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Module 4

Green Finance Risk Management

Participant Reader

Climate risk: identify, measure, manage

Version 2.1, September 2026

GREEN FINANCE Micro-Credential Program

0.8 ECTS | 6 Lessons | Foundation to Quantitative Lab

Prepared by University of Twente (WP3: Curriculum Development)

WP3 Curriculum Twinning and Didactic Material Preparation
Deliverable D3.1: Training Materials Developed by Tandem Teams

About this reader

This participant reader accompanies the Module 4 training session delivered by the EU partner team within Work Package 3 of the GREEN FINANCE project. It adapts the Module 4 lecture decks (an overview plus six lessons) and the module chart set into a self-contained reference for participants and for academic staff who will re-deliver the module. It covers the full module so that lessons not presented live can be studied independently.

Scope. Module 4 concerns the *management* of climate-related financial risk: classification, assessment, scenario analysis, quantification, and stress testing. Disclosure and reporting (for example ISSB, SFDR, CSRD) belong to Module 5 and are referenced here only where the boundary matters.

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Module Overview

Module description

The agreed module description reads:

> This module covers the identification, measurement, and management of climate-related financial risks within financial institutions and investment portfolios. Students apply TCFD/TNFD frameworks, NGFS scenarios, carbon metrics, Climate Value-at-Risk, and stress testing methods, with all concepts contextualized for the ASEAN region.

The Module 4 / Module 5 boundary

Module 4 is about risk **management**: identify, measure, and manage. Module 5 is about risk **reporting**: disclose and communicate. TCFD and TNFD appear in Module 4 as *risk assessment* frameworks (the TCFD's risk management pillar and the TNFD's risk and impact management pillar)[a][b]. Their disclosure and reporting requirements, together with IFRS S1 and IFRS S2 of the International Sustainability Standards Board (ISSB), the EU Sustainable Finance Disclosure Regulation (SFDR) and the EU Corporate Sustainability Reporting Directive (CSRD), belong to Module 5.

[a] TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. Final Report, June 2017. Financial Stability Board.

[b] TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023.

Module parameters

Parameter	Value
ECTS	0.8
Total learner effort	20 to 24 hours
Duration	4 weeks (full module)
Lessons	6
Level	Foundation to PhD extension, with a quantitative lab
Assessment	100 percent coursework (no final exam)

The 0.8 ECTS stand for 20 to 24 hours of total learner effort over four weeks, contact hours and self-study together. Where a partner delivers only part of the module in a live session, the lessons left out can be studied independently.

Length and the WP3 format rules

The WP3 format rules ask that a module document run to 30 to 40 A4 pages. The Module 4 submission document is 55 pages, and the deviation is stated inside the document, so it reaches

every reader who opens the file.

Module 4 is diagram-led. It teaches a taxonomy, a set of frameworks, a scenario apparatus, a metric stack, and a stress-testing pipeline. Each of those is a structure, and a diagram states a structure in one page. If the band is a requirement, a reduced version within it is available on request.

Learning outcomes

The agreed learning outcomes read:

> This module addresses climate-related financial risks and their management within financial institutions and investment portfolios. Students learn to classify, measure, and manage climate risks using TCFD/TNFD frameworks, NGFS scenarios, carbon metrics, Climate Value-at-Risk (CVaR), and stress testing. All concepts are applied to the ASEAN context with equal coverage of Vietnam, Thailand, and the Philippines.

On completing this module, participants are able to:

1. **Classify** climate-related financial risks using the physical, transition, and liability taxonomy, and map transmission channels into financial institutions.
2. **Apply** the TCFD and TNFD frameworks for internal climate and nature risk assessment.
3. **Model** climate scenarios using NGFS pathways and Integrated Assessment Models.
4. **Calculate** financed emissions, carbon metrics, and Climate Value-at-Risk for portfolios.
5. **Design** climate stress tests using NGFS scenarios and evaluate supervisory approaches.
6. **Evaluate** ASEAN-specific climate vulnerabilities and adaptation finance mechanisms.

The outcomes rise in cognitive demand, from classifying and applying, through modelling and calculating, to designing and evaluating.

The six lessons

#	Lesson	Core focus	ASEAN case
1	Climate-Related Financial Risks and Taxonomy	Taxonomy, transmission, materiality	Vietnam (Mekong)
2	TCFD and TNFD Risk Assessment	Risk Management pillar, LEAP	Thailand (BOT)
3	Scenario Analysis and Climate Modeling	NGFS pathways, IAMs	Philippines (typhoons)
4	Carbon Metrics and Climate Value-at-Risk	Financed emissions, WACI, Climate VaR	Vietnam (banking)
5	Climate Stress Testing	Design, supervisory practice	Thailand (2011 floods)
6	ASEAN Climate Vulnerability	Integrated assessment, adaptation	Philippines (resilience)

Lesson 1 classifies climate risk, Lesson 2 applies the TCFD and TNFD frameworks, Lesson 3 models scenarios, Lesson 4 measures exposure, Lesson 5 stress-tests capital, and Lesson 6 applies all five to Vietnam, Thailand and the Philippines in one regional assessment.

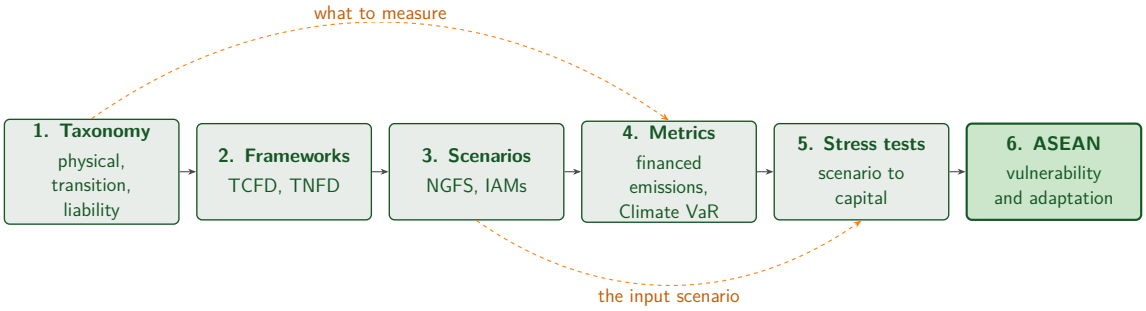


Figure 1: The six lessons in the order they are taught. The dashed edges mark two dependencies: the metrics of Chapter 4 measure what the taxonomy of Chapter 1 defines, and the stress tests of Chapter 5 run on the scenarios of Chapter 3.

Sources of the numbers. A number with a footnote comes from the source the footnote names. Every other input to a worked example is an illustrative teaching value, and no figure is an audited result for a named institution.

