White Paper

From Climate Science to Corporate Strategy

A credible and practical approach to quantifying climate risk and its impact on business performance

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Executive Summary

This paper introduces a climate scenario-adjusted valuation model that quantifies climate risks in financial terms by integrating climate science-based scenario analysis with established corporate valuation principles. We designed the approach to be transparent and auditable, fully aligning with emerging disclosure standards (such as IFRS S2 and the EU's ESRS E1 on climate).[1] [2] This ensures the framework can support both internal strategic planning and external reporting requirements, directly connecting climate risk factors to company financial performance.

At its core, the framework links *transition risks* (e.g. policy changes, technological shifts, market dynamics, reputational impacts) and *physical risks* (e.g. acute hazards like floods or cyclones, chronic stresses like heat or drought) directly to company financial statements through defined *transmission channels*. The analysis draws on a broad spectrum of data from climate science and economics. We use Network for Greening the Financial System[3] (NGFS) scenarios (derived from integrated assessment models), macroeconomic pathways from NiGEM,[4] and granular hazard datasets (augmented by ETH Zurich's CLIMADA[5] software) to capture potential impacts. These risk drivers are quantified as changes to revenues, operating costs, capital expenditures (CapEx) and asset impairments, or financing costs. We then integrate these impacts into a standard **discounted cash flow** (DCF) valuation model with strict rules to avoid any double counting between the cash flow projections and the discount rate adjustments. In this way, the model provides a comprehensive bridge between climate scenario outcomes and tangible financial performance metrics.

For transition risk costs, the methodology maps emissions profiles, carbon pricing and compliance costs, technology adoption curves, shifting market demand, and even governance credibility into adjustments of future cash flows. For physical risk costs, it employs geospatial asset mapping, asset-specific vulnerability matrices, and probabilistic damage modeling to compute **expected annual losses** (EAL) from climate hazards.[6] This approach can be further extended with tail-risk calculations to account for infrequent but severe events, ensuring both frequent chronic impacts and rare acute

disasters are captured in the risk assessment. A case study is included to illustrate how these quantified risk impacts translate into line-by-line financial statement adjustments, informing decisions on resilience investments and strategic pivots for the company's business model.

The paper also addresses several *key implementation challenges*. These include ensuring scenario consistency across all inputs, managing the long-time horizons and deep uncertainties inherent in climate projections, maintaining data quality, and accounting for firms' adaptive capacity over time. We emphasize that methodological rigor and transparency are crucial to avoid pitfalls like double counting of risks, false precision in estimates, or inconsistent system boundaries. By aligning our modeling outputs with the latest disclosure standards, the framework allows scenario analysis results to be communicated credibly to regulators, investors, and internal stakeholders. In effect, it closes the gap between climate science, corporate strategy, and financial reporting[7] by making the financial implications of climate scenarios clear and auditable.

Ultimately, this climate scenario–adjusted valuation equips firms to answer a central question: How resilient is our business model and strategy under plausible future climate scenarios? Embedding climate risk into financial analysis and valuation helps companies not only meet regulatory disclosure requirements, but also strengthen investor confidence and guide capital allocation toward long-term resilience.

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Introduction

Over the past decade, the practice of finance and the science of climate have converged to a point where the materiality of climate risk can be quantified with increasing precision. Long-standing financial disciplines: capital budgeting, cost of capital estimation, and performance measurement, now intersect with advances in climate science, scenario design, and impact modeling. This convergence enables decision-useful estimates of how climate risks affect enterprise value, rather than treating sustainability as a parallel or purely qualitative exercise.[8]

Since at least 2012, a growing body of work across academia and the financial sector has documented that well-designed, performance-linked sustainability strategies can be financially accretive, lowering weighted average cost of capital, improving debt terms (particularly when tied to credible key performance indicators), and supporting superior long-term return on equity.[9] In parallel, the transmission channels of transition risk on the path to net zero are increasingly well understood. Beyond explicit carbon pricing, these channels include technology cost curves and adoption rates, shifts in product demand and input mixes, regulatory and legal constraints, and reputational dynamics. Crucially, these drivers can be expressed using traditional cash-flow mechanics: revenues, operating costs, *capital expenditure* (CapEx) and *operating expenditures* (OpEx) retiming, asset lives and impairments, taxes, and financing spreads, so that climate is integrated into, not layered on top of, fundamental valuation.[10]

This paper advances a quantitative framework that translates scenario-based climate drivers into financial outcomes across both transition and physical risk categories, consistent with the **Task Force on Climate-Related Financial Disclosures** (TCFD) taxonomy. For transition risk, we leverage the NGFS scenario set to extract time-stepped deltas and intensity changes in key variables (e.g., carbon prices, energy system composition, sectoral productivity and cost trajectories) and map them to firm and sector-level transmission channels. For physical risk, we employ hazard-exposure-vulnerability constructs, drawing from the **CLIMate ADAptation** (CLIMADA) framework to monetize climate hazards. These are indexed through a vulnerability mapping across different asset types, which are in turn linked to the carrying values reported on the asset side of company balance sheets. This approach ensures that projected hazard intensities and frequencies are consistently translated into expected annual losses, tail-risk shocks, and resilience investment requirements, and ultimately into financial adjustments that reconcile with company accounting.

The structure of the framework serves as the outline of the paper. We begin with data foundations, including **Network for Greening the Financial System** (NGFS) scenario inputs, hazard datasets, and asset-level vulnerability mappings. We then describe transmission channels and their parameterization, ensuring risks are not double-counted but appropriately allocated between cash flows and discount rates. We proceed to the translation of these channels into financial line items across revenues, costs, and asset values, showing how adjustments flow through income statements and balance sheets. We then turn to validation exercises, benchmarking against historical observations, peer practices, and external models. Finally, we present an illustrative case study to demonstrate the application of the methodology.

The framework is designed for reporting relevance. It is aligned with TCFD's focus on governance, strategy, risk management, and metrics and targets; it is prepared with reference to the EU's **Corporate Sustainability Reporting Directive** (CSRD) and accompanying **European Sustainability Reporting Standards** (ESRS) guidelines (notably ESRS E1 on climate); and while not yet fully mapped to International Financial Reporting Standards' (IFRS) International Sustainability Standards Board (ISSB) S2 yet, the methodology is compatible with its disclosure architecture. Once a climate-adjusted performance and valuation are produced, the outputs can be configured to isolate specific drivers, whether to inform strategy and capital allocation, to construct decision-useful risk indicators, or to populate reporting requirements.

This paper distills our research into a transparent, modular, and auditable approach to quantifying climate risk, grounded in established financial techniques and the latest climate scenarios.

Data Foundations

Robust quantification requires a firm grounding in the data sources that underpin both transition and physical climate risk analysis. The accuracy of the final analysis, and the ability for its results to be fully interrogated, rest upon an informed approach to data selection. This section introduces the core datasets used in this framework, without yet turning to how they are operationalized in financial modeling. Our purpose here is to establish the provenance, scope, and limitations of the inputs that shape the results.

At the heart of our approach are the NGFS scenarios, a harmonized set of public pathways designed to test the resilience of economies, financial institutions, and firms under different climate futures. Scenario narratives are organized along two axes: *transition risk* and *physical risk*. Rapid and coordinated climate action reduces long-term physical damages but raises transition costs; conversely, slower or fragmented action tempers immediate transition costs but heightens exposure to physical hazards. Of the available NGFS scenarios, we focus on *Net Zero 2050, Delayed Transition, Current Policies, and Fragmented World*, which together span the range of orderly and disorderly pathways.[11]

Underlying these scenarios are **integrated assessment models** (IAMs), which are computational frameworks that couple energy-economy dynamics with land-use and climate systems. IAMs were developed to reconcile choices between mitigation costs today and physical damages tomorrow, thus linking climate science and macroeconomics, creating quantitative baselines for policymakers and technologists. Early models such as Nordhaus' DICE[12] suggested gradual transitions as cost-optimal; more recent data-rich IAMs increasingly demonstrate that the damages of unchecked climate change exceed the upfront costs of rapid mitigation. The **NGFS Phase V** scenarios employ three complementary IAM families: **Regional Model of Investment and Development-Model of Agricultural Production and its Impact on the Environment** (REMIND-MAgPIE), **Model for Energy Supply Strategy Alternatives**

and their General Environmental Impact-Global Biosphere Management Model (MESSAGE-GLOBIOM**),** and **Global Change Assessment Model** (GCAM)**,** to generate consistent projections of technology deployment, emissions, energy prices, and the shadow carbon prices required to satisfy temperature constraints. These outputs then flow into macroeconomic models, notably the **National Institute Global Econometric Model** (NiGEM), which translate abatement costs and the Kotz et al.[13] damage function into time series for **gross domestic product** (GDP), consumption, and sectoral value added.

Parallel to transition pathways, the NGFS scenarios integrate physical risk data.[14] CMIP6/ISIMIP climate model ensembles provide temperature, precipitation, and extreme-weather indicators at 0.5-degree grid resolution.[15] [16] These variables are used as hazard scalers in the CLIMADA platform, which monetizes expected damages by combining hazard, exposure, and vulnerability. In this way, hazard data (flood depths, wind speeds, wildfire probabilities, drought indices) can be overlaid with geospatially referenced asset registers and mapped through vulnerability functions to generate probabilistic loss distributions.

