, with extended treatment of the (re)insurance pathway in Section 6.4.5, which reflects its conceptual significance for the proposed framework. Section 6.5 then synthesizes how the five pathways jointly reverse the vicious cycle diagnosed in Figure 1, and Section 6.6 concludes.

6.1. Overview of ISO 37116 Risk Finance

ISO 37116 (Sustainable cities and communities—Disaster risk finance—Principles and general requirements for financing ex-ante investment in risk reduction) equips organizations—both capital seekers and providers—with common principles and standardized requirements for financing ex-ante investments in risk reduction and disaster preparedness within cities and communities (referred to as "ex-ante DRR finance"). This establishes a common benchmark for mobilizing funds toward proactive risk mitigation.

6.1.1. Market Participants and Applicability (Users)

ISO 37116 applies across diverse financial instruments—loans, bonds, equity, insurance, guarantees, and grants—with debt instruments (loans and bonds) as its primary focus. Its users span sovereign and municipal borrowers, infrastructure developers, corporate enterprises, and financial institutions as capital providers; compliance obligations rest primarily with the borrower, while lenders assume verification and monitoring roles, typically supported by external reviews.

6.1.2. Typology of Financing Mechanisms under ISO 37116

ISO 37116 delineates three primary categories of DRR financing: (A) project-, asset-, or activity-specific loans and bonds, into which most resilient-infrastructure projects fall; (B) entity-level corporate financing, structured around an organization's enterprise-wide DRR capabilities and governance; and (C) DRR-solution financing for providers of risk-reduction technologies and services to third parties.

6.1.3. Core Regulatory Requirements under ISO 37116

- Its normative framework rests on two foundational pillars: eligibility criteria—the investment must demonstrably "aim to reduce disaster risk", substantiated through evidence-based risk assessments—and procedural requirements governing standardized protocols during both the ex-ante structuring phase (prior to financial close) and the ex-post monitoring phase (subsequent to capital deployment).

Three caveats qualify the operational applicability of ISO 37116 and warrant explicit acknowledgment. First, as a process-oriented standard, ISO 37116 imposes verification and disclosure costs that may be disproportionately burdensome for small and medium-sized enterprises and for sub-national entities in low-capacity jurisdictions;

absent dedicated technical assistance, this risks reproducing the geographic concentration of DRR finance documented in Section 3.1. Second, because ISO 37116 enters into force only in 2026, no historical performance data exist on its real-world implementation, and lessons drawn from analogous standards (notably the ICMA Green Bond Principles and Sustainability-Linked Bond Principles) suggest that consistent application across jurisdictions typically requires a multi-year maturation period. Third, the standard's interaction with existing taxonomies—the EU Taxonomy, the ISSB IFRS S1/S2, and ICMA-aligned frameworks—has yet to be clarified, and overlapping or inconsistent disclosure requirements could initially raise rather than reduce transaction costs. The hybrid SFDRR × ISO 37116 framework proposed below should therefore be understood as a foundational architecture whose effective operationalization will depend on parallel investments in technical assistance, harmonization with adjacent taxonomies, and iterative refinement informed by early-adopter experience.

6.2. Strategic Proposals for the Societal Implementation of SFDRR and ISO 37116

ISO 37116 offers a new framework for reconceptualizing the global paradigm of disaster risk management, reframing DRR from a 'cost' to a strategic 'investment' that safeguards future cash flows and bolsters structural resilience. By operationalizing the ISO 37116 framework, the processes and efficacy of ex-ante investments—historically difficult to quantify due to their counterfactual nature—are systematically standardized. Institutional investors can thus integrate DRR as a well-defined asset class within ESG and impact portfolios, enabling market-driven sustainable risk finance. Sections 6.4.1–6.4.5 develop five sectoral implementation pathways, summarized in Table 5. Each pathway specifies (i) the target capital pool, (ii) the key structural barrier it addresses, (iii) the hybrid SFDRR–ISO 37116 mechanism applied, and (iv) the resulting financial instruments and expected market outcomes. In addition, Figure 4 illustrates the expected effects of ex-ante investment.

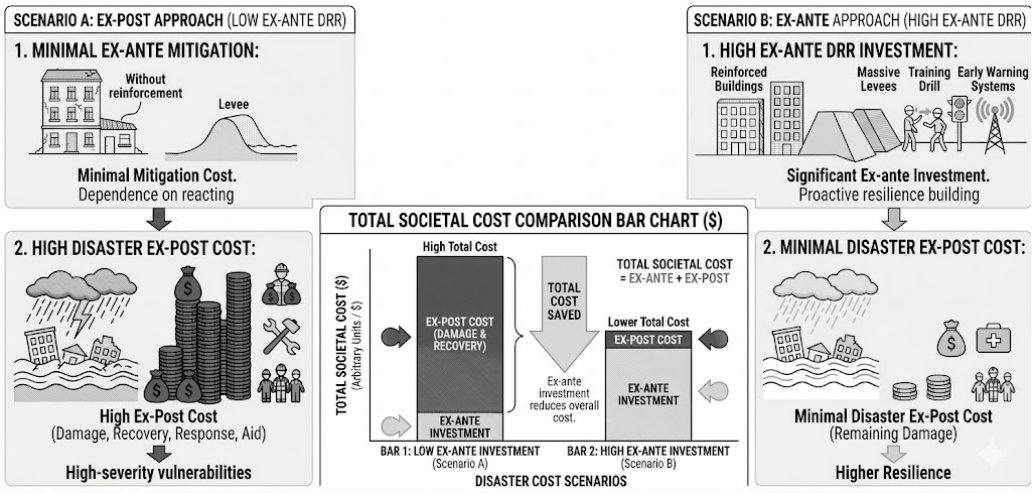


Figure 4. Conceptual illustration of Total Societal Cost Comparison: Ex-post vs. Ex-ante Approach to Disaster Risk.

Scenario A (low ex-ante DRR investment) minimizes upfront mitigation cost but generates large ex-post damage and recovery expenditures; Scenario B (high ex-ante DRR investment) absorbs a larger ex-ante outlay but substantially compresses ex-post cost. The total societal cost—defined as the sum of ex-ante mitigation expenditures and ex-post damage, recovery, response, and aid—is lower in Scenario B. The figure is illustrative rather than calibrated and is intended to convey the directional logic underpinning the SFDRR × ISO 37116 framework developed in Sections 6.2–6.4. Source: authors' synthesis.