Tools and methods

The module uses lectures for frameworks and theory, workshops for scenario exercises, a data lab in Python for metrics and stress tests, a stress-test design simulation, and guided self-study. Tools referenced across the lessons include Python (pandas, matplotlib, seaborn), the NGFS Scenario Explorer, a PCAF style financed-emissions calculator, and GIS for flood-zone mapping. Assessment is 100 percent coursework and is set out in full in Appendix B: thirty-six multiple-choice questions covering all six lessons, with an answer key, plus one applied exercise built on the Appendix A case, marked against a four-dimension rubric.

Use of generative AI. Generative AI was used as a writing and research assistant in preparing this module. The tool was Claude (Anthropic), versions Opus 4.8, Opus 5 and Opus 5.5, used from July 2026 to 27 September 2026. Its use was confined to idea generation and brainstorming, language editing, literature classification, coding assistance for the chart and data-processing scripts, checking recorded numbers and quotations against their published sources, and interactive literature searching. The authors specified and reviewed the content. Every cited source was checked against the original publication, and every figure states its provenance on its own face, distinguishing sourced values from derived values and from illustrative teaching assumptions. The authors remain fully responsible for the originality, accuracy, integrity, references, and conclusions of the material.

Key Terms and Acronyms

Acronyms

Acronym	Expansion
TCFD	Task Force on Climate-related Financial Disclosures
TNFD	Taskforce on Nature-related Financial Disclosures
FSB	Financial Stability Board, an international body that monitors and makes recommendations about the global financial system[1]
G7	Group of Seven, an informal partnership of advanced economies: Canada, France, Germany, Italy, Japan, the United Kingdom and the United States, along with the European Union[2]
NGFS	Network of Central Banks and Supervisors for Greening the Financial System
PCAF	Partnership for Carbon Accounting Financials
PACTA	Paris Agreement Capital Transition Assessment, free open-source software that measures the alignment of financial portfolios with climate scenarios[3]
SBTi	Science Based Targets initiative, a corporate climate action organisation that enables companies and financial institutions worldwide to play their part in combating the climate crisis[4]
TPI	Transition Pathway Initiative, created in 2017 by asset owners and other investors to understand how companies manage the transition to a low-carbon economy[5]
CDP	CDP, formerly the Carbon Disclosure Project
WACI	Weighted Average Carbon Intensity
VaR	Value-at-Risk
CVaR	Climate Value-at-Risk in the agreed learning outcomes, written Climate VaR in the chapters; Appendix A uses CVaR for Conditional Value-at-Risk
ITR	Implied Temperature Rise
GHG	Greenhouse Gas
EVIC	Enterprise Value Including Cash
PD	Probability of Default
LGD	Loss Given Default
EAD	Exposure at Default

[1] FSB. About the FSB. Financial Stability Board.

[2] Global Affairs Canada. Canada and the G7. Government of Canada, holder of the 2025 G7 presidency.

[3] RMI. PACTA: Measure the alignment of financial portfolios with climate scenarios. Paris Agreement Capital Transition Assessment, RMI.

[4] SBTi. About us. Science Based Targets initiative.

[5] TPI. History and investor network. Transition Pathway Initiative.

Acronym	Expansion
EL	Expected Loss
CAR	Capital Adequacy Ratio
RWA	Risk-Weighted Assets
ERM	Enterprise Risk Management
BCBS	Basel Committee on Banking Supervision
ISSB	International Sustainability Standards Board
CSRD	Corporate Sustainability Reporting Directive (EU)
SFDR	Sustainable Finance Disclosure Regulation (EU)
CBAM	Carbon Border Adjustment Mechanism (EU)
IAM	Integrated Assessment Model
DICE	Dynamic Integrated Climate-Economy model, William Nordhaus's model of the economics of global warming[6]
RCP	Representative Concentration Pathway
SSP	Shared Socioeconomic Pathway
SRES	Special Report on Emissions Scenarios (IPCC)
IEA	International Energy Agency
NDC	Nationally Determined Contribution
ND-GAIN	Notre Dame Global Adaptation Initiative country index
GCF	Green Climate Fund
LEAP	Locate, Evaluate, Assess, Prepare (TNFD process)
IBAT	Integrated Biodiversity Assessment Tool
ENCORE	Exploring Natural Capital Opportunities, Risks and Exposure
ECB / BoE	European Central Bank / Bank of England
CBES	Climate Biennial Exploratory Scenario, the Bank of England's 2021 exercise on the financial risks posed by climate change for the largest UK banks and insurers[7]
MAS / BOT / BSP / SBV	Monetary Authority of Singapore / Bank of Thailand / Bangko Sentral ng Pilipinas / State Bank of Vietnam
HKMA	Hong Kong Monetary Authority, Hong Kong's central banking institution[8]
BNM	Bank Negara Malaysia
OJK	Otoritas Jasa Keuangan, the Indonesia Financial Services Authority, an independent state institution that has the function, duty, and authority to regulate, supervise, examine, and investigate[9]
BAAC	Bank for Agriculture and Agricultural Cooperatives (Thailand)
OIC	Office of Insurance Commission (Thailand)
SEADRIF	Southeast Asia Disaster Risk Insurance Facility
GRI	Global Reporting Initiative
IPCC	Intergovernmental Panel on Climate Change
IFRS	International Financial Reporting Standards
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration

[6] Nordhaus, W. D. (1992). The 'DICE' Model: Background and Structure of a Dynamic Integrated Climate-Economy Model of the Economics of Global Warming. Cowles Foundation Discussion Paper No. 1009, Yale University, February 1992.

[7] Bank of England (2022). Results of the 2021 Climate Biennial Exploratory Scenario (CBES). Bank of England, 24 May 2022.

[8] HKMA. The HKMA. Hong Kong Monetary Authority.

[9] Otoritas Jasa Keuangan (OJK). Task and Functions. Indonesia Financial Services Authority, ojk.go.id.

Acronym	Expansion
tCO2e	Tonnes of carbon dioxide equivalent
ASEAN	Association of Southeast Asian Nations
GDP	Gross Domestic Product
NPL	Non-Performing Loan
THB	Thai baht
GIS	Geographic Information System
ECTS	European Credit Transfer and Accumulation System

Key terms

Physical risk Losses when a climate hazard damages assets, cuts output or stops operations; hazards are acute (events) or chronic (trends).

Transition risk Financial risk from the shift to a low-carbon economy, in four types: policy and legal, technology, market, and reputation[10]; the TCFD lists "changing customer behavior" as a market risk[11].

Liability risk The impacts that could arise if parties who have suffered loss or damage from the effects of climate change seek compensation from those they hold responsible; Carney (2015) names liability risks, with physical risks and transition risks, as the three broad channels through which climate change can affect financial stability[12].