These datasets offer powerful capabilities but also carry structural limitations. IAMs necessarily simplify complex socioeconomic feedback, assume relatively frictionless markets, and offer only limited representation of adaptation costs or tipping points (such as the rapid repricing of assets following damages from a significant weather event). Physical risk projections inherit uncertainties from climate models, downscaling methods, and damage functions. For this reason, NGFS supervisors stress that scenarios should be treated as *stress tests rather than forecasts*, and that sensitivity checks around key assumptions are essential. Looking ahead, NGFS Phase VI aims to expand granularity further, integrating supply-chain shocks, explicit adaptation cost curves, and finer regional resolution.[17]

Together, these scenario pathways, IAM outputs, macroeconomic translations, and physical hazard datasets constitute the *data foundations* of our framework. In the sections that follow, we turn from data to *transmission channels,* showing how the raw variables of carbon prices, energy mixes, GDP shocks, and hazard intensities are mapped into financial mechanisms of transition and physical risk, consistent with the TCFD taxonomy.

Climate Risk: Transition and Physical Risks

More than half of the world's 250 largest companies disclose climate change as a financial risk, and central banks have begun to embed climate scenarios into their systemic stress testing frameworks.[18] This reflects a growing recognition that climate change creates material financial risks that are both *idiosyncratic to firms* and *systemic to the macroeconomy*, and that these risks require rigorous analysis consistent with financial principles.

The taxonomy provided by the TCFD remains the most widely adopted. It distinguishes between *transition risks* - those stemming from the socioeconomic shift to a low-carbon economy - and *physical risks*, which arise from the direct impacts of a changing climate.

Each category is composed of distinct drivers that can disrupt revenues, costs, asset values, or financing capacity. This paper is deliberately *risk-focused*. While opportunities exist in a low-carbon transition, monetizing them properly belongs in the domain of valuation analysis. Here, we concentrate on risks that can *impair* enterprise value.[19]

Transition Risks

The US **Environmental Protection Agency** (EPA) defines transition risks as those "associated with the pace and extent at which an organization manages and adapts to the internal and external pace of change to reduce greenhouse gas emissions and transition to renewable energy."[20] In practice, a company's vulnerability depends heavily on the credibility of its transition plan. Firms with robust, science-based decarbonization targets, e.g. **Science Based Targets Initiative** (SBTi) alignment and tangible investments in adaptation will face a lower risk premium than those lagging.[21]

Transition risks fall into four key categories:

- *Policy and Legal*: Increasing carbon prices and stricter regulations create direct cost items, while litigation risk grows for firms that fail to decarbonize or disclose adequately.
- *Technology*: Rapid innovation generates disruption as incumbents face obsolescence. Companies with weaker R&D pipelines or limited access to new technologies risk being displaced.
- *Market***:** Demand shifts toward low-carbon products and rising input costs (energy, water, commodities) erode profitability.
- *Reputation*: Reputational damage can amplify these risks by constraining capital access and market share.

These drivers translate into financial impacts such as higher OpEx, asset impairments, write-offs, increased CapEx for compliance and technology adoption, and shifts in revenue mix. Importantly, under the efficient market's assumption, firms' disclosed transition plans will be increasingly priced into their equity risk profiles over time. [22]

Physical Risks

Physical risks stem from the acute and chronic effects of climate change on the environment, assets, and supply chains. They present as *hazards* that impair productivity, disrupt operations, or damage capital stock. We structure them here by hazard type:

- *Droughts*: Prolonged water scarcity impacts agriculture directly and raises costs for water-intensive industries.
- *Extreme Heat*: Erodes labor productivity and increases cooling costs; poses both acute (heatwaves) and chronic risks.

- *Cyclones and Hurricanes:* Cause acute damage to infrastructure and assets, with non-linear loss scaling.
- *Wildfire*: Acute but recurring seasonal risk, heavily influenced by local conditions and adaptation measures.
- *Flooding and Extreme Precipitation:* Lead to property damage and systemic disruptions to supply chains; chronic rainfall changes can degrade long-term productivity.

The financial impacts of physical risks include reduced revenues from lower sales or disrupted production, increased costs for repairs, insurance, or adaptation, write-offs of impaired assets, higher capital costs, and in some cases loss of insurability for high-risk assets.[23]

Transmission Channels

Having established the taxonomy of risks, we now turn to the *transmission channels***,** the mechanisms through which transition and physical risks enter the financial system of a company. These channels serve as the bridge between scenario data and corporate financial statements.

To avoid double counting, each risk driver is allocated either to *cash-flow adjustments* or to *discount rate adjustments*, but *never both* - this is the *non-duplication rule* that will inform this approach and should be considered best practice.

As our team has researched these transmission channels, we have identified a set of common *impact variables***,** quantitative parameters that capture the magnitude of effects such as carbon cost per ton, energy price uplifts, labor productivity losses, insurance premium changes, or damage ratios by hazard type. These variables are calibrated against NGFS scenario data and CLIMADA hazard-impact functions and are used consistently across models to ensure comparability and auditability.

Transition Risk Transmission Channels

15. *Carbon Pricing and Regulation*: Carbon taxes or emissions trading schemes translate directly into higher operating costs. These costs are modeled line-by-line against Scope 1 and 2 emissions, with adjustments for sectoral leakage and policy stringency.
16. *Technology Shifts*: Innovation alters CapEx schedules and OpEx. Costs of adopting new technologies (e.g., electrification, **carbon capture and sequestration** (CCS) are modeled as increased CapEx or OpEx, while stranded assets appear as impairments or shortened useful lives.
17. *Market Dynamics*: Shifts in consumer demand toward low-carbon products affect revenues, while higher input prices (energy, water, agricultural commodities) inflate

Cost of Goods Sold (COGS). These are reflected in top-line growth assumptions and gross margin adjustments.

18. *Reputation and Capital Access*: While difficult to quantify independently, reputational risks manifest through higher financing costs or reduced revenue growth. These are modeled as modest adjustments to debt spreads or revenue trajectories, contingent on company-specific narratives.

Physical Risk Transmission Channels

1. *Acute Hazards*: Events such as cyclones, floods, or wildfires are modeled through EAL's and tail-risk events. CLIMADA hazard modules, coupled with vulnerability functions, provide probabilistic damage ratios that translate into operating cost shocks or asset impairments.
2. *Chronic Hazards*: Long-term stressors such as droughts, extreme heat, or sea-level rise are embedded in baseline productivity, revenue growth, and input cost assumptions. For example, heat-induced labor productivity losses are treated as reductions in output per worker, while droughts affect agricultural input prices.
3. *Insurance and Adaptation Costs*: Rising premiums or declining availability of insurance are included as recurring operating expenses. Adaptation investments (e.g., flood defenses, fireproof retrofits) are reflected as CapEx outlays that reduce future expected losses. The incorporation of insurance costs into climate-adjusted valuation remains limited, both in corporate practice and in academic literature, largely because it requires assumptions about how insurers will adapt their underwriting and claims behavior in a changing climate. In theory, insurance should cover many physical losses, replacement of damaged assets and, where negotiated, lost operating revenues from major disruptions. In practice, however, the ability of insurers to continue offering affordable coverage in disaster-prone regions is increasingly uncertain. As climate hazards intensify, the industry must work closely with regulators and corporate clients to design forward-looking structures that sustain risk transfer, prevent the creation of stranded assets, and ensure continued access to viable and affordable insurance markets.[24]

Valuation Methodology

Having identified the data and mapped the transmission channels, we now turn to the *valuation methodology***,** the means by which quantified risks are incorporated into company financials and valuations. Here, we adopt DCF analysis as the central framework. DCF is the dominant method for intrinsic valuation and the one most consistent with CSRD, IFRS S2, and ESRS disclosure requirements. It provides a structured way to embed climate risk into financial projections, ensuring consistency with established capital market practices.

DCF analysis involves three principal levers:

1. Projected Cash Flows

Free cash flows are forecast to an explicit horizon, with each line item adjusted for climate-related risks that can be quantified with defensible data:

- *Policy and Legal Risks*: Jurisdiction-specific carbon price curves are applied to Scope 1 and 2 emissions, yielding direct carbon costs. Compliance requirements are modeled as OpEx (additional headcount, reporting, audits), while regulatory phase-outs or litigation outcomes can trigger CapEx or impairments.
- *Technology Risks*: Adoption of low-carbon substitutes and process electrification are captured as incremental CapEx or OpEx, benchmarked against cost curves for renewables, CCS, or hydrogen. Failure to invest may show up as lost market share or stranded assets.
- *Market Risks*: Commodity-price trajectories, such as long-run differentials between green and grey ammonia or increased agricultural input costs, are reflected in COGS. Shifts in consumer demand toward low-carbon products affect revenues directly.
- *Reputation Risks*: While inherently qualitative, reputational drivers manifest indirectly through financing spreads or demand destruction. These are included conservatively as adjustments to revenues or borrowing costs where appropriate.
- *Physical Risks*: Acute perils such as cyclones, floods, or wildfires are modeled via CLIMADA to produce expected annual losses and tail-risk distributions, which are then introduced as OpEx shocks or asset impairments. Chronic phenomena such as drought-induced water scarcity, extreme heat, or sea-level rise are embedded in baseline productivity assumptions and long-term growth trajectories.

This structure ensures that cash-flow forecasts integrate both transition and physical drivers without conflating them.

2. Discount Rate

The discount rate translates climate risk into the price of capital but should only reflect *non-diversifiable* uncertainties. Non-diversifiable risks in this case represent those that are intrinsic to the market and broader economy, particularly in this context represented by disorderly futures and scenarios that invoke greater uncertainty as to the size and consistency of the cash flows of all firms in the market. Firm-specific exposures (e.g., a factory in a floodplain) are diversifiable and therefore embedded in cash flows, not in the **weighted average cost of capital** (WACC).

- *Capital Asset Pricing Model (CAPM) Framework*: Required return on equity is expressed as $RE = Rf + \beta(E(Rm) - Rf)$. Beta, measuring covariance with the market, is the appropriate lever to represent systematic climate risk.