6.3. Asia-Pacific Implementation Priorities

First, the Asia-Pacific region—historically framed as the world's largest protection gap—should now be repositioned not as a recipient of catch-up finance, but as a leading region for the operationalization of ex-ante investment. Three regional assets support this repositioning: a maturing indemnity-based and parametric CAT-bond market concentrated in Japan, Australia, and Singapore-domiciled SPVs; ESG-disclosure regimes that are increasingly aligned with ISSB principles; and well-established public-finance channels (JICA, ADB, AIIB, GFDRR) that are already partially compatible with the SFDRR macro-indicator layer. Anchored in the entry into force of ISO 37116:2026 as the common process-governance language, three sub-regional clusters can be

mobilized along differentiated trajectories. (a) Mature markets—Japan, Australia, and New Zealand—already host indemnity-based and parametric CAT-bond issuance and possess the regulatory and actuarial infrastructure to embed ISO 37116 process governance into existing (re)insurance and infrastructure-finance pipelines (Pathways 6.4.3 and 6.4.5); these markets are well-positioned to serve as the regional reference platform, including through extending entity-level resilience rating practices of the kind reviewed in Section 5 to a wider corporate base. (b) Mid-tier markets—Singapore, Hong Kong, mainland China, and the Taiwan market—function as issuance hubs and capital intermediaries; their most tractable entry point is the corporate finance pathway (6.4.4), where ISO 37116 compliance can be embedded into the region's already-mature ESG-disclosure regimes to scale ex-ante-linked instruments across borders. (c) Emerging markets—the Philippines, Indonesia, Vietnam, Cambodia, and the Pacific Island Countries—face a binding constraint on primary-insurance market thickness; rather than retracing the global ex-post-to-ex-ante trajectory, these jurisdictions can leapfrog directly into an ex-ante-linked financing architecture through blended-finance vehicles (6.4.1) anchored in MDB first-loss tranches and conditioned on ISO 37116 compliance from inception. Existing bilateral and multilateral channels—JICA's regional loan portfolios, ADB's disaster risk financing programs, AIIB's infrastructure lending, and the World Bank's GFDRR—can deliver this architecture directly, by embedding ISO 37116 compliance as additional conditionality without renegotiating the underlying financing instruments.

Second, the (re)insurance sector and statutory ex-post compensation regimes—historically the dominant fiscal channel for disaster response across the region—should themselves be structurally re-engineered into ex-ante-linked instruments, rather than treated as the residual that ex-ante finance merely supplements. Concretely, this entails: (i) accelerated regional rollout of Resilience-Linked Insurance (RLI) and Ex-ante-Linked Reinsurance treaties (Section 6.4.5), in which premiums and cession terms are contractually tied to ISO 37116-verified ex-ante investment progress; (ii) re-design of parametric instruments to incorporate ex-ante-investment-linked premium rebates, extending the logic of CAT-bond spread compression to the primary-insurance layer; and (iii) reform of statutory ex-post relief frameworks (e.g., national disaster relief acts and subsidized recovery-loan programs) so that the level of public support is calibrated against verified ex-ante investment by sub-national governments, companies, and households—converting the long-standing Samaritan's Dilemma dynamic diagnosed in Section 3.4 into a positive ex-ante incentive.

Two regional structural frictions warrant parallel treatment: (i) currency mismatch between USD-denominated CAT bonds and local-currency primary insurance contracts, partially mitigable through Singapore- and Hong Kong-domiciled SPVs and emerging local-currency parametric instruments; and (ii) heterogeneity of hazard exposure—typhoon and flood risk dominating in Southeast Asia versus seismic and tsunami risk in Japan and the Philippines—which implies that the SFDRR macro-indicator layer should be parameterized at the country level rather than applied uniformly. A staged implementation sequence—blended finance → sovereign → corporate/ex-ante-linked (re)insurance—is therefore proposed for the Asia-Pacific region as a whole, calibrated to each sub-regional cluster's primary-insurance market depth and ESG-disclosure capacity. Executed in this sequence and anchored in the SFDRR × ISO 37116 reference architecture, the region's transformation moves beyond closing the protection gap toward establishing Asia-Pacific as a proving ground for the ex-ante investment paradigm.

6.4. Five Sectoral Implementation Pathways

Table 5 summarizes the five sectoral pathways through which the hybrid SFDRR × ISO 37116 framework can be operationalized, identifying for each pathway the target capital pool, the structural barrier inherited from the diagnosis in Sections 2–3, and the resulting financial instruments. Across all five pathways, the underlying hybrid mechanism follows the same architectural logic—combining SFDRR macro-indicators (primarily Targets A–D) as the quantitative evaluation layer with ISO 37116 process governance as the procedural assurance layer—with pathway-specific applications elaborated in Sections 6.4.1–6.4.5 below. The five pathways should be read not as a parallel menu but as an integrated architecture whose collective reversal of the vicious cycle (Figure 1) is visualized in Figure 5.

Table 5. Five Sectoral Implementation Pathways of SFDRR × ISO 37116 [1].