Transmission channel The pathway by which a climate event becomes a financial loss. Credit risk: the borrower repays less than it owes, by defaulting or by leaving a smaller recovery. Market risk: losses on the instruments the bank holds when prices, rates or spreads move. Operational risk: the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events[13]. Liquidity risk: the bank cannot meet its cash outflows without selling assets at a loss or borrowing at a penalty.

Double materiality Reporting both on how sustainability matters affect the undertaking (financial materiality) and on the impacts of the undertaking on people and the environment (impact materiality); the CSRD calls this the double materiality perspective[14].

Stranded asset An asset that has suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities; physical environmental impacts, the transition risks of policy and technology, and new legal liabilities can each create one[15].

TCFD pillars Governance, strategy, risk management, and metrics and targets. Governance covers the organisation's governance around climate-related risks and opportunities, with the

[10]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, Final Report, Figure 1.

[11]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, Final Report, Table 1.

[12]Carney, M. (2015). Breaking the tragedy of the horizon: climate change and financial stability. Speech at Lloyd's of London, 29 September 2015. Bank of England. Full text: BIS Review r151009a.

[13]BCBS (2021). Revisions to the Principles for the Sound Management of Operational Risk. Basel Committee on Banking Supervision, March 2021, section 3, paragraph 1, page 2.

[14]Directive (EU) 2022/2464 of 14 December 2022 (Corporate Sustainability Reporting Directive, CSRD), recital 29. Text as signed: PE-CONS 35/22, Council of the European Union, 16 November 2022.

[15]Caldecott, B., Kruitwagen, L., Dericks, G., Tulloch, D. J., Kok, I., and Mitchell, J. (2016). Stranded Assets and Thermal Coal: An analysis of environment-related risk exposure. Smith School of Enterprise and the Environment, University of Oxford, January 2016, page 9.

board's oversight and management's role[16]; strategy covers the impacts of those risks and opportunities on the businesses, strategy and financial planning; risk management covers the processes used to identify, assess and manage climate-related risks; and metrics and targets cover the measures used to assess and manage them.

Three lines of defence In the first line of defence, climate-related risk assessments may be undertaken at client onboarding, credit application and credit review; the second line, the risk function, assesses and monitors climate-related risk independently and challenges the first line's assessment, while the compliance function ensures adherence to rules and regulations; the third line, the internal audit function, gives independent review and objective assurance of the first two lines and of the internal control framework[17] (BCBS Principle 4).

NGFS scenario categories Orderly (Net Zero 2050, Below 2 °C, Low Demand): ambitious policy introduced early and tightened gradually, with physical and transition risk both relatively subdued. Disorderly (Delayed Transition): policy delayed or divergent, with subdued physical and high transition risk. Hot house world (NDCs, Current Policies): some policy in some jurisdictions, too little to halt significant warming, with severe physical risk. Too little, too late (Fragmented World): a late and uncoordinated transition that fails to limit physical risk.

Integrated assessment model A model that couples an economic, an energy and a climate module. The NGFS runs three, REMIND-MAgPIE, GCAM and MESSAGEix-GLOBIOM, and passes their paths to NiGEM, a macroeconomic model, for GDP, interest rates and prices[18]; physical damages feed back into the transition pathways only in REMIND-MAgPIE's runs with integrated damages[19].

Sensitivities β and γ The climate sensitivity β is the relative rise in default probability per degree of warming, in $PD_{climate} = PD_{base}(1 + \Delta T \cdot \beta)$. The default sensitivity to output γ is the rise in default probability, in percentage points, per percentage point of GDP lost, in $\Delta PD = -\gamma \times \Delta GDP$.

Scope 1, 2 and 3 A company's emissions from operations it owns or controls (Scope 1), from the energy it buys (Scope 2), and from its value chain (Scope 3). Category 15 of Scope 3 covers investments: a reporting company's Scope 3 emissions from investments are the Scope 1 and Scope 2 emissions of investees[20].

Financed emissions The share of a borrower's emissions attributed to a lender, the dominant (Scope 3, Category 15) component of a bank's footprint.

Weighted average carbon intensity A portfolio's exposure to carbon-intensive companies: each holding's emissions per $ million of revenue, weighted by its share of the portfolio[21].

Climate Value-at-Risk The impact of climate-related risks on the market value of a portfolio under one specified scenario, over years to decades, with no probability attached to the scenario; it splits into physical and transition components. The chapters write Climate VaR.

Climate stress test A test of whether a bank's capital survives a climate scenario, built from five design elements in sequence: scenario selection, exposure mapping, transmission to the risk

[16]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, the recommendations and recommended disclosures of Figure 4 of the Final Report, as set out on the TCFD recommendations page, fsb-tcfd.org.

[17]BCBS (2022). Principles for the effective management and supervision of climate-related financial risks. Basel Committee on Banking Supervision, June 2022, Principle 4, paragraphs 20 to 22, page 4.

[18]NGFS (2024). NGFS Climate Scenarios Technical Documentation, version 5.0, November 2024, page 11.

[19]NGFS (2024). NGFS Climate Scenarios Technical Documentation, version 5.0, November 2024, page 22.

[20]GHG Protocol (2011). Corporate Value Chain (Scope 3) Accounting and Reporting Standard. WRI and WBCSD, September 2011. Table 5.4, page 37; page 51; glossary, page 140.

[21]TCFD (2021). Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures, October 2021. Table 3, Common Carbon Footprinting and Exposure Metrics, page 52.

parameters, loss estimation, and capital impact, with the post-stress capital adequacy ratio as its output.

Regulatory capital Tier 1 capital, made of Common Equity Tier 1 and Additional Tier 1, plus Tier 2 capital; Basel III requires Common Equity Tier 1 of at least 4.5 percent of risk-weighted assets, Tier 1 of at least 6.0 percent and total capital of at least 8.0 percent[22].

Risk-weighted assets A bank's exposures, each weighted by its riskiness; the denominator of the capital adequacy ratio.

Capital adequacy ratio Regulatory capital over risk-weighted assets. The Basel III floor is the 8.0 percent minimum plus the 2.5 percent conservation buffer, 10.5 percent in all[23]. The Bank of Thailand sets 8.5 percent plus a 2.5 percent buffer, 11 percent in all, and the BSP sets 10 percent, 12.5 percent with its buffer.

Expected and unexpected loss Expected loss is the average loss a bank anticipates, $PD \times LGD \times EAD$, and provisions meet it; unexpected loss is the loss above that average, and capital meets it: Basel III's initiatives on provisioning target expected losses, and its capital measures target unexpected losses[24].

Expected credit loss Under IFRS 9 a bank holds a loss allowance for expected credit losses equal to 12-month expected credit losses until credit risk has increased significantly since initial recognition, and equal to lifetime expected credit losses after that[25].

Hazard The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury or other health impacts, as well as damage and loss to property and infrastructure[26].