- *Systematic Transition Risks*: A globally coordinated rise in carbon prices or breakthrough in green technologies can shift entire markets. Empirical studies show high-emission portfolios covary more strongly with market drawdowns. In practice, this supports modest upward adjustments to beta (e.g., 5-15 bps in aggressive transition scenarios) rather than arbitrary premiums.
- *Policy and Jurisdictional Risks*: Concentrated regulatory exposure may justify a sector or country-risk premium if strongly correlated with equity shocks.
- *Physical Risks*: Idiosyncratic hazards remain in cash flows. Only residual global covariance (e.g., systemic insurance repricing or macro-scale climate shocks) belongs in WACC.
- *Debt Markets*: Any adjustment to cost of equity must flow consistently into cost of debt, reflecting higher default probabilities and wider spreads under stressed scenarios.

Because historical betas and premia were estimated in a climate-stable regime, past relationships are imperfect guides to a warming world. Adjustments must therefore be applied sparingly, tested across a plausible range, and disclosed alongside climate-neutral rates. This "*steady-hand*" approach ensures transparency while acknowledging uncertainty in market pricing of climate risk.

3. Terminal Growth Rate

Terminal value, which often dominates present value, is anchored in NGFS scenario GDP paths. A revenue-weighted blend of country-level GDP growth (2040–2100) under alternative temperature outcomes provides an upper bound for steady-state assumptions. The NGFS scenarios include GDP growth rates for each major economy. Long-term predicted GDP growth rates are commonly used as the growth rates embedded within the terminal value calculations for valuation. Those rates indicated by the NGFS scenarios can be directly substituted here to maintain faithfulness to the futures prescribed by the scenarios. Shorter-term, sector and firm-specific revenue growth rates are reflected in the manually projected cash flows (which themselves are longer than most DCFs).

Implementation

The methodology proceeds in three steps:

1. *Risk Identification*: Map transition and physical drivers onto the firm's value chain, using scenario data and company-specific disclosures.
2. *Allocation*: Apply the non-duplication rule, ensuring each risk is reflected either in cash flows or in WACC, not both.
3. *Calibration*: Sensitize variables against NGFS pathways, using at least one orderly Paris-aligned scenario and one high-warming pathway. This bounds financial

outcomes within a scenario-adjusted valuation range that is auditable and compliant with disclosure standards.

Quantification Approach - Transition Costs

Transition cost quantification requires a structured, data driven approach to ensure that all relevant channels are represented. Our framework proceeds in several layers:

Emissions Mapping and Carbon Costs

We begin with mapping of the firm's Scope 1, Scope 2, and where feasible, Scope 3 emissions. Jurisdiction-specific carbon price curves from NGFS scenarios are then applied, generating forward-looking cost schedules. These costs flow directly into OpEx, adjusted for the firm's mitigation trajectory and the credibility of its transition plan.

Compliance and Regulatory Costs

Regulatory risk is modeled through incremental head count, reporting, and audit costs. These are estimated using benchmarks from firms already subject to ISSB/CSRD-aligned rules. Jurisdictional differences are reflected through scaling factors tied to NGFS macroeconomic pathways.

Technology Costs and Stranded Assets

Adoption of low-carbon technologies, such as electrification of processes, hydrogen integration, or CCS, is modeled through capital expenditure curves. These are informed by IAM technology cost trajectories and industry cost benchmarks. Stranded asset risk is modeled as impairment charges or shortened useful lives, consistent with financial reporting standards.[25]

Market Risks

Market risks capture both demand-side and supply-side shocks:

- Demand destruction from shifts in consumer preferences (e.g., from ICE vehicles to EVs)
- Supply-side cost increases, including commodity prices for agricultural inputs and energy
- Cross-sectoral impacts captured through NGFS GDP and consumption variables.

Reputation Risks

Reputation is not modeled as an independent driver, but as a modifier of revenue growth and financing spreads. Where reputational risk is material, it manifests in higher costs of capital or reduced sales, aligning with the efficient-markets perspective that only quantifiable factors enter valuations.

Integration into Financial Models

Transition costs are embedded line-by-line into the DCF framework:

- Carbon costs → OpEx
- Compliance costs → Selling, General & Administrative expenses (SG&A)
- Technology adoption → CapEx and OpEx
- Stranded assets → Impairments
- Market risks → Revenue growth assumptions

Residual, non-diversifiable uncertainties (e.g., systemic carbon price shocks) are reflected in discount rates under the non-duplication rule.

While transition risks primarily reshape the firm's operating environment through policy, technology, markets, and reputation, physical risks arise from nature-driven shocks that directly impact assets and operations. Quantifying these requires a distinct, asset level methodology that captures hazard exposure, vulnerability, and probabilistic loss distributions.

Quantification Approach - Physical Costs

Quantifying physical climate costs requires an asset level methodology that integrates hazard projections, vulnerability functions, and exposure data into probabilistic loss distributions. Our methodology builds on years of research and tool development.

Data Sources

We integrate three primary data pillars:

- **Climate Analytics' Climate Impact Explorer (CIE)** provides hazard scalers under NGFS scenarios for key perils including floods, droughts, cyclones, wildfires, and extreme heat. [26]
- **Climate Adaptation Damage Assessment (CLIMADA),** developed by ETH Zürich/IPTA, is an opensource platform with peril-specific hazard modules, exposure datasets, and empirically calibrated damage functions.
- **Library of Calibrated Damage Functions** is a repository of vulnerability curves developed over years of research providing standardized relationships between hazard intensities and damage ratios across asset types.[27]

Additionally, we draw from the **Climate Adaptation Coverage Assessment Platform (Kibana Toolkit, IPTA)**, which enhances our ability to visualize, calibrate, and validate loss distributions.[28]

Methodology

Asset Identification and Geospatial Mapping

We construct a georeferenced exposure database of all relevant assets. Each entry includes coordinates (latitude/longitude); replacement value; structural class (e.g., light wood frame, reinforced concrete, steel frame, prefabricated metal); and functional occupancy (industrial plant, warehouse, residential building, data center, agricultural land).

These assets are overlaid with high resolution hazard maps from CIE and CLIMADA. Each pixel in the exposure dataset is matched to hazard intensities for relevant perils (flood depth, cyclone gust speed, wildfire probability, drought index, etc.). The outcome is an **asset hazard exposure matrix**. This matrix enables two key aspects of analysis. First, it provides a structured way to roll up asset-level results into portfolio or company-side climate risk metrics, if desired. Second, it is a tool for decision support by prioritizing adaptation investments by showing which assets are most at risk, under which hazards, and under which climate pathways. When combined with a vulnerability analysis (describeb below), it also allows calculation of damage ratios for each asset.

Vulnerability Assessment

Hazard intensities are transformed into damage ratios via a vulnerability matrix. Key hazard-specific considerations include:

- **Floods:** Foundation elevation, presence/type of basement, structural materials, and local flood defenses
- **Cyclones:** Roof-wall connections, garage door ratings, opening protection, roof shape, wind design zone
- **Wildfires:** Roof material, defensible space clearance, building code compliance, and vegetation density
- **Heat Stress:** Cooling system availability, roof reflectance, insulation, and workforce exposure

Where company specific data is incomplete, we apply sectoral averages from the calibrated library, ensuring consistency with both insurance practice and engineering data.[29]

Probabilistic Damage Estimation

CLIMADA's event generators produce thousands of stochastic events per peril:

- **Cyclones:** Synthetic track catalogs produce wind and surge fields consistent with NGFS scaled SST warming.
- **Floods:** Riverine flood depths are scaled with NGFS/CIE hazard multipliers before being convolved with exposure.

- **Wildfires:** Annual burned area fractions are mapped directly to assets, adjusted by *vulnerability multipliers.*

For each event, *hazard intensity* × *vulnerability factor* × *replacement value* yields a loss estimate. Aggregating these across thousands of events provides:

- **Expected Annual Loss (EAL):** The recurring average annualized damage
- **Value at Risk (VaR):** Tail-risk metrics (e.g., 1 in 100 year loss)
- **Full Loss Distribution:** A probability distribution of losses, critical for stress testing and capital planning, if required

Integration into Financial Models

Outputs are integrated into financial statements:

- **OpEx:** EAL is treated as recurring expenses.
- **CapEx:** Adaptation investments (flood barriers, wildfire retrofits, cooling infrastructure) are modeled as resilience expenditures that reduce vulnerability factors.
- **Asset Impairments:** Repeated losses or high tail-risk exposures trigger impairments or shortened useful lives.
- **Insurance:** Rising premiums and declining coverage availability are modeled as recurring OpEx tied to hazard-specific loss distributions.

This methodology provides a robust, auditable framework for physical risk quantification. It combines NGFS-aligned hazard projections, CLIMADA's probabilistic loss engine, and calibrated vulnerability functions with geospatial asset mapping and financial integration. The result is a transparent, detailed, and replicable process for converting climate hazards into line-by-line financial impacts, fully aligned with CSRD, IFRS S2, and ESRS disclosure requirements.

Taken together, the quantification of transition and physical risks provides a comprehensive picture of how climate change affects company value. Transition risks are integrated into line items through policy, technology, market, and reputation channels, while physical risks are mapped through hazard, exposure, and vulnerability to generate expected losses and asset impairments. Although the methodologies are rigorous, they are straightforward to implement when broken down into parts; Transition risks in its parts such as emissions mapping, compliance costs, and technology adoption for transition, all non-exhaustive examples; and asset mapping, vulnerability functions, and probabilistic loss modeling for physical risk. The following case study demonstrates how these building blocks can be applied in practice to produce an accessible, credible, and decision-useful climate-adjusted valuation.