Pathway	Target Actors/Capital Pool	Key Barrier Addressed	Resulting Financial Instruments
6.4.1 Blended finance (international coordination—macro level)	MDBs; concessional public and philanthropic donors; senior institutional co-investors targeting emerging-market resilience projects	Absence of a credible attestation mechanism for ex-ante resilience orientation ("resilience-washing" risk); lack of comparable, priceable outcome metrics for private investors	Hybrid-compliant first-loss tranches in MDB-led blended finance vehicles; auditable assurance comparable to green-bond verification
6.4.2 Sovereign finance (public sector)—conditionality anchored in SFDRR indicators	National and subnational governments; ministries of finance; public procurement authorities; sovereign Resilience Bond issuers	Generous and unconditional ex-post sovereign compensation structurally erodes ex-ante investment incentives and reproduces moral hazard	Preferential subsidy rates; reduced recovery-loan interest; hybrid-conditional public procurement and PPP qualification; sovereign Resilience Bonds
6.4.3 Critical infrastructure (long-term investment)—quantifying stranded-asset risk	Long-term institutional investors (pension funds, life insurers, infrastructure funds); PPP concessionaires; debt syndicates	Absence of rigorous ex-ante quantification of physical risk produces unmeasured stranded-asset exposure and elevates the discount rate applied to long-duration infrastructure cash flows.	"Managed stranded-asset risk profiles" justifying lower discount rates; compression of project-finance spreads; hybrid-standard KPIs in PPP concession agreements
6.4.4 Corporate finance, real estate, and retail—voluntary private-sector reinvestment	Commercial banks; corporate borrowers; real-estate ESG benchmarks (e.g., GRESB); mortgage lenders and households	Lenders and investors lack a credible, washing-resistant means of pricing resilience at the entity, asset, and household level	Resilience-Linked Loans with SPT-based preferential spreads; GRESB-integrated "Resilience Premium"; "resilience mortgages" with potential Basel-permitted capital relief
6.4.5 (Re)insurance Sector—Transforming Risk-Transfer Mechanisms into Risk-Reduction Partnerships	Primary insurers and reinsurers; CAT-bond sponsors and institutional investors; parametric-instrument issuers; supervisory authorities (IAIS, EIOPA)	Industry engages with disaster risk almost exclusively through ex-post indemnification; absence of a standardized, underwritable measure of ex-ante mitigation prevents resilience-based pricing	Ex-ante premium discounts; tighter parametric trigger calibration; CAT-bond spread compression; new product class—Resilience-Linked Insurance (RLI) and Ex-ante-Linked Reinsurance treaties

[1]: The hybrid mechanism in each pathway combines (i) an SFDRR macro-indicator layer—primarily Targets A–D and country-specific monitoring indicators—with (ii) an ISO 37116 process-governance layer covering risk-assessment-based eligibility and ex-ante/ex-post monitoring protocols. Pathway-specific applications are detailed in Sections 6.4.1–6.4.5.

6.4.1. Blended Finance

The blended finance pathway addresses a foundational market failure identified in Section 3.1: in the Asia-Pacific region, less than 3% of global CAT-bond issuance covers regional exposures, and primary insurance market thickness is insufficient to attract standalone private capital toward emerging-market resilience projects. The hybrid mechanism applies SFDRR Targets A–D (mortality, affected population, direct economic loss, critical-infrastructure damage), measured against transparent country- or project-level baselines, as the macro evaluation layer. In parallel, ISO 37116:2026 risk-assessment-based eligibility requirements and ex-ante/ex-post monitoring protocols supply the process governance layer. Operationally, hybrid compliance functions as the eligibility gate for first-loss tranches in MDB-led blended finance vehicles, providing auditable assurance comparable to green-bond verification. Over time, this is intended to cultivate disaster risk reduction as a credible, scalable asset class capable of crowding in private capital—a precondition emphasized in the Asia-Pacific implementation sequencing argued in Section 6.3. A working template already exists in blended-finance practice: the InsuResilience Investment Fund, capitalized with KfW-provided junior tranches that absorb first losses in order to crowd private institutional capital into climate-risk insurance and resilience ventures across developing countries, demonstrates precisely the first-loss architecture proposed here and is directly extensible to ISO 37116-verified DRR investment portfolios.

6.4.2. Sovereign Finance

The sovereign finance pathway directly targets the moral-hazard dynamic diagnosed in Sections 2.1 and 3.4: when ex-post sovereign compensation (such as the support framework operating under Japan's Disaster Relief Act) is generous and unconditional, it structurally erodes ex-ante investment incentives at the household and company level. The hybrid mechanism applies country-specific SFDRR monitoring indicators as conditionality benchmarks for ex-post fiscal support and sovereign bond proceeds (macro layer), combined with verified ISO 37116 procedural compliance applied to recovery-budget allocation, public procurement, and PPP qualification (process layer). The resulting financial architecture spans preferential subsidy rates, reduced recovery-loan interest, expedited administrative procedures, hybrid-conditional public procurement and PPP qualification, and sovereign Resilience Bond issuance. Collectively, these instruments convert national fiscal expenditure from a passive ex-post drain into a structural channel linking domestic resilience investment to global ESG capital flows. In the Asia-Pacific context, established bilateral channels such as JICA and ADB offer a near-term operational entry point for this conditionality alignment (Section 6.3). Developing-country practice already prefigures this conditionality: the World Bank's Catastrophe Deferred Drawdown Option (Cat DDO) conditions access to contingent liquidity on the existence of an active national disaster-risk-management framework [58], and could be upgraded to reference ISO 37116-verified investment plans as the qualifying condition.

6.4.3. Critical Infrastructure

The critical-infrastructure pathway addresses an information failure that elevates the cost of capital for long-duration assets: in the absence of rigorous ex-ante quantification of physical risk, infrastructure cash flows carry unmeasured stranded-asset exposure, prompting investors to apply elevated discount rates that compound across the asset's life cycle. The hybrid mechanism applies SFDRR-derived metrics—most notably Expected Maximum Loss reduction—as benchmarks for managed exposure profiles (macro layer), and embeds ISO 37116 asset-level governance as contractual KPIs in PPP concession agreements (process layer). The intended financial outcomes are threefold: (i) "managed stranded-asset risk profiles" that justify lower discount rates and reduce the cost of capital; (ii) stabilized business continuity that compresses credit risk for debt syndicates; and (iii) tighter project-finance spreads. Long-term institutional investors—pension funds, life insurers, and dedicated infrastructure funds—constitute the principal capital pool whose allocation behavior the hybrid standard is designed to influence. Japan's experience offers a concrete illustration: the Tōhoku Expressway—seismically reinforced in the years after the 1995 Kobe earthquake—was secured for emergency traffic from the day after the 2011 earthquake as the north–south spine of the "Operation Comb Teeth" road-clearing strategy, and reopened fully to general traffic within two weeks, demonstrating how verifiable resilience investment in long-duration assets converts into recovery-speed benefits that long-term investors can price.