Exposure The presence of people, livelihoods, infrastructure or economic assets in places and settings that could be adversely affected[27].

Vulnerability The propensity or predisposition to be adversely affected, including sensitivity to harm and lack of capacity to cope and adapt[28]. In the context of climate change impacts, risk results from dynamic interactions between climate-related hazards and the exposure and vulnerability of the affected human or ecological system[29].

[22]BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Paragraphs 49 and 50, page 12.

[23]BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Basel Committee on Banking Supervision, Annex 1: Calibration of the capital framework.

[24]BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Introduction, paragraph 31.

[25]IFRS Foundation. IFRS 9 Financial Instruments, paragraphs 5.5.1 to 5.5.5. IFRS Standards, 2021 issued edition, Part A.

[26]IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary, page 2911.

[27]IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary, page 2908.

[28]IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary, page 2927.

[29]IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary, entry Risk, page 2921.

Chapter 1

Climate-Related Financial Risks and Taxonomy

Climate risk comes in three categories, physical, transition and liability, and each reaches a bank through credit, market, operational or liquidity risk.

Learning objectives

Participants are able to:

1. Classify climate risks into physical, transition, and liability categories with their sub-classifications.
2. Map the transmission channels that link climate events to financial losses through credit, market, operational, and liquidity pathways.
3. Distinguish short, medium, and long-term risk horizons and their implications for portfolio management.
4. Apply double materiality (financial versus impact) to sectoral analysis across the economies of the Association of Southeast Asian Nations (ASEAN).
5. Compute a climate-adjusted expected loss from the probability of default (PD), loss given default (LGD) and exposure at default (EAD) under a warming scenario.
6. Assess the physical-risk exposure of a Mekong Delta loan book by sector share and hazard type.

1.1 Climate risk is a financial risk

In 2015 the then Governor of the Bank of England, Mark Carney, told an audience of insurers at Lloyd's of London that the catastrophic impacts of climate change will be felt beyond the traditional horizons of most actors[1]. He called this the *tragedy of the horizon*: a cost on future generations that the current generation has no direct incentive to fix. He set those impacts against the horizons of central banks, two to three years for monetary policy and the outer boundaries of the credit cycle, about a decade, for financial stability[2].

[1] Carney, M. (2015). Breaking the tragedy of the horizon: climate change and financial stability. Speech at Lloyd's of London, 29 September 2015. Bank of England. Full text: BIS Review r151009a.

[2] Carney, M. (2015). Breaking the tragedy of the horizon: climate change and financial stability. Speech at Lloyd's of London, 29 September 2015. Bank of England, page 4.

Natural disasters caused losses of roughly $250 billion worldwide in 2023, about $95 billion of them insured (Munich Re)[3]. The 2011 Thailand floods caused $46.5 billion of damage and losses[4], and the manufacturing sector bore roughly 70 percent of the total after six industrial estates in Ayutthaya and Pathum Thani flooded[5]. Studies of how natural disasters disrupt global supply chains often take Thailand as a case, and global supply chains increase the potential for physical risk to reach banks' counterparties[6]. Typhoon Rai hit the Philippines in December 2021 and affected close to 2 million people, with extensive damage to public infrastructure and the farming sector[7]. These are realised losses from today's climate, before the additional warming projected for mid-century.

Four properties make climate risk systemic

Climate risk is **correlated** (a single typhoon hits thousands of borrowers at once), **non-diversifiable** (every sector and geography is exposed), **non-linear** (tipping points create sudden, irreversible losses), and **forward-looking** (historical data understates future exposure). These properties make it a systemic risk that affects the whole financial system simultaneously.

1.2 The taxonomy: physical, transition, liability

Climate risk divides into three categories. **Physical risk** is the loss when a climate hazard damages assets, cuts output or stops operations. Its hazards split into *acute* events (typhoons and cyclones, flooding, wildfires, heatwaves) and *chronic* trends (sea-level rise, sustained temperature change, altered precipitation). Acute risks are insurable in principle, but climate change may itself affect the future availability and affordability of insurance, and in the medium to long term more risks may become uninsurable or unaffordable[8]. Chronic risks are gradual trends, and a bank manages them by adjusting its portfolio. Dietz et al. (2016) estimate the impact of climate change itself on the present market value of global financial assets: along a business-as-usual emissions path the expected climate value at risk is $2.5 trillion[9], rising to $24.2 trillion at the 99th percentile[10].

Transition risks arise from the adjustment towards a lower-carbon economy. The Task Force on Climate-related Financial Disclosures (TCFD) sorts them into four types, policy and legal, technology, market and reputation[11], and lists "changing customer behavior" as a market risk[12]. Policy and legal risk covers carbon pricing, emission mandates and the EU Carbon Border Adjustment Mechanism, in its definitive regime from 2026[13]; technology risk covers renewables and electric vehicles that make fossil assets obsolete; market risk covers shifting

[3]Munich Re (2024). Natural disaster figures 2023. Media information, 9 January 2024.
[4]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning.
[5]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Overview, page 2.
[6]BCBS (2021). Climate-related risk drivers and their transmission channels. Basel Committee on Banking Supervision, April 2021, page 12.
[7]World Bank (2021). World Bank Support for the Impacts of Typhoon Rai in the Philippines (Odette). Brief, 28 December 2021.
[8]BCBS (2021). Climate-related risk drivers and their transmission channels. Basel Committee on Banking Supervision, April 2021, page 26.
[9]Dietz, S., Bowen, A., Dixon, C., and Gradwell, P. (2016). Climate value at risk of global financial assets. Nature Climate Change, 6, 676 to 679.
[10]Dietz, S., Bowen, A., Dixon, C., and Gradwell, P. (2016). Climate value at risk of global financial assets. Nature Climate Change, 6, 676 to 679.
[11]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, Final Report, Figure 1.
[12]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, Final Report, Table 1.
[13]European Commission, Taxation and Customs Union. Carbon Border Adjustment Mechanism.

demand, customer behaviour and commodity volatility; and reputation risk covers divestment and boycotts. Physical risk rises with *warming*, and transition risk rises with *policy ambition*. An orderly transition has low transition risk; a hot house world has low transition risk and extreme physical risk. Stranded assets are assets that have suffered unanticipated or premature write-downs, devaluations or conversion to liabilities, and the transition risks of policy and technology can create them[14]: fossil reserves that cannot be burned, coal plants retired early, carbon-intensive real estate below efficiency standards.