Illustrative Case Study: Data Center Operator

Business Profile:

The subject company operates 10 major data centers across North America, each with an approximate replacement value of **US$500 million** (total asset base around $5 billion). Data centers are highly capital and energy intensive, serving as critical infrastructure for the digital economy. In the FY 2025 baseline, the firm's revenue is about **$10.0 billion**, expected to grow ***~3%*** annually. The ***EBITDA margin*** is roughly ***27.5%***, translating to ***$2.75 billion*** EBITDA before any climate-related impacts. This margin reflects substantial ongoing power and cooling expenses, offset by the scale of operations. The company also incurs continuous ***maintenance capital expenditures*** (approximately **$167 million per year** on a $5 billion asset base) roughly equal to depreciation, indicating that routine upkeep investment is required just to maintain current capacity. Overall, the business model relies on reliable energy supply and physical resilience to keep these data centers operational with high uptime, given the critical services they provide.

Scenario Description:

Two contrasting climate scenarios aligned with NGFS pathways are applied to the data center portfolio: an ***"Net Zero 2050"*** scenario and a ***"Current Policies"*** scenario. The Net Zero 2050 scenario represents an ***ambitious, orderly transition*** in which aggressive climate policies limit warming to ~1.5°C by mid-century through steep emissions reductions. This pathway entails progressively higher carbon prices, rapid decarbonization, and significant transition activity, but it substantially mitigates physical climate hazards over the long run. In contrast, the Current Policies scenario assumes ***no new climate initiatives beyond those already in place***, leading to a much higher warming trajectory (on the order of 3°C+ by 2100). With limited mitigation, the Current Policies pathway subjects the company's asset base to more severe physical climate impacts over time.

Under Net Zero 2050, climate policies are stringent; carbon costs rise sharply, and the energy system decarbonizes - resulting in ***lower intensification of extreme weather*** by 2040–2050, versus Current Policies, where the lack of further mitigation leads to unabated climate change causing ***physical risks to escalate dramatically***. For example, hazard modeling indicates the data centers' EAL from climate extremes ***doubles under Current Policies (~US$55 million/year)*** compared to ***Net Zero (~US$25 million)*** by mid-century. Likewise, the ***99th-percentile Value at Risk*** for an extreme climate event (e.g. a 1-in-100 year flood or storm) is far higher in the high-warming case (approximately ***$400 million loss potential***) versus the low-warming case ***(~$180 million)***. These stark divergences align with macroeconomic scenario outcomes - global GDP is projected to be roughly ***14% lower by 2050 under current policies*** (high physical damage drag) versus about ***7% lower under a net-zero pathway***, reflecting how unchecked climate change imposes greater economic costs. In summary, the Net Zero 2050 scenario creates a challenging transition environment but limits physical damages, whereas the Current Policies scenario spares the company major transition costs but exposes it to significantly higher climate-driven losses and uncertainty.

Transition Risk Identification:

For a data center operator, the primary transition risk-drivers include ***policy and regulatory changes***, ***technological shifts for efficiency***, ***market demand changes***, and ***reputation/credit considerations***. These factors manifest differently under the two scenarios:

- **Policy/Regulatory Risk:** In the Net Zero 2050 scenario, robust climate policies introduce ***carbon pricing and stricter regulations*** that directly increase operating costs (e.g. carbon taxes on power and fuel) and compliance burdens. By contrast, the Current Policies scenario has ***negligible new carbon regulation***, resulting in limited carbon pricing or new climate mandates for the company to comply with. This means transition-related costs are expected to be much lower in the high-emissions scenario.
- **Technology Investments:** To align with Net Zero goals, the firm must invest in ***energy-efficient and low-carbon technologies***, such as advanced cooling systems or on-site renewables, to reduce its carbon footprint and energy consumption from the grid. These are modeled as ***incremental capital expenditures*** in the Net Zero case and are relatively minor in scale. In the Current Policies case, such investments are less urgent since there is no regulatory support - the company may still pursue efficiency for cost savings, but there is no external requirement driving large technology shifts.
- **Market and Reputation:** Data center services are considered mission-critical with stable demand. The analysis assumes ***minimal market demand shift*** away from the company in either scenario – customers continue to require data services, and there's no "low-carbon" alternative product to displace the core business. Likewise, reputational risk (e.g. backlash for high emissions) is not modeled as a major factor, given the firm has a credible ***transition plan*** and the industry's critical role. Thus, ***revenues are projected to grow*** similarly in both scenarios, without punitive loss of market share or pricing power due to transition factors. Any ***legal/litigation risk*** related to climate (part of policy risk) is also assumed to be low since the company is proactively managing its emissions trajectory.

In summary, carbon pricing and related regulatory compliance are the dominant transition risks for this company. These risks are ***significant*** in the Net Zero scenario (higher costs to operate and invest in cleaner tech), whereas in the Current Policies scenario they are largely ***absent***, i.e. few policy-driven costs. Other transition risk channels (technology, market, reputation) are present but relatively ***muted or manageable*** for this data center operator, as reflected in the similar growth outlook maintained across the two scenarios.

Transition Risk Quantification:

To quantify transition risks in financial terms, the analysis adjusts the company's projections for ***operating costs, capital expenditures, discount rate,*** *and* ***long-term growth*** assumptions under each scenario. All adjustments follow the methodology's ***non-duplication rule***, i.e., each risk impact is either modeled in cash flows or in the discount rate, but ***not double-counted***. Below we detail the transition-related adjustments for both the Net Zero 2050 scenario and the ***Current Policies*** scenario:

Operating Expenditures (OpEx):

Carbon Pricing Costs: In the Net Zero 2050 scenario, a rising carbon price is applied to the data centers' operational emissions consisting primarily of electricity usage and backup generators. Starting around ***$10/ton*** in ***2025*** and escalating to roughly ***$150/ton*** by ***2045***, this policy translates into a ***carbon tax expense*** growing from about ***$10 million in 2025 to $150 million per year by 2045***. These figures assume the company emits on the order of ***1 MtCO_2 annually***, so the carbon price directly drives a substantial new operating cost in a Paris-aligned pathway. We also include ***climate regulatory compliance costs*** (for example, enhanced reporting and audit requirements) as small increases in ***SG&A expense*** in the Net Zero case.

By contrast, under the Current Policies scenario, there are ***no new carbon taxes or stringent emissions rules*** beyond the status quo. Any carbon cost is minimal – roughly ***$5 million*** initially**,** rising to ***~$30 million/year by 2045*** under modest assumed carbon price increases ***(only ~$5 to $30/ton over two decades)***. In other words, the firm's direct OpEx related to climate policy remains very low in the absence of aggressive regulation. ***Energy costs*** might still rise slightly in Current Policies (due to market trends or existing policies), but there is no externally imposed carbon price shock. Overall, the Net Zero scenario imposes significant additional operating costs from carbon pricing and compliance, whereas Current Policies spares the company these transition OpEx hits (though it will incur higher physical costs instead, as discussed later). The small OpEx savings in the Current Policies path (lack of carbon taxes) are acknowledged but are far outweighed by the physical damage costs that materialize in the scenario.

Capital Expenditures (CapEx):

Under an accelerated transition (Net Zero 2050), the company plans ***proactive investments to decarbonize and improve energy efficiency***. This includes clean technology upgrades to cooling systems, power backup, and possibly on-site renewable energy installations. The case study models them as ***minor additional CapEx*** spread over the initial years of the company's cash flows, the rationale being the firm can achieve most emissions reductions through purchasing electricity from the grid and operational tweaks, with only small incremental investments (e.g. higher-efficiency HVAC equipment or energy storage) needed to meet policy requirements. We note that these costs are included explicitly in the Net Zero scenario cash flows (i.e. as upticks in

CapEx), therefore following the methodology of mapping technology shifts and compliance to the financial statements.

In the Current Policies scenario, by comparison, there is ***no regulatory driver*** for major decarbonization investments. The company would largely continue its business-as-usual CapEx plan to primarily just routine maintenance and any growth-related projects, without needing to divert funds to carbon mitigation technology. Thus, we assume ***negligible incremental transition CapEx*** in the Current Policies case beyond normal operations. (Notably, the **physical risk adaptation CapEx** the firm undertakes is addressed separately in the physical risk section; here we are only discussing transition-driven expenditures.) The bottom line is that ***Net Zero demands higher upfront CapEx*** for cleaner operations, while Current Policies avoids those costs. However, the scale of these transition CapEx differences is small relative to the company's overall investment budget – the scenario's ***lack of carbon mandates yields some savings*****,** but minor in the scheme of total cash flows.

Discount Rate

The ***discount rate or WACC*** reflects how investors price the riskiness of future cash flows. According to the framework, foreseeable transition risks are quantified in cash flows ***(OpEx/CapEx)***, and only residual, non-diversifiable uncertainties should affect the discount rate. In practice, this means the analysis did not add any ***extra risk premium*** for transition policy uncertainty in either scenario; all known transition costs (carbon taxes, compliance, etc.) are already accounted for in the cash flow forecasts, and thus we keep the ***base WACC*** consistent between the scenarios initially for transition considerations. The Net Zero 2050 scenario is an ***"orderly" transition****,* which, while imposing costs, is relatively well-signaled and global in scope; it's reasonable to assume investors would not view the firm as fundamentally riskier in a policy-driven decarbonization pathway if the company has a well-reasoned plan (especially since our model explicitly captures those costs). Meanwhile, the Current Policies scenario entails minimal transition change. In this case, there is no added policy risk premium needed.