6.4.4. Corporate, Real Estate, and Retail Finance

The corporate, real estate, and retail finance pathway extends the hybrid framework to voluntary private-sector reinvestment. The structural barrier here is that lenders and investors lack a credible, washing-resistant means of pricing resilience at the entity, asset, or household level, which suppresses ex-ante investment in the

absence of explicit mandates. The hybrid mechanism applies Sustainability Performance Targets (SPTs) calibrated against SFDRR goals and reflected in real-estate ESG benchmarks (macro layer), combined with ISO 37116 process verification of either entity-level (Category B) or solution-level (Category C) DRR governance, as defined in Section 6.1.2 (process layer). The resulting product set spans Resilience-Linked Loans offering preferential spreads upon verified SPT achievement; GRESB-integrated "Resilience Premium" valuation in real-estate markets; and "resilience mortgages" potentially supported by Basel-permitted capital relief, extending ex-ante incentives to the household balance sheet. In the Asia-Pacific implementation sequence (Section 6.3), corporate finance applications are most tractable for regional headquarters of multinational companies with existing ESG reporting capacity. The DBJ DRR-BCM rated-loan program examined in Section 5 provides the operating prototype for this pathway; in developing-country contexts, comparable schemes can be launched by national development banks using simplified BCM checklists as a transitional evaluation instrument where full rating infrastructures do not yet exist.

6.4.5. (Re)insurance Sector—Beyond Incremental Refinement: A New Product Class Linked to Ex-ante Investment

The (re)insurance pathway deserves extended elaboration because it represents the most fundamental conceptual transformation proposed in this paper. As summarized in Table 5, the hybrid standard enables three incremental improvements to existing instruments: ISO 37116 compliance reduces epistemic uncertainty in catastrophe loss models (justifying ex-ante premium discounts), tightens parametric trigger calibration (narrowing basis risk), and signals quality in the CAT-bond market (compressing risk spreads). Yet these refinements remain anchored in the ex-post logic of loss indemnification critiqued in Section 2.3.

Realizing the sector's full contribution to aggregate-loss reduction therefore requires a new product class explicitly linked to ex-ante investment. Two product archetypes warrant priority development. Resilience-Linked Insurance (RLI)—multi-year policies whose premium trajectory is contractually tied to the insured's progress against ISO 37116-verified ex-ante investment plans and SFDRR-aligned loss-reduction targets—converts mitigation from a discretionary expenditure into a structural source of premium savings over the policy life. Ex-ante-Linked Reinsurance treaties, in which cession terms and reinstatement premiums are modulated by the cedent's demonstrated ex-ante investment, transmit the resilience incentive from primary insurers to their reinsurance counterparties and ultimately to policyholders. Without such instruments channeling capital toward ex-ante investment rather than only toward its ex-post compensation, the sector will remain tied to the accelerated-ex-post logic critiqued in Section 2.3, and the aggregate-loss trajectory documented in Section 3.1 will continue to expand even as risk-transfer markets mature. A partial real-world precedent exists in the U.S. National Flood Insurance Program's Community Rating System, which grants premium discounts scaled to verified community mitigation actions [59]; RLI generalizes this logic to corporate and sovereign insureds under an internationally auditable standard. Framed in terms of the layered architecture of Section 6.5, the sector's role is thereby recast: insurance and reinsurance cease to be merely ex-post compensation mechanisms and become the designated financing channel for the residual risk that remains after verified ex-ante mitigation—the indispensable complement to, rather than a substitute for, ex-ante investment.

6.5. Integrating the Five Pathways: Reversing the Vicious Cycle

Section 6.5 synthesizes how the five pathways elaborated above operate not as a parallel menu but as an integrated architecture. Figure 5 visualizes their collective reversal of the vicious cycle diagnosed in Figure 1, converting each self-reinforcing element into a corresponding positive-feedback mechanism. Sovereign finance (6.4.2) and blended finance (6.4.1) primarily target the sovereign-compensation guarantee layer; corporate/retail (6.4.4) and (re)insurance (6.4.5) primarily address the private-sector risk exposure layer; and critical infrastructure (6.4.3) connects the two by structurally reducing residual risk concentration on the public sector.

The macro layer (SFDRR Targets A–D, country-level baselines, and Expected Maximum Loss reduction benchmarks) and the process layer (ISO 37116 risk-assessment-based eligibility and ex-ante/ex-post monitoring protocols) jointly anchor the five sectoral pathways summarized in Table 5: blended finance (6.4.1), sovereign finance (6.4.2), critical infrastructure (6.4.3), corporate and retail finance (6.4.4), and the (re)insurance sector (6.4.5). The four embedded feedback loops—(1) ex-ante investment, (2) capital attraction, (3) lowered risk and improved data, (4) reduced loss—collectively reverse, element by element, the vicious cycle diagnosed in Figure 1. Each pathway numbered in this figure corresponds directly to the same-numbered pathway in Table 5. Source: authors' synthesis.

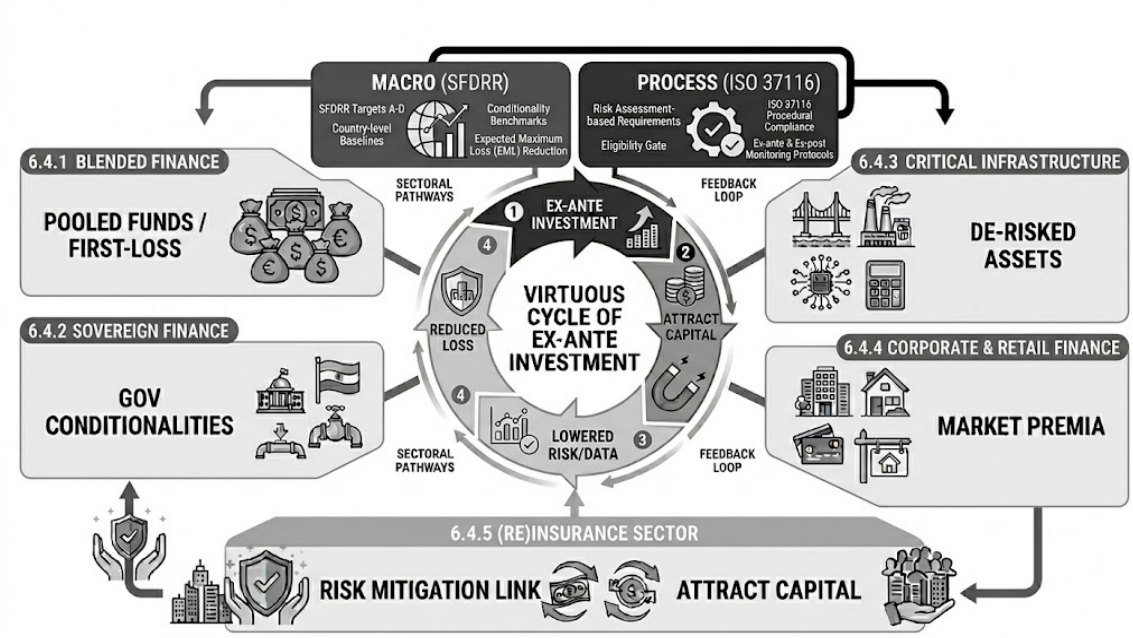


Figure 5. The Proactive Virtuous Cycle of Ex-ante DRR Financing (Positive Feedback Loop).