Liability risks are the third category. Carney (2015) defines them as the impacts that could arise if parties who have suffered loss or damage from the effects of climate change seek compensation from those they hold responsible[15]. Setzer and Higham (2023) count 2,341 cases in the Sabin Center's climate change litigation databases[16]. Among the strategic cases filed outside the United States, Setzer and Higham (2023) identify failure-to-adapt cases, which challenge a government or corporation for failing to adapt property or operations to physical risks or for failing to consider transition risks[17]. Setzer and Higham also identify climate-washing cases, which challenge inaccurate government or corporate narratives about contributions to the transition to a low-carbon future[18]. In 2021 a Dutch district court ordered Shell to cut its emissions 45 percent by 2030[19], and in November 2024 the Hague Court of Appeal rejected that claim: Shell is obliged to reduce its emissions, but the court was unable to determine which percentage should apply[20].

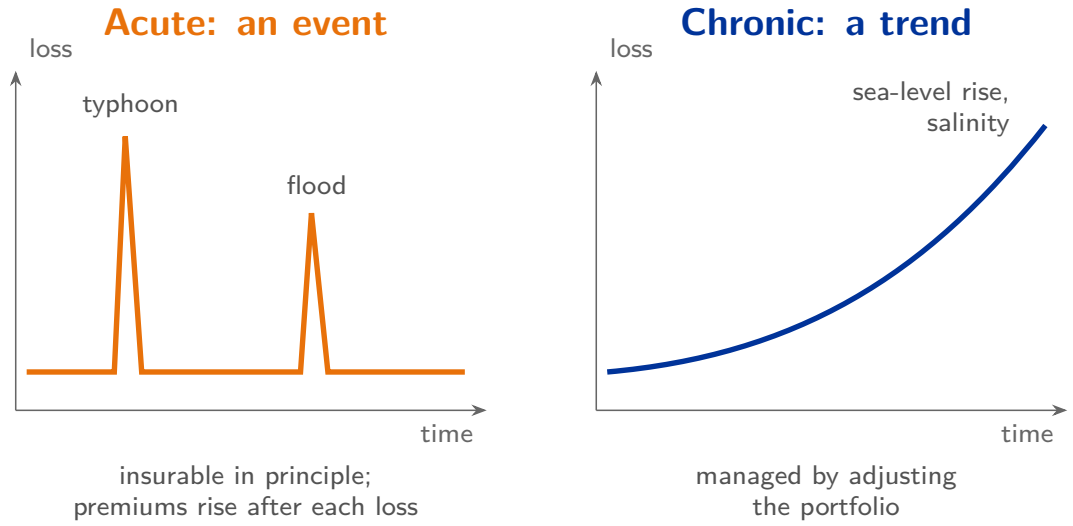


Figure 1.1: An acute hazard is an event, insurable in principle, with premiums that rise after each loss. A chronic hazard is a trend, and a bank manages it by adjusting its portfolio.

[14]Caldecott, B., Kruitwagen, L., Dericks, G., Tulloch, D. J., Kok, I., and Mitchell, J. (2016). Stranded Assets and Thermal Coal: An analysis of environment-related risk exposure. Smith School of Enterprise and the Environment, University of Oxford, January 2016, page 9.

[15]Carney, M. (2015). Breaking the tragedy of the horizon: climate change and financial stability. Speech at Lloyd's of London, 29 September 2015. Bank of England. Full text: BIS Review r151009a.

[16]Setzer, J. and Higham, C. (2023). Global trends in climate change litigation: 2023 snapshot. Grantham Research Institute, LSE.

[17]Setzer, J. and Higham, C. (2023). Global trends in climate change litigation: 2023 snapshot. Grantham Research Institute, LSE.

[18]Setzer, J. and Higham, C. (2023). Global trends in climate change litigation: 2023 snapshot. Grantham Research Institute, LSE.

[19]Milieudefensie et al. v. Royal Dutch Shell plc, Hague District Court, 26 May 2021. Sabin Center Climate Change Litigation Databases.

[20]Gerechtshof Den Haag (The Hague Court of Appeal), press release of 12 November 2024, Hague court denies claim for reduction in Shell's CO2 emissions.

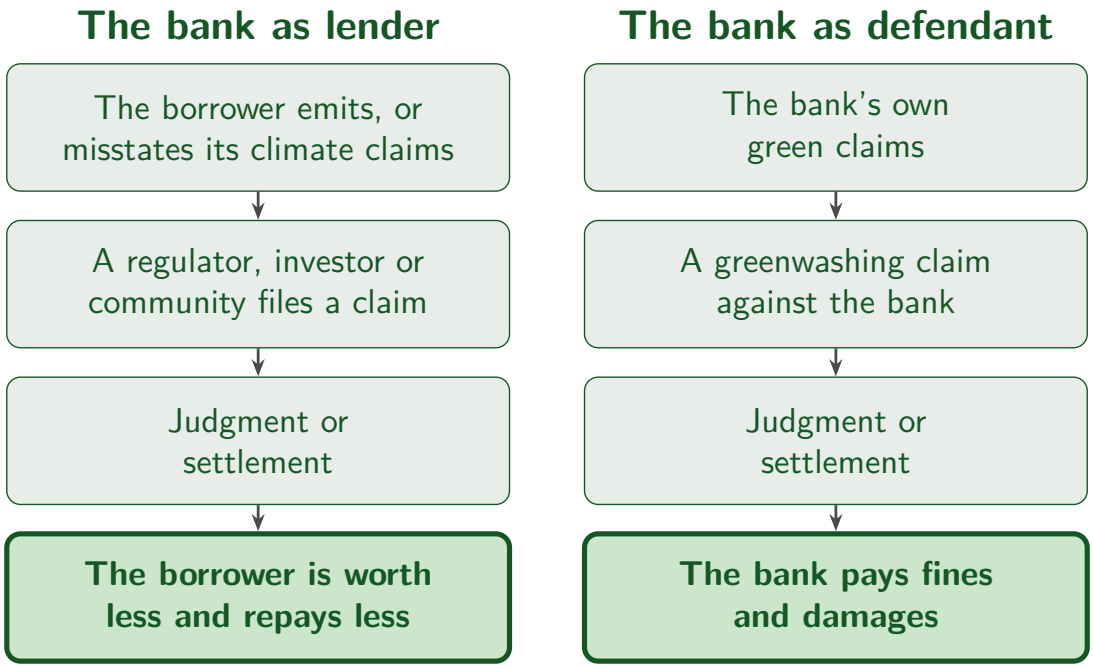


Figure 1.2: Liability risk reaches the lender through the courts, and the bank is hit twice: as lender to a defendant whose value falls, and as a defendant over its own green claims.

Carney (2015) named three broad channels through which climate change can affect financial stability: physical risks, liability risks and transition risks[21]. The TCFD (2017) files litigation or legal risk under policy and legal risk, one of its four types of transition risk[22].