It is noteworthy that if a scenario involved a ***disorderly or highly uncertain transition***, the analysis might consider a higher cost of capital to reflect the inherent volatility. In our chosen scenarios, however, the major systemic uncertainties come more from physical risks than from transition execution. Therefore, ***no upward adjustment to the discount rate*** is applied for transition risk alone. Adjustments to the discount rate will stem from ***physical risk and related residual uncertainty*****.**

Physical Risk Identification:

Physical risks refer to the potential for acute weather events and chronic climate changes to harm the company's assets and operations. Data centers are exposed to several key climate-related hazards:

- **Flooding and Storms:** Extreme precipitation events, riverine floods, and hurricane-induced storm surges can ***damage facilities or disrupt operations***. Some of the data centers (especially coastal or low-lying sites) face risk of flood inundation during severe storms. Tropical cyclones/hurricanes bring high winds and flooding that can cause acute physical damage to infrastructure, with losses ***scaling non-linearly*** with storm intensity.

- **Extreme Heat:** Data centers generate immense heat and rely on cooling systems. ***Heatwaves*** and ***higher average temperatures*** impose chronic stress on cooling infrastructure, increasing energy usage and asset operating costs to maintain safe temperatures. Extreme heat events can also threaten equipment reliability and even cause downtime if cooling capacity is exceeded. Thus, ***acute heatwaves*** are a risk (e.g. requiring emergency shutdowns), and ***chronic rising temperatures*** gradually increase cooling costs and strain to hardware.

- **Wildfires:** In certain regions, ***wildfire seasons*** pose a direct threat to data center facilities. Wildfires could physically damage structures and equipment, especially those near wildland-urban interfaces. Even if flames do not reach a facility, smoke and particulate pollution can infiltrate ventilation systems, and precautionary power shutdowns (or grid outages) can disrupt operations. Wildfire risk is highly ***location-dependent*** and can be mitigated by defensible space and fire-resistant construction, but it remains a significant ***acute seasonal risk*** that could occur annually under dryer and hotter climate conditions.

- **Drought and Water Stress:** Many data centers use water for cooling (e.g. in cooling towers). ***Prolonged droughts*** and water scarcity can ***raise* costs** for water-intensive operations and potentially constrain cooling capacity. If water supply is restricted, the data center might need to curtail usage or invest in alternative cooling methods. Drought can also indirectly affect the reliability of the electrical grid (hydropower reductions or thermal power plants etc), compounding operational risk. While not as immediately destructive as a storm, chronic water stress is an important hazard for data centers in arid regions.

- **Chronic Sea-Level Rise:** Over a multi-decade horizon, ***sea-level rise*** can exacerbate coastal flooding risk. Data centers near coasts could see higher baseline water levels, making moderate storms more damaging. This is a slower-onset trend but relevant for long-term asset planning (beyond the 20-year scope, sea-level rise could threaten sites absent major flood defenses). In the NGFS scenarios used, sea-level rise is partly captured in increased flood hazard over time, and we assume adaptation measures (e.g. raised flood walls) for vulnerable sites, if applicable.

Under both scenarios, the company faces these hazard types, but the ***frequency and severity of events sharply diverge*** between scenarios. In the Net Zero 2050 scenario, global mitigation efforts ***"bend the curve"*** on climate change; by mid-century, the intensification of hazards is limited. Extreme events still occur, but physical risk is substantially lower than it would be otherwise. In the Current Policies scenario, continued high emissions lead to significantly worsened climate extremes in that there are more frequent and intense storms and floods, more severe heatwaves and wildfires, etc. The case study's modeling shows the tangible difference - expected annual climate-related losses are roughly ***double under Current Policies versus Net Zero***, and in the worst-case, event losses are more than twice as high in the high-warming scenario. This indicates that unmitigated climate change greatly increases the uncertainty and hazard exposure for the data center operator. The physical risk identification thus highlights a critical trade-off - **lower transition scenario = higher physical risk**, and vice versa. Both scenarios require the company to understand its hazard exposure, but the ***urgency and scale*** of impacts are much greater under Current Policies.

Physical Risk Quantification

Quantifying physical climate risk involves translating the identified hazards into *financial impacts on cash flows and value.* This case study uses a ***probabilistic damage modeling approach***, leveraging the CLIMADA platform and scenario data to estimate expected damages for the company's assets. Climate hazard projections from the NGFS scenarios (e.g. intensity of floods, frequency of extreme heat, wildfire probabilities, etc.) are combined with the ***firm's exposure*** (the location and value of each data center) and ***vulnerability*** (how susceptible those facilities are to damage) to produce ***loss distributions***. In practical terms, thousands of stochastic event simulations are run for each peril (flood, storm, wildfire, etc.) using CLIMADA's damage functions, yielding metrics like ***Expected Annual Loss*** (the average annual damage), and ***Value at Risk*** for extreme events. These results then inform specific financial adjustments. Below, we break down how physical risks are integrated into the valuation for both scenarios, across operating costs, capital expenditures, asset values, insurance costs, discount rate, and growth assumptions:

- **Expected Damage Costs (OpEx):** The **EAL** climate hazards is treated as a ***recurring operating expense*** in the cash flow model. In the Net Zero scenario, because global warming is limited, the EAL for the portfolio is relatively low, on the order of ***$25 million per year*** by the 2040s. In the Current Policies scenario, the EAL grows significantly over time with worsening hazards, reaching roughly ***$50–60 million per year*** by the 2040s. These expected damage costs include physical repairs, replacement of damaged equipment, and operational disruptions due to moderate weather events (e.g. minor floods, storms, cooling failures in heatwaves) occurring on an annual basis. The ***cumulative present value*** of these physical damage costs materially ***erodes enterprise value*** under the high-emissions scenario. In modeling terms, we explicitly add the ***projected EAL each year as an OpEx*** line item, increasing over time for Current Policies (and remaining relatively flat for Net Zero, even declining slightly in later years if warming stabilizes). By doing so, we ensure the ***baseline EBITDA*** is adjusted for expected climate losses. This treatment captures chronic and frequent acute losses directly in cash flows. It's important to note that ***tail-risk events*** (very severe, low-probability disasters) are not scheduled deterministically in the cash flows; however, their potential impact is considered via ***scenario risk analysis*** - specifically in how they influence insurance and discount rate (see below).
- **Insurance Costs (OpEx):** Insuring data center assets against climate-related damage is becoming more costly as hazards intensify. In the Current Policies scenario, we assume ***property insurance premiums*** rise steeply, on the order

of a ***2–3× increase by year 20*** for high-risk locations. This assumption is informed by external analyses warning that without significant adaptation, insurance for climate-exposed assets could become prohibitively expensive or even unavailable by mid-century. We incorporate this by ***escalating the insurance expense in the OpEx*** - the company's insurance costs grow much faster under Current Policies than they do under Net Zero. By contrast, in the Net Zero scenario the risk outlook is better, so insurance premiums only ***rise modestly*** (roughly tracking inflation and slight risk reductions). Ultimately, in the high-risk scenario it costs the company a lot more each year to insure its facilities (or self-insure where the market withdraws), which subtracts from cash flows. This models the ***indirect cost of risk transfer*** – climate risk doesn't just hit through direct damage, but also through higher insurance OpEx. If certain assets become effectively ***uninsurable*** due to extreme risk, the analysis assumes the firm would bear those potential losses itself, equivalent to even higher operating costs or possible eventual write-offs.

- **Asset Impairments (Asset Values/Depreciation):** More severe physical risks can lead to ***stranded assets or premature asset write-downs***. In the Current Policies scenario, we assume earlier asset impairment charges for the most vulnerable data centers. For example, a coastal facility that in a normal climate might have a 30-year useful life may effectively have only ~20 years of economic life due to escalating flood risk. We model this by ***shortening the depreciation horizon*** for such assets and scheduling an ***impairment expense*** in the mid-2030s in the Current Policies cash flows (reflecting a major climate-related hit, e.g. a flood that knocks out part of a facility's value). This reduces the book value of the asset and results in a one-time non-cash charge (which in DCF affects value through a lower terminal asset base and potentially higher replacement CapEx needs). In the Net Zero scenario, we do ***not assume any climate-driven impairments***, i.e. assets are assumed to live out their intended lifespans supported by both the global risk reduction and the adaptation measures in place. Financially, asset impairments in the high-risk scenario contribute to lower free cash flow (if modeled as a cost for repairs) and a ***lower terminal value*** (since some assets effectively have to be replaced sooner or end up stranded with no value). This aligns with the expectation that ***unchecked physical climate change can strand assets*** and cause earlier capital write-offs. The model ensures this impairment loss is counted in the Current Policies cash flows and not double-counted in the discount rate.

- **Resilience Investments (CapEx):** A critical part of the analysis is the company's ***adaptation response***. The data center operator is investing US$200 million in ***resilience CapEx*** during years 1–5 of the projection. This proactive program includes measures such as upgrading flood defenses, improving cooling systems to handle extreme heat, installing fire suppression and defensible buffers for wildfire, and other hardening of facilities. These investments are explicitly modeled as additional CapEx outflows early in the projection (which temporarily lowers free cash flow). However, they are undertaken because they ***reduce future damage***, in effect, the adaptation measures reduce the vulnerability of the assets by ~30% on average. In terms of outcomes, by the end of the investment program (year 5), the ***EAL is about $20 million lower*** than it would have been without these measures in the Current Policies scenario. We thus see a ***net benefit (positive NPV)*** for the adaptation project - the present value of avoided losses exceed the $200 million cost. In the Net Zero scenario, the same $200 million adaptation is assumed for prudence, though it effectively "over-builds" safety (because hazards are less intense). The ***absolute loss avoidance*** in Net Zero is smaller (maybe <$10 million/year benefit) since baseline risk was low, but it still provides reliability benefits. To maintain like for like comparison, we included the same adaptation CapEx in both scenarios. In summary, ***resilience CapEx is modeled as a cash outflow*** in the early years and as a ***reduction in future OpEx losses*** thereafter. This "spend now to save later" approach yields what we term an ***"adaptation uplift"*** to value by ***"bending down"*** the loss curve, the company preserves some enterprise value that would otherwise be lost to climate damage. The case study results will show how this adaptation affects the valuation under each scenario.