A necessary corollary of this integrated architecture is the explicit management of residual risk. Even under full deployment of the five pathways, ex-ante investment reduces and reshapes—but does not eliminate—disaster risk. Consistent with the risk-layering principle formalized in Section 2.2 (Table 3), the residual risk that remains after cost-effective mitigation must continue to be financed through complementary instruments: retained reserves and contingency budgets for high-frequency, low-severity layers; insurance and reinsurance for intermediate layers; and CAT bonds, contingent credit, and sovereign backstops for tail layers. The hybrid SFDRR × ISO 37116 framework is therefore designed to rebalance—not replace—the ex-post and risk-transfer components of disaster risk finance: its function is to ensure that the size of each residual layer is progressively compressed by verified ex-ante investment, while the layered financing architecture remains in place to absorb the risk that mitigation cannot economically eliminate.

6.6. Summary: The Convergence of Macro-Metrics and Micro-Processes

Because ISO 37116 functions primarily as a process-oriented standard, its operationalization alone is insufficient to establish a comprehensive capital flow framework for ex-ante risk mitigation. Systemic market failures can be meaningfully addressed through the deployment of a hybrid framework. This framework combines ISO 37116 as the 'common taxonomy for process governance' and the SFDRR as the 'quantitative basis for evaluation metrics', thereby establishing a unified, cross-industry foundation for risk pricing.

Ultimately, an effective strategy for strengthening comprehensive societal resilience requires embedding this integrated framework across multiple layers of the financial and economic system. Implementation should extend from establishing conditionalities for statutory disaster relief frameworks—such as calibrating ex-post sovereign support to verified ex-ante investment levels—to defining eligibility criteria for blended finance tranches, optimizing discount rates for long-term infrastructure investments, narrowing corporate credit spreads, and enhancing traditional (re)insurance underwriting practices. Throughout, these implementation layers presuppose the continued operation of layered ex-post and risk-transfer instruments for the residual risk that ex-ante investment cannot eliminate.

7. Conclusions

This paper has examined the paradigm shift in disaster risk finance from ex-post compensation toward ex-ante investment through three complementary contributions. First, the historical and structural analysis showed how fiscal, insurance-market, and behavioral limitations of the ex-post model reinforce a self-perpetuating vicious cycle that can only be broken by structural capital reallocation rather than incremental reform. Second, the company-level case study of Alps Electric during the 2011 Great East Japan Earthquake provided illustrative—though not confirmatory—evidence that ex-ante DRR-BCM investment translates into contained extraordinary losses and accelerated revenue recovery, patterns qualitatively consistent with the dual-channel mechanism posited

by the Tatano–Tsuchiya recovery-curve framework [41]. Third, the proposed SFDRR × ISO 37116 hybrid framework offers a common measurement infrastructure combining process governance and quantitative indicators, embeddable across blended finance, sovereign finance, critical infrastructure, corporate and retail finance, and the (re)insurance sector, with staged priority for the Asia-Pacific region where the protection gap is most acute. Throughout, the framework is positioned as complementary to—rather than a replacement for—risk-transfer and ex-post mechanisms, which remain indispensable for financing the residual risk that ex-ante investment reduces and reshapes but does not eliminate.

Limitations and Future Research Agenda

Four principal limitations merit explicit acknowledgment. The empirical analysis rests on a single treated unit and is therefore best read as hypothesis-generating; large-sample econometric validation using the full population of DBJ DRR-BCM rated transactions remains a priority research agenda. The framework's cross-border scalability is further constrained by the absence of internationally comparable resilience data infrastructure and by the institutional complexity of integrating the hybrid standard into existing ESG evaluation matrices and the actuarial underwriting models of (re)insurers. The fourth limitation concerns measurement validity: the outcome variables analyzed in Section 5—extraordinary losses and revenue trajectories—are financial proxies for damage and recovery rather than direct operational measures of DRR-BCM performance, such as actual factory downtime, production-line interruption, relocation costs, or post-disaster supply-chain functionality; direct verification of the operational channel would require plant-level data that are not publicly disclosed. These four constraints—empirical generalizability, measurement validity, data standardization, and institutional embedding—must be addressed in parallel to realize the framework's full scalability.

Looking forward, pilot implementation through Multilateral Development Banks (MDBs), UN-affiliated agencies, and institutional long-term investors, combined with the development of standardized sovereign-level and company-level resilience disclosures aligned with International Sustainability Standards Board (ISSB) principles, would enable the hybrid framework to function as a genuine capital-pricing infrastructure rather than a normative aspiration. The 2026 entry into force of ISO 37116, the ongoing Sendai Framework Mid-Term Review, and the 2025 G20 South Africa Presidency's prioritization of pre-arranged DRR financing together provide a uniquely aligned policy window to operationalize this agenda. Such validation should also examine explicitly how verified ex-ante investment interacts with the layered residual-risk financing architecture described in Section 6.5. In particular, a structured evaluation of early ISO 37116 pilot applications—once the standard is embedded in live financial instruments—should form a core component of this agenda, testing whether verified ex-ante investment is in fact priced into financing terms as proposed.

While the empirical evidence presented in this paper is illustrative rather than confirmatory, the hybrid SFDRR × ISO 37116 framework offers, in our view, a promising architectural foundation for the next generation of disaster risk finance—one whose empirical validation should proceed in parallel with the early-adopter implementation opportunities opened by the policy window emerging during the 2026–2030 period that bridges ISO 37116 entry-into-force and the Sendai Framework end-cycle. The framework should accordingly be read as a structured proposal awaiting piloting and empirical validation, rather than as a validated architecture.

Author Contributions

Y.H.: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing—original draft, Visualization. K.O.: Validation, Methodology, Writing—review and editing. S.N.: Conceptualization, Supervision (international DRR policy aspects), Writing—review and editing. K.M.: Supervision (disaster risk management and engineering aspects), Writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Institutional Review Board Statement

This study utilized publicly available data and therefore did not require ethical review or consent.