1.3 Transmission channels

A climate event becomes a financial loss through one or more transmission channels, and these channels interact. The four core channels are **credit risk**, where drought lifts the probability of default (PD), floods lift loss given default (LGD) through damaged collateral, and borrowers under stress draw their credit lines, which lifts exposure at default (EAD); **market risk** (asset repricing and mark-to-market losses); **operational risk** (business disruption); and **liquidity risk** (fire sales and deposit withdrawals). Two further channels matter at system level: the **insurance** channel, which absorbs part of the loss where cover exists, and the **asset management** channel, through which portfolio repricing and coordinated divestment propagate losses. In emerging and less developed countries the protection gap is wider, and insured losses are less than 10 percent of total damages[23].

Credit risk is the channel studied most: existing literature largely focuses on the impacts of climate risk drivers on banks' credit risk, and to a lesser extent on market risk[24]. The channels interact: in the account of the ASEAN central banks, shocks to household income and business profitability raise loan delinquencies, rising credit risk may result in tightening credit conditions, and access to liquidity from the money market may be constrained for banks perceived to have

[21]Carney, M. (2015). Breaking the tragedy of the horizon: climate change and financial stability. Speech at Lloyd's of London, 29 September 2015. Bank of England. Full text: BIS Review r151009a.

[22]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, Final Report, June 2017, section B.1.a, Transition Risks: Policy and Legal Risks.

[23]BCBS (2021). Climate-related risk drivers and their transmission channels. Basel Committee on Banking Supervision, April 2021, page 30, citing Munich Re (2020).

[24]BCBS (2021). Climate-related risk drivers and their transmission channels. Basel Committee on Banking Supervision, April 2021, Executive summary, page 1.

Table 1.1: Climate risk taxonomy: categories, channels, and horizons

Category	Sub-type	Financial channel	Horizon
Physical	Acute	Insurance claims, collateral damage	Short
	Chronic	Asset devaluation, yield decline	Medium to long
Transition	Policy and legal	Compliance costs, stranded assets	Short to medium
	Technology	Stranded assets, capex needs	Medium
	Market	Revenue decline, cost of capital	Short to medium
	Reputation	Revenue decline, cost of capital	Short to medium
Liability	Litigation	Contingent liabilities, settlements	Medium to long
	Adaptation failure	Damages, regulatory fines	Medium
	Greenwashing	Fines, reputational loss	Short

higher counterparty risks[25]. After the 2011 Thailand floods, most rural farming households had loans with the Bank for Agriculture and Agricultural Cooperatives, and farmers who had lost their harvests were concerned they would default on their loans[26].

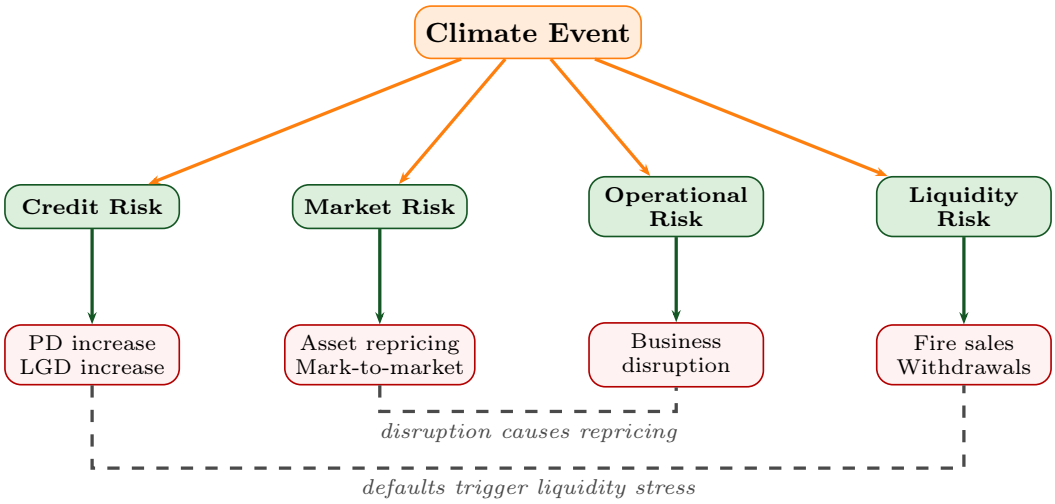


Figure 1.3: A single climate event reaches the balance sheet through four channels at the same time. The interaction between them makes the resulting loss non-linear.

[25] ASEAN central banks and monetary authorities (2020). Report on the Roles of ASEAN Central Banks in Managing Climate and Environment-related Risks, 17 November 2020, page 11. Published by Bank Negara Malaysia.

[26] World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Overview, page 4.

1.4 Time horizons

Climate risks operate across three timescales that mismatch traditional planning. Short-term risk (zero to three years) covers acute physical events, policy shocks, and regulatory enforcement, relevant to trading books and annual budgets. Medium-term risk (three to ten years) covers transition acceleration and the onset of chronic physical change, relevant to corporate loan books and infrastructure investment. Long-term risk (ten to thirty years and beyond) covers systemic transformation and tipping points, relevant to sovereign bonds, pension funds, and real-estate solvency. Long-term risk lies beyond the horizons Carney gives for monetary policy and financial stability, and this mismatch is his tragedy of the horizon.

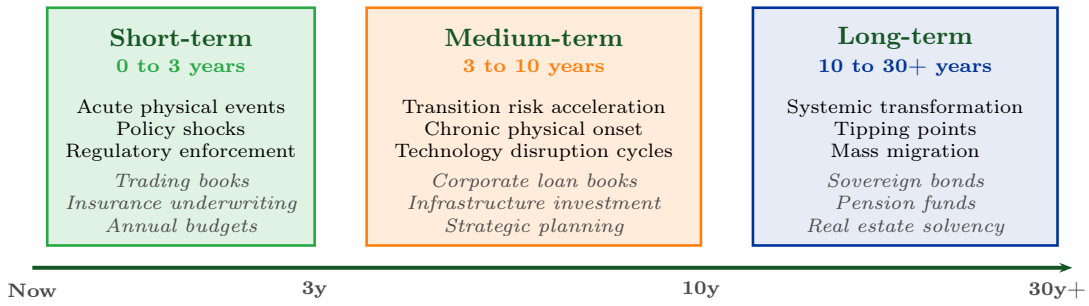


Figure 1.4: The tragedy of the horizon: the planning windows that govern trading books, loan books and pension funds, set against the timescale over which the risk arrives.

1.5 Single and double materiality

Materiality decides which climate risks matter enough to require action, and three frameworks define it differently. *Financial materiality* is an outside-in view: IFRS S1 of the International Sustainability Standards Board (ISSB) requires disclosure of the sustainability-related risks and opportunities that could reasonably be expected to affect an entity's cash flows, its access to finance or cost of capital[27]. *Impact materiality* is an inside-out view: in the standards of the Global Reporting Initiative (GRI), material topics are those that represent an organisation's most significant impacts on the economy, environment and people[28]. The EU Corporate Sustainability Reporting Directive (CSRD) asks for both, information on the undertaking's impacts on sustainability matters and on how sustainability matters affect its development, performance and position[29]. The directive calls this the *double materiality* perspective, in which the risks to the undertaking and the impacts of the undertaking each represent one materiality perspective[30].