- **Discount Rate (Risk Premium):** While most physical risk impacts are quantified in the cash flows (as described above), the analysis considers that some ***residual risk and uncertainty*** from physical climate change warrants an adjustment to the discount rate. Investors might demand a higher return for assets exposed to severe climate volatility, especially for the tail risks that are difficult to diversify away. In the Current Policies scenario, we assign a slightly **higher WACC** to reflect this greater systematic risk. Practically, this was modeled as a small risk premium of a few ***tens of basis points*** on the cost of equity (e.g. equivalent to adding ~0.3%–0.5% sensitivity to WACC) in the high-physical-risk scenario. That increase is meant to capture the ***non-diversifiable uncertainty*** (e.g. the chance of extreme climate shocks causing economy-wide or market instability) that remains beyond what we explicitly put in the cash flows. By contrast, the Net Zero scenario is viewed as having lower residual risk; we assume ***no additional risk premium*** (or a negligible one) for physical uncertainties. Illustrating the difference - the core discount rate (absent climate factors) might be ~8% WACC for both scenarios initially, but we might use ***~8.3% in Current Policies versus 8.0% in Net Zero***. Although this premium is small, compounded over 20 years it has a meaningful impact on valuation (even a <1% change in discount rate can shift NPV by a few percent). It's important to emphasize we ***do not double-count*** risks; the WACC uplift in Current Policies should only capture the ***hard-to-quantify uncertainty***, e.g. the possibility that things turn out worse than expected, or that investor sentiment penalizes high-risk firms. This approach is consistent with financial theory that firm-specific foreseeable risks, such as a particular site's flood risk, are "diversifiable" and handled in cash flows, whereas systemic risks, such as like economy-wide climate downturns) affect the discount rate. The result is a higher cost of capital under the high-warming scenario, which further diminishes the present value of future cash flows in that scenario.

Long-Term Growth Rate:

We set terminal growth to reflect NGFS-aligned US GDP pathways, recognizing lower long-run potential growth under high-warming conditions. Specifically, we use 2.5% for Net Zero 2050, and 2.2% for Current Policies. This approach anchors terminal value to scenario-consistent macro trajectories, aligns with our methodology that terminal growth should be bounded by country-level GDP potential, and captures that macro damages and productivity losses are materially larger under CP (e.g., ~14% global GDP loss by 2050 under CP vs ~7% under NZ). We keep explicit-period revenue growth at ~3% in both scenarios, reflecting that data centers are increasingly essential services, so scenario differentiation enters primarily through the terminal value.

Scenario-Adjusted Valuation

Finally, we combine the transition and physical risk adjustments to derive a ***scenario-adjusted enterprise valuation*** for the company under each scenario. For our case study, a 20-year discounted cash flow (DCF) model was used, incorporating the modified cash flows (reflecting carbon costs, hazard losses, insurance, adaptation capEx, etc.) and scenario-specific discount rates discussed above and a terminal value growth rate. The result is two distinct enterprise values - one for the Net Zero 2050 scenario and one for the Current Policies scenario.

Net Zero 2050 Scenario Valuation: In the Net Zero case, the company faces higher operating costs from carbon pricing and some additional CapEx for transition, but benefits from lower physical damages and a slightly lower risk premium. ***Free cash flows*** are somewhat reduced by transition costs, yet the stability and lower hazard losses help preserve long-term value. Using a WACC reflecting no extra physical risk premium, the ***enterprise value (EV)*** calculated under Net Zero is higher than under Current Policies, on the order of **5%.** We can interpret this as the low-physical-risk pathway yielding the more favorable valuation for the company, despite the transition expenses. The climate-friendly scenario avoids a lot of future damage and uncertainty, which supports a stronger valuation.

Current Policies Scenario Valuation: In the high-emissions scenario, the company saves on carbon taxes and compliance costs but suffers greater ongoing losses (OpEx) from climate damages, higher insurance outlays, periodic asset impairments, and faces a slightly higher discount rate on its cash flows. These factors cause ***lower expected free cash flows*** and a ***heavier discount***, reducing the company's intrinsic value. Our analysis finds the EV in the Current Policies scenario comes out about ***5% lower than in the Net Zero scenario***. In other words, failing to mitigate climate change is estimated to **erode roughly 5% of the company's value** versus an orderly transition case (all else being equal).

This ***~5% valuation gap*** is material in corporate finance terms. A swing of several percent in enterprise value translates to potentially billions of dollars for a company of this size. It underscores that ***long-term climate outcomes can tangibly impact firm value***, even for a data infrastructure-centric business, when accounted for both transition and physical risks in a rigorous DCF framework. The drivers of the EV difference are clear: (1) ***Higher costs and lower cash flows*** in the Current Policies scenario due to physical damages, adaptation expenses, insurance costs, and lost asset value (all dragging down cash flow and terminal value), and (2) a ***higher discount rate*** applied to those cash flows, meaning future earnings in the risky scenario are valued less in present terms. We carefully avoided double-counting, i.e. we didn't count the same risk in both cash flow and WACC, so the ***5% delta represents the combined effect*** of distinct cash flow impacts and a modest risk premium.

Importantly, the analysis considered the effect of the company's ***adaptation efforts*** on valuation. The $200 million resilience investment proved to be value-accretive - it ***reduced the EV drag*** in the Current Policies scenario by preserving cash flows that would have been lost to climate damages. In fact, if the company did not invest in adaptation at all, our modeling suggests the Current Policies scenario EV could end up around ***7–8% lower than the Net Zero scenario*** (i.e. several extra points of value lost). By spending on adaptation measures, the firm achieved an ***"adaptation uplift"***, narrowing that gap to ~5%. This highlights that adaptation was a worthwhile endeavor, yielding a ***positive NPV*** *and* ***mitigating some of the shareholder value at risk*** from climate change. Conversely, even with adaptation, there remains a residual value hit in the high-warming scenario, illustrating that not all climate risk can be engineered away, especially the systemic aspects.

Challenges and Considerations

Implementing climate-scenario-adjusted valuation in financial analysis entails a multitude of methodological challenges. These challenges span both *transition risks* (arising from policy, market, and technology shifts as the economy moves toward net zero) and *physical risks* (stemming from climate-induced weather events and long-term changes). Below we outline the most material challenges, grouped thematically, reflecting both academic rigor and practical financial modeling realities.

Scenario Design and Consistency Across Variables

A fundamental challenge lies in ensuring scenarios are *internally consistent* across policy, economic, and hazard variables. Transition and physical risk pathways must align with the same emissions trajectory, temperature outcome, and socioeconomic assumptions. Combining mismatched inputs (e.g., a high-policy transition pathway with hazards from a weak-policy world) produces contradictions and undermines credibility.

Scenario integrity requires:

- **Sourcing consistently from** authoritative scenario sets (NGFS, IPCC, IAM families).
- **Avoiding patchwork assumptions** that create gaps or double counting.
- **Clarifying System Boundaries**, especially around spillovers. A global carbon price not only hits direct emissions but cascades through supply chains, energy markets, and consumer demand. Mapping these interactions without omission or duplication is a persistent challenge.

Financial regulators highlight the difficulty of *downscaling* global scenarios to firm-level impacts. Translating aggregate shocks (like GDP loss from heat stress) into company-specific cash flow projections requires careful calibration to avoid overstating or understating exposures.[30]

Time Horizons and Accounting for Uncertainty

Most corporate forecasts span 3–5 years, whereas climate scenarios extend to 2030, 2050, or 2100.

- **Valuation windows:** Our modeling employs *15-year and 20-year horizons* to capture transition cycles and escalating physical risks.
- **Beyond horizon:** Longer-run effects are captured in terminal growth assumptions and residual risk schedules, rather than speculative line-by-line adjustments far into the future.
- **Uncertainty layers:** *Scenario uncertainty* (future emissions), *structural uncertainty* (model form), and *parametric uncertainty* (input values such as carbon price or climate sensitivity) all compound over time.

- **Best practice:** Regulators recommend using multiple scenarios to bound possible futures rather than assigning probabilities. *Sensitivity analysis* on critical inputs (e.g., carbon prices, discount rates, damage functions) is essential to show robustness.

The goal is not precise prediction but an informed understanding of how valuations respond under diverse climate conditions. [31]

Data Granularity and Quality

Robust valuations rely on high-quality data, yet gaps remain pervasive.

Physical risk data:

- Requires asset-level geolocation and hazard projections.
- Many firms lack complete geospatial data.
- Climate models often have coarse resolution, forcing reliance on proxies or vendor datasets.

Vulnerability functions:

- Translating hazard intensities into damages depends on calibrated damage curves, which must reflect local building standards, asset types, and regional resilience.
- Miscalibration can distort results.

Transition data:

- Scope 1 and 2 emissions are increasingly disclosed, but Scope 3 data remain incomplete and inconsistent.
- As IFRS S2 acknowledges, Scope 3 reporting is challenging, yet critical for transition risk quantification.

Comparability:

- Differing methodologies across firms hinder like-for-like analysis, requiring normalization and conservative assumptions.
- Transparency around data limitations, along with sensitivity analysis (e.g., ±20% error margins), is essential to preserve credibility.[32]

Financial Modeling and Double Counting

Integrating climate risk into valuation models raises the core challenge of *where to book the impact* - cash flows or discount rates. We apply the non-duplication rule introduced earlier:

- **Cash flow adjustments** are appropriate where risks can be quantified with reasonable confidence (carbon costs, compliance expenses, hazard damages).

- **Discount rate adjustments** should capture only residual, non-diversifiable uncertainties not reflected in cash flows.