Informed Consent Statement

Not applicable.

Data Availability Statement

All data supporting the findings of this study are derived from publicly disclosed corporate filings and international policy documents. Specifically: (i) corporate financial data (extraordinary losses, quarterly revenue) for Alps Electric and the six comparison companies were obtained from annual securities reports submitted to the Japanese Financial Services Agency and retrieved via EDINET (https://disclosure.edinet-fsa.go.jp/, accessed on 15 April 2026); (ii) DBJ DRR-BCM program data were obtained from publicly released DBJ program documentation [42]; (iii) ISO 37116:2026 documentation is available via the ISO catalogue; (iv) SFDRR monitoring data are publicly available at https://sendaimonitor.undrr.org/. A compiled dataset of the Alps Electric comparative analysis is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare the following interests. Y. Hiruma is employed by the Development Bank of Japan Inc. (DBJ), which operates the DBJ DRR-BCM Rated Loan Program analyzed as a case study in Section 5. To mitigate potential bias, (i) all financial data used in the comparative analysis were obtained exclusively from publicly disclosed corporate filings (via EDINET), (ii) the selection of comparison companies was based on pre-specified industry- and exposure-based criteria (Appendix A) rather than on outcomes, and (iii) no proprietary DBJ data on the rated company were used. K. Omi is employed by DBJ Institute, Inc., a member of the DBJ Group. S. Nishikawa and K. Meguro declare no competing interests. DBJ had no role in the study design, data interpretation, or the decision to submit the manuscript for publication. Additionally, the DBJ DRR-BCM program was publicly documented in the 2013 UNISDR (now UNDRR) publication Business and Disaster Risk Reduction and is thus a widely observable international benchmark, rather than a proprietary DBJ asset. The program's external recognition, combined with the exclusive use of publicly disclosed EDINET financial data and pre-specified selection criteria (Appendix A), mitigates the risk that the authors' affiliations would influence the empirical findings or their interpretation. In reporting Alps Electric's pre-2011 BCM development history, this study relies exclusively on the company's own publicly available disclosures and on the public DBJ rating announcement of August 2011. No non-public information regarding DBJ–Alps Electric transactional or assessment relationships has been used.

Use of AI and AI-Assisted Technologies

The authors used AI-assisted tools at three clearly delimited stages of the research process, in compliance with Scilight Press's editorial policy on Artificial Intelligence. First, Semantic Scholar and Elicit were used to identify candidate references for the literature review on disaster risk finance, and Litmaps was used to chronologically map the resulting corpus. The final selection, critical appraisal, and analytical interpretation of all sources were performed manually and independently by the authors. Second, generative AI tools (large language models) were used solely to improve the readability and language of the English manuscript drafted by the authors, in line with Scilight Press's policy that "these technologies should only be used to improve the readability and language of the work". No AI tool was used to generate analytical content, conclusions, normative arguments, interpretations of empirical results, or any substantive intellectual contribution. All AI-generated text edits were reviewed and approved by the authors, who take full responsibility for the accuracy and integrity of the manuscript. Third, all empirical analyses—extraordinary-loss compilation, revenue indexing, and recovery-duration estimation—were performed manually by the authors using publicly disclosed EDINET filings, without AI assistance. No AI or AI-assisted tools were used in the creation or alteration of any figure, image, or artwork in this manuscript. All tables and figures were created by the authors using Microsoft Excel and PowerPoint, and Adobe Illustrator. The authors confirm that no AI or AI-assisted technology is listed as an author or co-author of this work. The authors are solely accountable for all content presented herein.

Appendix A. Comparison Company Selection Criteria

Inclusion Criteria:

(C1) Listed on the Tokyo Stock Exchange in the "Electric Appliances" industry classification (TOPIX-17 sector code 5).

(C2) Documented production sites in the disaster-affected prefectures of northeastern Japan—i.e., the Tōhoku region (Iwate, Miyagi, Fukushima) and the adjacent northern Kantō prefecture of Ibaraki—as of 11 March 2011, verified through the company's annual securities report (yūka-shōken hōkokusho).

(C3) Consolidated revenue of at least JPY 200 billion in fiscal year ending March 2010, comparable to Alps Electric's scale (JPY 599 billion in FY2010).
(C4) Continuous quarterly financial disclosure from Q1 FY2010 through Q4 FY2012.
(C5) Not enrolled in the DBJ DRR-BCM Rated Loan Program as of 11 March 2011.

Selected Comparison Companies (n = 6): Renesas Electronics, Murata Manufacturing, Fujitsu, Furukawa Electric, TDK, Tokyo Electron—all satisfying C1–C5.

Treated Company: Alps Electric Co., Ltd. (merged with Alpine Electronics in 2019 to form Alps Alpine Co., Ltd.). According to the company's own public disclosures, Alps Electric had been building its BCM system since 2005, and this pre-existing BCM system was subsequently externally verified by public DBJ DRR-BCM rating in August 2011.

Data Source: Retrieved from EDINET (https://disclosure.edinet-fsa.go.jp/) for all companies; access date: 4 April 2026.