Double materiality in an ASEAN loan book

Consider a coal-fired power plant in Vietnam that sells its output under a long-term purchase agreement. Its financial materiality may be low in the short term, but its impact materiality is high. Under double materiality both dimensions require disclosure and man-

[27]IFRS Foundation (2023). IFRS S1 General Requirements for Disclosure of Sustainability-related Financial Information, paragraph 3. International Sustainability Standards Board (ISSB), June 2023.

[28]GRI (2021). GRI 3: Material Topics 2021, Introduction, page 4. Global Reporting Initiative, effective 1 January 2023.

[29]Directive (EU) 2022/2464 of 14 December 2022 (Corporate Sustainability Reporting Directive, CSRD), Article 1(4), replacing Article 19a(1) of Directive 2013/34/EU. Text as signed: PE-CONS 35/22, Council of the European Union, 16 November 2022.

[30]Directive (EU) 2022/2464 of 14 December 2022 (Corporate Sustainability Reporting Directive, CSRD), recital 29. Text as signed: PE-CONS 35/22, Council of the European Union, 16 November 2022.

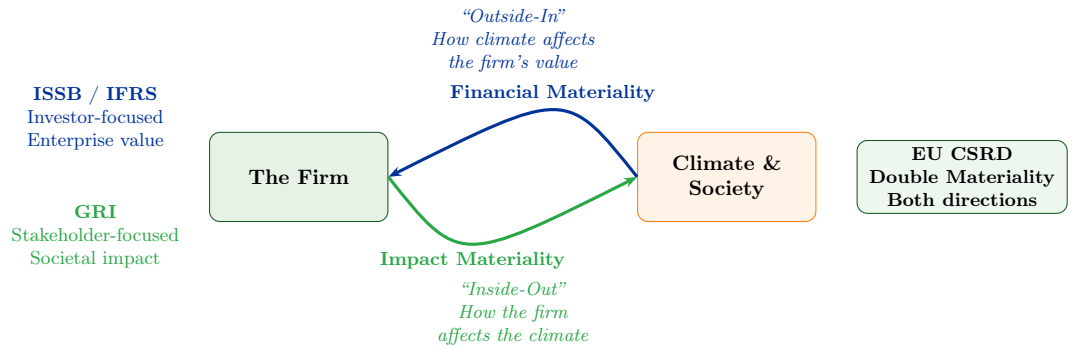


Figure 1.5: Financial materiality looks inward from the climate to the firm; impact materiality looks outward from the firm to the climate. The EU CSRD requires both directions at once.

agement. In ASEAN, Singapore Exchange Regulation (SGX RegCo) has amended its listing rules to phase in the climate requirements in the ISSB Standards for listed issuers from 1 January 2025[a]; the ISSB Standards apply financial materiality.

[a]IFRS Foundation (2025). Jurisdictional snapshot: Singapore. Updated 12 June 2025.

1.6 Climate-adjusted expected loss

The standard credit expected-loss (EL) identity extends to incorporate climate effects:

$$EL_{climate} = \underbrace{PD_{base}\,(1 + \Delta T \cdot \beta_{climate})}_{PD_{climate}} \times \underbrace{(LGD_{base} + \Delta LGD_{physical})}_{LGD_{climate}} \times EAD$$

where ΔT is the warming beyond today's climate in °C and $\beta_{climate}$ is a sector-specific climate sensitivity of PD per degree (illustrative values: near 0.35 for agriculture, 0.25 for energy, 0.05 for technology). $\Delta LGD_{physical}$ is the collateral lost to physical damage, and EAD is held at today's value. PD_{base} comes from historical default rates; ΔT and $\beta_{climate}$ come from a scenario, so $PD_{climate}$ is a projection.

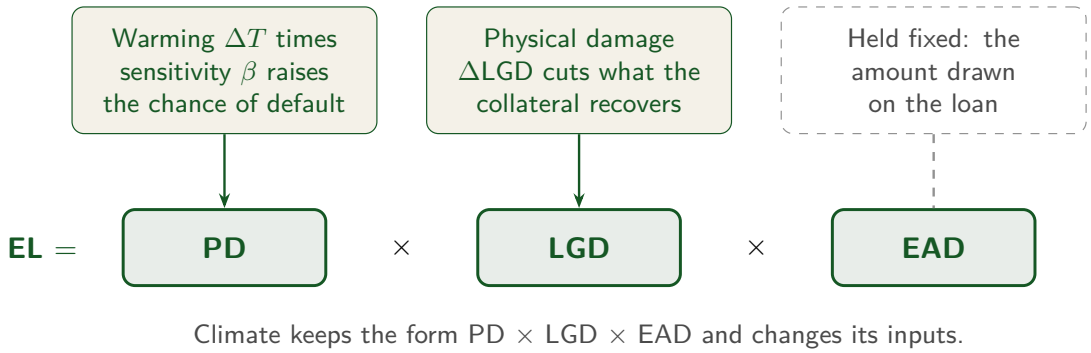


Figure 1.6: Climate keeps the form $PD \times LGD \times EAD$ and changes its inputs. Warming times sensitivity raises PD, physical damage cuts what the collateral recovers, and EAD is held at today's value.

With $PD_{climate} = 0.05 \times (1 + 2.0 \times 0.35) = 0.085$ and $LGD_{climate} = 0.60 + 0.05 = 0.65$, the expected loss rises from \$9.0 million to \$16.6 million, an 84 percent increase for the agriculture sector alone. Default probability rises by the factor $0.085/0.05 = 1.70$ and loss given default by