Double counting can occur if the same risk is reflected twice, for instance, reducing revenues due to carbon taxes while also inflating WACC for "policy risk." Similarly, macro scenario outputs (GDP dampening from climate impacts) must not be combined with equivalent firm-level shocks. Clear *system boundaries* are critical - direct company costs should be modeled at the micro level, while macro effects embedded in scenario inputs should not be reapplied.

Adaptive Capacity and Dynamic Response Modeling

Climate valuation must not assume firms are passive recipients of shocks. In practice, companies adapt:

- **Physical risk adaptation:** Building flood defenses, upgrading HVAC for heat stress, relocating vulnerable sites. Modeling requires assumptions about timing, cost, and effectiveness.
- **Transition adaptation:** Capital turnover, technology adoption, and asset retirements. For example, accelerated retirement of coal assets under 2°C pathways, with CapEx for renewables. These actions materially alter emissions exposure and competitive positioning.

Modeling adaptive capacity is inherently uncertain; timing, scale, and effectiveness vary. Analysts should bound outcomes by comparing "no adaptation" vs. "reasonable adaptation" cases, while documenting assumptions clearly. Adaptive responses by governments and consumers (e.g., public infrastructure, shifts in demand) further complicate dynamics but cannot be ignored. The ability and willingness of companies to adapt in the face of increasing risk at a future date, whether physical or transitional, particularly when the risk becomes observably financially material, cannot readily be estimated by an analyst. This is crucial as 'climate laggards', i.e. companies that appear to face significant transition risks due to inaction, may be able to quickly rectify their position, supported by capital or technological resources, potentially limiting the accuracy of attributions of increased risk.

Implementing climate-adjusted valuation entails grappling with scenario design, long horizons, data gaps, modeling boundaries, and adaptive dynamics. These challenges underscore why robust methodologies and transparent assumptions are essential. Addressing them lays the groundwork for subsequent steps, such as aligning valuation practice with emerging *disclosure standards* like CSRD/ESRS and IFRS S2, ensuring outputs are not only analytically sound but also compliant with evolving regulatory expectations.[33]

Alignment with Evolving Disclosure Standards (IFRS S2 and ESRS E1-9)

Any methodology for climate-scenario-adjusted valuation must ultimately be compatible with the disclosure frameworks that are rapidly becoming mandatory for companies worldwide. As discussed in the introduction, our aim is not only to quantify climate risk in financial terms but to do so in a way that can withstand scrutiny from regulators, investors, and auditors. The convergence of accounting and climate science requires that our outputs be decision-useful, transparent, and aligned with standards that dictate how climate information must appear in corporate reporting. Two standards in particular - **IFRS Sustainability Disclosure Standard S2** (Climate-Related Disclosures) and **ESRS E1-9** (Climate Change - Financial Effects) set the benchmark for what regulators and stakeholders now expect.

IFRS S2: Climate-Related Disclosures

Issued by the ISSB in 2023, IFRS S2 requires companies to disclose their significant climate-related risks and opportunities and describe how these may affect their strategy, business model, and financial performance.[34] Central to the standard is the requirement that management assess the *climate resilience* of their business under alternative scenarios, commonly a 1.5°C - 2°C orderly transition pathway and a higher-warming disorderly or current-policies case.

In practice, IFRS S2 requires companies to:

- Distinguish between *transition risks* (policy, technology, market, reputation) and *physical risks* (acute and chronic hazards).
- Quantify impacts by financial statement line items, such as revenue erosion, OpEx increases, asset impairments, or higher financing costs.
- Connect scenario analysis to tangible financial metrics, including impairments, provisions, and adjusted asset useful lives.
- Document assumptions clearly, including discount rates, carbon prices, and hazard functions.

This means that an internal climate valuation exercise must be robust enough to flow directly into published disclosures. If scenario results suggest a material impairment or shortened useful life for a high emitting asset, IFRS S2 obliges management either to adjust financial statements or to disclose the risk transparently. The bar is therefore high. Valuations must be evidence-based, transparent, and sufficiently documented to withstand any audit challenges.[35]

ESRS E19: Climate Change - Financial Effects

The ESRS, issued under the CSRD, go a step further in requiring companies to disclose the *anticipated financial effects of material transition and physical risks* as well as climate-related opportunities. ESRS E1-9 sits alongside other climate standards (e.g., E1-6 on gross GHG emissions, E1-8 on internal carbon pricing) and ties quantitative financial effects back to emissions, strategy, and governance. A distinctive feature of the ESRS is its *double materiality* perspective, i.e. firms must disclose not only how climate change affects them financially, but also how their activities impact climate outcomes. For E1-9, the focus is on financial materiality, but it must be consistent with environmental materiality disclosures elsewhere.

Key challenges in applying E1-9 include:

- *Consistency across disclosures:* Financial impacts reported under E1-9 must align with the risk narratives, emissions trajectories, and adaptation measures disclosed under other ESRS requirements.
- *Clear attribution:* Transition and physical risks must be quantified separately to avoid double counting, even where risks interact (e.g., a storm causing asset damage that also triggers higher insurance premiums or regulatory scrutiny).
- *Granularity vs. communication:* While underlying models may be highly complex, disclosures must present results in a clear and digestible format, such as ranges of financial impact under different scenarios.

In practice, this requires careful judgment. For instance, if management discloses that a facility will be adapted to withstand flooding, then the reported financial effect should reflect residual risk after adaptation, not before. Conversely, if no adaptation is assumed, the financial effect should clearly state it represents a pre-mitigation loss estimate.[36]

Bridging Methodology and Disclosure

The methodologies outlined earlier in this paper - structured scenario design, extended but disciplined time horizons, robust treatment of data quality, clear system boundaries, and adaptive response modeling - provide the building blocks for disclosure alignment. Several principles stand out:

- *Traceability:* Every modeled financial impact must be linked back to a scenario driver and methodological assumption, enabling audit and regulatory review.
- *Separation of risk types:* Transition and physical risks are reported distinctly, consistent with IFRS S2 and ESRS categories.
- *Avoid double counting:* Careful mapping ensures macroeconomic shocks embedded in scenarios are not layered on again at the micro level.
- *Strategic integration:* Disclosures must not stop at just reporting impacts; they must explain how risks are managed. Investors expect to see capital allocation, resilience investments, or R&D efforts tied to the risks disclosed.

Toward Investor-Relevant Communication

Both IFRS S2 and ESRS E1-9 stress that climate disclosures are not academic exercises. They must inform investor and stakeholder decision making. This means presenting results in clear, comparable, and investor friendly ways, while maintaining methodological rigor. For example, scenario-adjusted valuations should show not only expected losses or cost increases but also management's response, such as planned adaptation CapEx or strategic pivots.

Bridging the complexity of our modeling with the clarity required in disclosures is itself a challenge. Highly technical assumptions (e.g., vulnerability functions, stochastic loss distributions) must ultimately be expressed as high-level impacts on EBITDA, balance sheet strength, or cost of capital.

Conclusion

Aligning climates-scenario-adjusted valuation with IFRS S2 and ESRS E1-9 closes the loop of our methodology. Beginning with rigorous data foundations and consistent scenarios, translating risks into financial line items, and addressing methodological challenges, we end with the disclosures that meet the standards of global regulators. When performed with transparency and discipline, this alignment not only ensures compliance but also enhances strategic decision making, positioning companies to demonstrate resilience, credibility, and leadership in the face of climate change.

Alignment with Scientific Scenarios and Financial Integrity: The proposed framework inherits the same scientific analysis that underpins NGFS climate scenarios and integrated assessment models. By using this foundation, the methodology aligns with a credible, research-backed view of future climate and economic conditions. The scenarios are built on IAMs that couple energy, economy, and climate dynamics, ensuring internal consistency between mitigation actions and physical climate outcomes. Data inputs and calibration steps are transparently documented for use: variables (e.g. carbon prices, technologies, hazard intensities) are explicitly calibrated to NGFS scenario data and peer-reviewed damage functions. This approach guarantees that the financial loss estimates remain faithful to the scenarios' intent. The model sensitizes company-specific assumptions to at least one orderly (Paris-aligned) scenario and one disorderly high-warming scenario, bracketing outcomes within an auditable range.

The valuation approach adheres to established corporate finance principles. All quantified climate impacts (whether from transition policy costs or physical damages) flow through classic valuation mechanics, such as revenues, expenses, capital expenditures, asset lives and finally as an input to the DCF analysis. In line with best practices, it allocates risks to cash flows whenever they can be reasonably quantified (e.g. explicit carbon costs, physical damage losses) and reserves capital cost adjustments for residual uncertainties that cannot be captured in cash flow projections. This non-duplication principle,[37] also emphasized in standard CFA guidance on valuation, means the model does not penalize the company twice for the same risk.

The terminal growth rates in the valuation are anchored to long-run macroeconomic trajectories from the scenarios, rather than arbitrary placeholders. For example, the terminal growth is set in line with scenario-aligned GDP growth (e.g. ~2.5% in a Net Zero 2050 world versus ~2.2% under Current Policies). Anchoring the terminal value to scenario GDP paths captures the differentiated impact of climate change on long-run growth.

Accessibility: The framework is designed to be accessible and decision-useful for non-technical leaders from C-suite executives and board members to enterprise risk officers. The model's structure is deliberately modular and transparent, allowing users to see how each module (e.g. a carbon price trajectory or a flood damage function) affects financial outcomes, under different scenarios. Additionally, it provides the outputs required by ESRS and IFRS standards. By translating abstract climate science into financial line items, the approach speaks the language of business, which makes the results digestible for those who may not be climate scientists. This means the 'climate-adjusted' financial results can be directly used in reporting and communication with regulators and investors, bolstering trust and transparency. Executives can use these outputs to answer the practical question of "How resilient is our business model under various climate futures?" and then act on that insight.