References

1. UNDRR. *International Cooperation in Disaster Risk Reduction*; United Nations Office for Disaster Risk Reduction: Geneva, Switzerland, 2021.
2. OECD. *Fostering Catastrophe Bond Markets in Asia and the Pacific*; OECD Development Centre Studies: Paris, France, 2024.
3. Aon plc. *2025 Climate and Catastrophe Insight*; Aon plc: London, UK, 2025.
4. United Nations Office for Disaster Risk Reduction. *Global Assessment Report on Disaster Risk Reduction 2022—Our World at Risk: Transforming Governance for a Resilient Future*; United Nations: Geneva, Switzerland, 2022. https://doi.org/10.18356/9789210015059.
5. United Nations. Sendai Framework for Disaster Risk Reduction 2015–2030. In *UN General Assembly Resolution A/RES/69/283*; UN: Geneva, Switzerland, 2015.
6. G20 Disaster Risk Reduction Working Group. *G20 Disaster Risk Reduction Ministerial Declaration: Resilience for All—Strengthening Disaster Risk Reduction through Solidarity, Equality and Sustainability*; G20 South Africa Presidency, 2025. Available online: https://www.preventionweb.net/media/111645/download (accessed on 15 April 2026).
7. *ISO 37116:2026*; Sustainable Cities and Communities—Disaster Risk Finance—Principles and General Requirements for Financing Ex-Ante Investment in Risk Reduction. ISO: Geneva, Switzerland, 2026.
8. Ghesquiere, F.; Mahul, O. *Financial Protection of the State against Natural Disasters: A Primer*; World Bank: Washington, DC, USA, 2010.
9. Buchanan, J.M. The Samaritan's Dilemma. In *Altruism, Morality, and Economic Theory*; Phelps, E.S., Ed.; Russell Sage Foundation: New York, NY, USA, 1975; pp. 71–85.
10. General Insurance Rating Organization of Japan (GIROJ). Earthquake Insurance Statistics; GIROJ: Tokyo. Available online: https://www.giroj.or.jp/databank/earthquake.html (accessed on 28 July 2026).
11. Raschky, P.A.; Weck-Hannemann, H. Charity hazard—A real hazard to natural disaster insurance? *Environ. Hazards* **2007**, *7*, 321–329. https://doi.org/10.1016/j.envhaz.2007.09.002.
12. Cummins, J.D.; Mahul, O. *Catastrophe Risk Financing in Developing Countries: Principles for Public Intervention*; The World Bank: Washington, DC, USA, 2008. https://doi.org/10.1596/978-0-8213-7736-9.
13. Tanner, T.; Surminski, S.; Wilkinson, E.; et al. *The Triple Dividend of Resilience: Realising Development Goals through the Multiple Benefits of Disaster Risk Management*; Overseas Development Institute and World Bank: London, UK, 2015.
14. Hallegatte, S.; Rentschler, J.; Rozenberg, J. *Lifelines: The Resilient Infrastructure Opportunity*; World Bank: Washington, DC, USA, 2019.
15. Rokhideh, M.; Fearnley, C.; Budimir, M. Multi-Hazard Early Warning Systems in the Sendai Framework for Disaster Risk Reduction: Achievements, Gaps, and Future Directions. *Int. J. Disaster Risk Sci.* **2025**, *16*, 103–116. https://doi.org/10.1007/s13753-025-00622-9.
16. Ikeda, M.; Palakhamarn, T.; Anbumozhi, V.; et al. Study on the Importance of Investment in DRR and Advanced DRR Technology in ASEAN Countries. In *ERIA Discussion Paper No. 513*; Economic Research Institute for ASEAN and East Asia: Jakarta, Indonesia, 2024.
17. Global Facility for Disaster Reduction and Recovery. *Annual Report 2025: Bringing Resilience to Scale*; World Bank: Washington, DC, USA, 2025.
18. Milly, P.C.D.; Betancourt, J.; Falkenmark, M.; et al. Stationarity Is Dead: Whither Water Management? *Science* **2008**, *319*, 573–574. https://doi.org/10.1126/science.1151915.
19. Hochrainer-Stigler, S.; Mechler, R.; Pflug, G.; et al. Funding public adaptation to climate-related disasters. Estimates for a global fund. *Glob. Environ. Chang.* **2014**, *4*, 253–256. https://doi.org/10.1016/j.gloenvcha.2014.01.011.

20. Giglio, S.; Kelly, B.; Stroebel, J. Climate Finance. *Annu. Rev. Financ. Econ.* **2021**, *13*, 15–36. https://doi.org/10.1146/annurev-financial-102620-103311.
21. Stroebel, J.; Wurgler, J. What do you think about climate finance? *J. Financ. Econ.* **2021**, *142*, 487–498. https://doi.org/10.1016/j.jfineco.2021.08.004.
22. Bolton, P.; Kacperczyk, M. Do investors care about carbon risk? *J. Financ. Econ.* **2021**, *142*, 517–549. https://doi.org/10.1016/j.jfineco.2021.05.008.
23. Pástor, Ľ.; Stambaugh, R.F.; Taylor, L.A. Sustainable investing in equilibrium. *J. Financ. Econ.* **2021**, *142*, 550–571. https://doi.org/10.1016/j.jfineco.2020.12.011.
24. Pástor, Ľ.; Stambaugh, R.F.; Taylor, L.A. Dissecting green returns. *J. Financ. Econ.* **2022**, *146*, 403–424. https://doi.org/10.1016/j.jfineco.2022.07.007.
25. Campiglio, E.; Daumas, L.; Monnin, P.; et al. Climate-related risks in financial assets. *J. Econ. Surv.* **2023**, *37*, 950–992. https://doi.org/10.1111/joes.12525.
26. Basel Committee on Banking Supervision. *Climate-Related Financial Risks: Measurement Methodologies*; Bank for International Settlements: Basel, Switzerland, 2021.
27. Plichta, M.; Scott, Z.; Nagaria, D. *The State of Pre-Arranged Financing for Disasters 2025*; Centre for Disaster Protection: London, UK, 2025.
28. Swiss Re Institute. *Sigma 1/2025: Natural Catastrophes: Insured Losses on Trend to USD 145 Billion In 2025*; Swiss Re: Zurich, Switzerland, 2025.
29. Kellett, J.; Caravani, A. *Financing Disaster Risk Reduction: A 20 Year Story of International Aid*; Overseas Development Institute: London, UK; Global Facility for Disaster Reduction and Recovery: Washington, DC, USA, 2013.
30. Jarzabkowski, P.A.; Chalkias, K.; Cacciatori, E.; et al. *Disaster Insurance Reimagined: Protection in a Time of Increasing Risk*; Oxford University Press: Oxford, UK, 2023. https://doi.org/10.1093/oso/9780192865168.001.0001.
31. Beirne, J.; Renzhi, N.; Volz, U. Feeling the Heat: Climate Risks and the Cost of Sovereign Borrowing. *Int. Rev. Econ. Financ.* **2021**, *76*, 920–936.
32. Klusak, P.; Agarwala, M.; Burke, M.; et al. Rising Temperatures, Falling Ratings: The Effect of Climate Change on Sovereign Creditworthiness. *Manag. Sci.* **2023**, *69*, 7468–7491. https://doi.org/10.1287/mnsc.2023.4869.
33. Kousky, C. *Understanding Disaster Insurance: New Tools for a More Resilient Future*; Island Press: Washington, DC, USA, 2022.
34. Kunreuther, H. Mitigating disaster losses through insurance. *J. Risk Uncertain.* **1996**, *12*, 171–187. https://doi.org/10.1007/bf00055792.
35. Kunreuther, H.; Michel-Kerjan, E.; Ranger, N. Insuring future climate catastrophes. *Clim. Chang.* **2013**, *118*, 339–354. https://doi.org/10.1007/s10584-012-0625-z.
36. Cantelmo, A.; Melina, G.; Papageorgiou, C. Macroeconomic outcomes in disaster-prone countries. *J. Dev. Econ.* **2023**, *161*, 103037. https://doi.org/10.1016/j.jdeveco.2022.103037.
37. He, J.; Wu, L.; Meng, Z.; et al. Cost-Benefit Analysis Method for Disaster Prevention and Restoration Resource Investment in Power Systems Based on Resilience Assessment. In Proceedings of the 2024 IEEE 8th Conference on Energy Internet and Energy System Integration (EI2), Shenyang, China, 29 November–2 December 2024; pp. 4756–4762. https://doi.org/10.1109/ei264398.2024.10991619.
38. Hallegatte, S.; Rentschler, J.; Walsh, B. *Building Back Better: Achieving Resilience through Stronger, Faster, and More Inclusive Post-Disaster Reconstruction*; World Bank: Washington, DC, USA, 2018.
39. Ministry of Land, Infrastructure, Transport and Tourism. *Manual for Economic Surveys on Flood Control [in Japanese]*; MLIT: Tokyo, Japan.
40. Nagami, K.; Inoue, R.; Komori, D. Flood Risk Perception in an Inherently Flood-Prone Urban Area: Based on a Land Price Analysis in the Arakawa River Downstream Area, Tokyo. *J. Disaster Res.* **2025**, *20*, 222–232. https://doi.org/10.20965/jdr.2025.p0222.
41. Tatano, H.; Tsuchiya, S. Economic Impacts of the Transportation Network Disruption: An Extension of SCGE Model. In *Methodologies for Estimating the Economic Impacts of Natural Disasters*; Springer: Singapore, 2021; pp. 85–95.
42. Development Bank of Japan Inc. DBJ DRR-BCM Rated Loan Program—Principles and Outline: Designing a Disaster-Resilient Japan. DBJ: Tokyo. Available online: https://www.dbj.jp/en/service/sustainability_rating/bcm/overview.html (accessed on 2 April 2026).
43. UNISDR. *Business and Disaster Risk Reduction: Good Practices and Case Studies*; United Nations Office for Disaster Risk Reduction: Geneva, Switzerland, 2013. Available online: https://www.preventionweb.net/files/33428_334285essentialscasestudies.pdf (accessed on 18 November 2026).
44. World Economic Forum. *Global Risks 2012*, 7th ed.; World Economic Forum: Geneva, Switzerland, 2012. Available online: https://www3.weforum.org/docs/WEF_GlobalRisks_Report_2012.pdf (accessed on 18 November 2026).