The path forward for companies: This integrative approach equips firms with a forward-looking capability enabling them to identify where value is at risk, evaluate the payoff of resilience investments, and credibly demonstrate their climate resilience to stakeholders. It provides an actionable path for companies to incorporate climate change into core strategic and financial decisions, rather than treating it as a separate sustainability sidebar. Data and science will continue to advance with new research, and companies can thus refine their risk assessments as better data emerges, without overhauling the entire approach, a crucial consideration given the rapid advancements in climate science.

APA Citation for the Paper:

Azim, A., & Khan, S. (2025). From climate science to corporate strategy: A credible and practical approach to quantifying climate risk and its impact on business performance [White paper]. BSR. https://www.bsr.org/en/our-insights/report-view/quantifying-climate-risk-financial-valuation

Glossary:

Asset Hazard Exposure Matrix: A geospatial mapping that links each asset's location, value, and type to peril intensities (e.g., flood depth, wind speed, heat) for loss estimation.

Calibrated Damage Functions (CDFs): Empirical/engineering curves translating hazard intensity into expected damage ratios by asset class.

Carbon Capture and Sequestration (CCS): Technologies that capture CO_2 from point sources or air and permanently store it (e.g., in geological formations).

CLIMADA: Open-source platform (ETH Zurich/IPTA) for probabilistic modeling of hazards, exposure, vulnerability, and adaptation benefits (outputs include EAL and VaR).

Climate Adaptation Coverage Assessment Platform: Toolkit to visualize and parameterize hazard–exposure–vulnerability data and assess adaptation options in physical-risk modeling.

Climate Analytics' Climate Impact Explorer (CIE): Scenario-consistent hazard scalers (e.g., flood, heat, drought, wildfire) used to drive physical-risk quantification.

Corporate Sustainability Reporting Directive (CSRD): EU directive mandating standardized sustainability disclosures, including climate risks and financial effects.

Cost of Goods Sold (COGS): Direct production costs (materials, energy, direct labor); climate risks affect COGS via input prices, carbon costs, and disruptions.

Discounted Cash Flow (DCF): Valuation method discounting projected free cash flows and terminal value at a risk-appropriate rate to estimate enterprise value.

Environmental Protection Agency (EPA): U.S. environmental regulator; its rules and guidance influence transition risk and compliance costs.

European Sustainability Reporting Standards (ESRS): Detailed standards under CSRD covering E/S/G topics; include climate metrics, targets, and scenario analysis.

Expected Annual Losses (EAL): Long-run average of annualized losses from climate hazards (damage plus downtime), combining hazard frequency/severity with exposure and vulnerability.

GCAM (Global Change Analysis Model): IAM linking energy, economy, land, water, and climate systems to produce emissions and technology pathways.

Gross Domestic Product (GDP): Aggregate economic output; scenario GDP paths anchor long-run demand/productivity and terminal-growth assumptions.

IFRS Sustainability Disclosure Standard S2 (IFRS S2): ISSB climate-related disclosure standard requiring governance, strategy, risk, metrics/targets, and scenario analysis.

Integrated assessment models (IAMs): Models coupling socioeconomic/energy/land systems with climate physics to assess mitigation costs, emissions, and pathways (e.g., REMIND-MAgPIE, MESSAGE-GLOBIOM, GCAM).

MESSAGE-GLOBIOM: IIASA framework combining energy system optimization (MESSAGEix) with land-use/agriculture (GLOBIOM) for scenario-consistent trajectories.

Network for Greening the Financial System (NGFS): Central bank supervisor network providing reference climate scenarios and guidance for assessing transition and physical risks.

NGFS Phase V: Latest NGFS scenario release with updated IAMs, damage functions, macro linkages (e.g., NiGEM), and expanded physical-risk variables.

NiGEM (National Institute Global Econometric Model): Multi-country macro-econometric model translating scenario inputs into GDP, inflation, and sectoral paths.

REMIND-MAgPIE: Coupled IAM combining energy–economy optimization (REMIND) with land-use/food modeling (MAgPIE).

Science Based Targets initiative (SBTi): Standard-setter validating corporate emissions-reduction targets against 1.5°C/Well-Below-2°C pathways.

Task Force on Climate-Related Financial Disclosures (TCFD): FSB framework defining governance, strategy, risk management, and metrics/targets for climate disclosure, including scenario analysis.

Weighted average cost of capital (WACC): Firm's blended cost of debt and equity used to discount cash flows.

Sources:

1. International Sustainability Standards Board (ISSB), *IFRS S2 Climate-related Disclosures* (London: IFRS Foundation, June 2023).
2. European Commission, *Commission Delegated Regulation (EU) 2023/2772 of 31 July 2023 … establishing European Sustainability Reporting Standards (ESRS)*, including ESRS E1 “Climate Change,” *Official Journal of the European Union*, L 387 (22 December 2023)
3. Network for Greening the Financial System (NGFS), *NGFS Climate Scenarios: Technical Documentation*, Phase V (January 2025).
4. National Institute of Economic and Social Research (NIESR), *NiGEM Model Manual 2023* (London: NIESR, 2023)
5. CLIMADA Project (ETH Zürich), “Welcome to CLIMADA! — CLIMADA 6.0.0 Documentation,” accessed September 8, 2025.
6. Federal Emergency Management Agency (FEMA), “Expected Annual Loss (EAL) | National Risk Index,” accessed September 8, 2025
7. Task Force on Climate-related Financial Disclosures (TCFD), *Guidance on Scenario Analysis for Non-Financial Companies* (October 2020).
8. International Sustainability Standards Board (ISSB), *IFRS S2 Climate-related Disclosures—Basis for Conclusions* (London: IFRS Foundation, June 2023).
9. Gunnar Friede, Timo Busch, and Alexander Bassen, “ESG and Financial Performance: Aggregated Evidence from More than 2000 Empirical Studies,” *Journal of Sustainable Finance & Investment* 5, no. 4 (2015): 210–233.
10. UK Financial Reporting Council, *Thematic Review: Discount Rates* (May 2022).
11. NGFS, *Long-term Climate Scenarios—Main Presentation (Phase V)*, November 2024 (scenario set and framework).
12. William D. Nordhaus, “The ‘DICE’ Model: Background and Structure of a Dynamic Integrated Model of Climate and the Economy,” *Cowles Foundation Discussion Paper* No. 1009, 1992.
13. Maximilian Kotz, Anders Levermann, and Leonie Wenz, “The Economic Commitment of Climate Change,” *Nature* 629 (2024): 737–742.
14. NGFS, *Explanatory Note: Damage Functions, NGFS Scenarios, and the Economic Commitment of Climate Change* (Phase V), November 2024.

15. Veronika Eyring et al., “Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6),” *Geoscientific Model Development* (2016).
16. ISIMIP Coordination Team, “ISIMIP3b CMIP6-based bias-adjusted atmospheric climate input data (0.5° grid),” dataset description and documentation.
17. NGFS, *Press Release: First Vintage of Short-Term Climate Scenarios* (May 7, 2025)
18. KPMG, “Climate Risk and Financial Disclosures: Current Practices,” *KPMG Global* (2023)
19. TCFD, *Final Report: Recommendations of the Task Force on Climate-related Financial Disclosures* (June 2017).
20. US Environmental Protection Agency (EPA), “Climate Change and Financial Risks,” EPA Climate Indicators and Risk Guidance, accessed September 2025.
21. Science Based Targets initiative (SBTi), *Foundations of Science-Based Target Setting* (October 2019).
22. Bolton, Patrick, Morgan Després, Luiz Awazu Pereira da Silva, Frédéric Samama, and Romain Svartzman. *The Green Swan: Central Banking and Financial Stability in the Age of Climate Change.* Basel: Bank for International Settlements, 2020.
23. European Central Bank, *Climate-Related Risks to Financial Stability* (May 2021).
24. Mills, Evan. “Insurance in a Climate of Change.” *Science* 309, no. 5737 (2005): 1040–1044; and Geneva Association, *Climate Change Risk Assessment for the Insurance Industry* (2021).
25. International Accounting Standards Board (IASB), *IAS 36 Impairment of Assets* (London: IFRS Foundation, 2023)
26. Climate Analytics, *Climate Impact Explorer (CIE): NGFS-Aligned Climate Hazard Explorer*, accessed September 2025.
27. CLIMADA Documentation v6.0, “Vulnerability and Impact Functions.” accessed September 2025.
28. ETH Zürich/IPTA, *Climate Adaptation Coverage Assessment Platform (Kibana Toolkit)*, documentation release, 2024.
29. Basel Committee on Banking Supervision, *Climate-related Risk Drivers and Their Transmission Channels* (2021)

30. NGFS, "*Scenarios Are Neither Forecasts Nor Predictions*," in *Not Too Late: Confronting the Growing Odds of a Late and Disorderly Transition* (2022)
31. IFRS Foundation, *IFRS S2 Climate-related Disclosures*, June 2023
32. The Green Transition and Adaptive Capacity of Firms," *Review of Financial Studies* 36, no. 9 (2023): 3485–3521
33. FEMA, *Hazus Technical Manual* (Washington, DC: FEMA, 2020)
34. International Sustainability Standards Board (ISSB), *IFRS S2 Climate-related Disclosures* (London: IFRS Foundation, June 2023).
35. IFRS Foundation, *Basis for Conclusions on IFRS S2 Climate-related Disclosures* (June 2023).
36. European Commission, *Commission Delegated Regulation (EU) 2023/2772 of 31 July 2023 … establishing European Sustainability Reporting Standards (ESRS)*, including ESRS E1 "Climate Change," *Official Journal of the European Union*, L 387 (22 December 2023)
37. https://rpc.cfainstitute.org/

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