45. Hiruma, Y.; Noda, K. Survey on the Disaster Preparedness and Business Continuity of Companies Based on the Hearing etc. Investigation to CRO in the Great East Japan Earthquake and Consideration of Enterprise Risk Management in Future. *J. Jpn. Soc. Civ. Eng. Ser. A1 Struct. Eng. Earthq. Eng. SE EE* **2012**, *68*, I_1224–I_1238. https://doi.org/10.2208/jscejseee.68.i_1224.
46. Carvalho, V.M.; Nirei, M.; Saito, Y.U.; et al. Supply Chain Disruptions: Evidence from the Great East Japan Earthquake. *Q. J. Econ.* **2021**, *136*, 1255–1321. https://doi.org/10.1093/qje/qjaa044.
47. Todo, Y.; Nakajima, K.; Matous, P. How Do Supply Chain Networks Affect the Resilience of Firms to Natural Disasters? Evidence from the Great East Japan Earthquake. *J. Reg. Sci.* **2015**, *55*, 209–229. https://doi.org/10.1111/jors.12119.
48. Dasgupta, P. *The Economics of Biodiversity: The Dasgupta Review*; HM Treasury: London, UK, 2021.
49. Network for Greening the Financial System. *Nature-Related Financial Risks: A Conceptual Framework to Guide Action by Central Banks and Supervisors*; NGFS Secretariat, Banque de France: Paris, France, 2023.
50. Taskforce on Nature-related Financial Disclosures. *Recommendations of the Taskforce on Nature-related Financial Disclosures*; Taskforce on Nature-related Financial Disclosures: London, UK, 2023
51. United Nations Environment Programme; S&P Global Sustainablel. *Nature Risk Profile: A Methodology for Profiling Nature-Related Dependencies and Impacts*; UNEP: Nairobi, Kenya, 2023.
52. Calice, P.; Diaz Kalan, F.; Miguel, F. *Nature-Related Financial Risks in Brazil*; World Bank: Washington, DC, USA, 2021.
53. Karolyi, G.A.; Tobin-de la Puente, J. Biodiversity finance: A call for research into financing nature. *Financ. Manag.* **2023**, *52*, 231–251. https://doi.org/10.1111/fima.12417.
54. Giglio, S.; Kuchler, T.; Stroebel, J.; et al. *Biodiversity Risk*; National Bureau of Economic Research: Cambridge, MA, USA, 2023.
55. Caldara, D.; Iacoviello, M. Measuring Geopolitical Risk. *Am. Econ. Rev.* **2022**, *112*, 1194–1225. https://doi.org/10.1257/aer.20191823.
56. Caldara, D.; Conlisk, S.; Iacoviello, M.; et al. *The Effect of the War in Ukraine on Global Activity and Inflation*; Board of Governors of the Federal Reserve System: Washington, DC, USA, 2022.
57. World Economic Forum. *The Global Risks Report 2026*, 21st ed.; World Economic Forum: Geneva, Switzerland, 2026.
58. World Bank. *Catastrophe Deferred Drawdown Option (Cat DDO): Product Note*; World Bank: Washington, DC, USA, 2021. Available online: https://thedocs.worldbank.org/en/doc/1820b53ad5cba038ff885cc3758ba59f-0340012021/original/Cat-DDO-IBRD-Product-Note.pdf (accessed on 1 August 2026).
59. Federal Emergency Management Agency (FEMA). *National Flood Insurance Program: Community Rating System—Coordinator's Manual*; Federal Emergency Management Agency (FEMA): Washington, DC, USA, 2017.