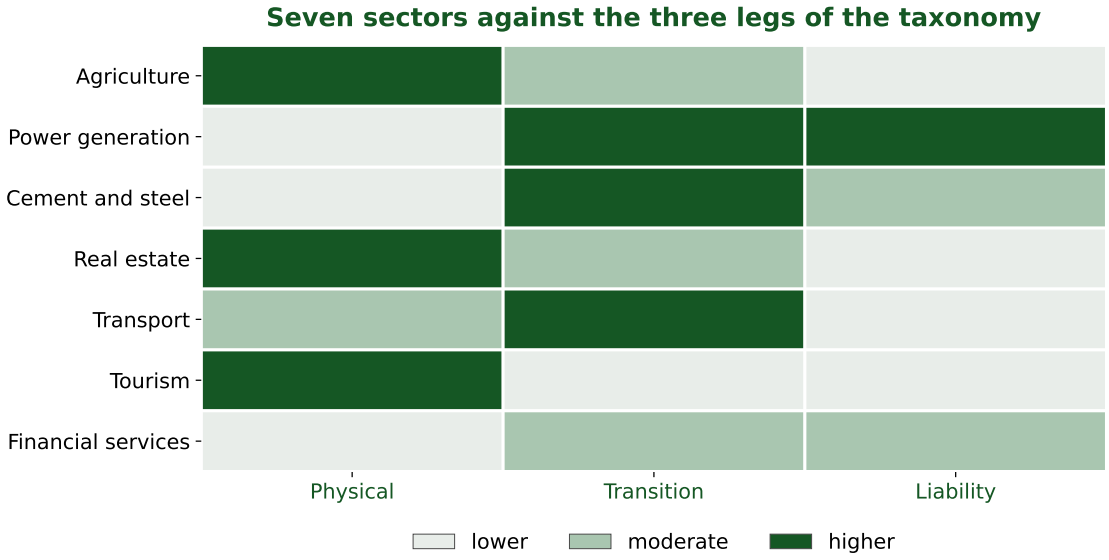
Table 1.2: Worked example: the Mekong Delta rice portfolio at plus 2.0 °C

Metric	Baseline	Plus 2.0 °C
Probability of default (PD, %)	5.0	8.5
Loss given default (LGD, %)	60	65
Exposure at default (EAD)	$300 million	$300 million
Expected loss	$9.0 million	$16.6 million
Added expected loss	n/a	**plus $7.6 million (plus 84 percent)**

$0.65/0.60 = 1.083$, and the two rises multiply: $1.70 \times 1.083 = 1.84$. A bank that holds provisions of $9.0 million against this book for the baseline needs $7.6 million more under the scenario. Every input in the example is an illustrative teaching value, chosen to make the mechanism visible.

1.7 Sectoral exposure

Sectors differ in which leg of the taxonomy reaches them. Agriculture and fisheries face mainly physical risk, power generation mainly transition risk, and real estate and transport both. A heatmap scoring each sector from 1 to 5 on acute physical, chronic physical, policy, technology, market and litigation risk, weighted by portfolio share, gives a portfolio risk score. A bank concentrated in agriculture and power generation is exposed to both physical and transition risk.



Assumed teaching example, not measured data: Qualitative teaching judgement, not a risk assessment: three named bands, no score.

https://digital-ai-finance.github.io/Green-Finance/module4-lesson1-climate-risks/

Figure 1.7: Seven sectors against the three legs of the taxonomy, in three named bands. Which leg reaches a sector is well established; a portfolio-specific assessment sets how strongly.

ASEAN case: Vietnam's Mekong Delta

The Mekong Delta is home to about 18 million people[a]. It is the country's largest producer of rice, with 54 percent of Vietnam's output, and holds the largest aquaculture area in

the country, 70 percent of the total[b]. Minderhoud et al. (2019) put its mean elevation at about 0.8 m above sea level[c]. Climate change has already contributed to sea-level rise and to the growing incidence of salt water intrusion into the interior of the Delta, and under Representative Concentration Pathway (RCP) 4.5 sea level on its east and west coasts is projected to rise by 22 to 23 cm by 2050[d]. Minderhoud et al. (2019) find that moderate sea-level rise may put 25 percent of the Delta below sea level by the end of the century, while the Delta subsides at present delta-average rates exceeding 1.1 cm per year[e]. For a bank with, say, 30 percent of its book in agriculture and 20 percent in real estate, half the portfolio is directly exposed to physical risk across all three horizons. In the Philippines the dominant hazard is *acute* (an average of about 20 tropical cyclones a year in the Philippine region, 8 or 9 of which cross the country[f]), against Vietnam's dominant *chronic* hazard (sea-level rise, subsidence and salt water intrusion). Acute risk is transferred through insurance; chronic risk is reduced by changing the portfolio.

[a]World Bank (2022). New World Bank Group Report Proposes Path for Vietnam to Address Climate Risks. Press release, 1 July 2022.

[b]World Bank (2021). Agricultural Land Use and Sustainable Livelihoods in the Mekong Delta: Alternative Scenarios and Policy Implications. Australia-World Bank Group Strategic Partnership in Vietnam, page 2.

[c]Minderhoud, P. S. J., Coumou, L., Erkens, G., Middelkoop, H., and Stouthamer, E. (2019). Mekong delta much lower than previously assumed in sea-level rise impact assessments. Nature Communications, 10, 3847.

[d]World Bank (2021). Agricultural Land Use and Sustainable Livelihoods in the Mekong Delta: Alternative Scenarios and Policy Implications. Australia-World Bank Group Strategic Partnership in Vietnam, page 2.

[e]Minderhoud, P. S. J., Coumou, L., Erkens, G., Middelkoop, H., and Stouthamer, E. (2019). Mekong delta much lower than previously assumed in sea-level rise impact assessments. Nature Communications, 10, 3847.

[f]PAGASA. Tropical Cyclone Information. Philippine Atmospheric, Geophysical and Astronomical Services Administration, DOST.

PhD extension: climate risk as endogenous systemic risk

Battiston et al. (2017) use a network approach to financial dependencies to trace how climate policy risk propagates through the financial system[a]. An open research question is when network amplification exceeds the original exogenous loss, and how ASEAN interbank topology compares with EU networks in contagion vulnerability.

[a]Battiston, S., Mandel, A., Monasterolo, I., Schuetze, F., and Visentin, G. (2017). A climate stress-test of the financial system. Nature Climate Change, 7, 283 to 288.

Key takeaways

- Physical risk is acute plus chronic and rises with warming; transition risk falls into four types and rises with policy ambition; liability risk arises when parties who have suffered loss or damage from climate change seek compensation from those they hold responsible, and Setzer and Higham (2023) count 2,341 climate litigation cases[31].
- Four transmission channels (credit, market, operational, liquidity) interact; credit risk is the channel the literature has studied most.
- Double materiality (EU CSRD) adds the firm's impact on the climate to the financial view.

[31]Setzer, J. and Higham, C. (2023). Global trends in climate change litigation: 2023 snapshot. Grantham Research Institute, LSE.

- For the Mekong Delta rice portfolio the climate-adjusted identity raises expected loss 84 percent, from $9.0 million to $16.6 million, over a PD taken from historical default rates.

Chapter 2

TCFD and TNFD Risk Assessment

The Task Force on Climate-related Financial Disclosures published its recommendations in June 2017, in four areas: governance, strategy, risk management, and metrics and targets.

Two global frameworks give climate and nature risk a common structure: the Task Force on Climate-related Financial Disclosures (TCFD) for climate, and the Taskforce on Nature-related Financial Disclosures (TNFD) for nature.

Learning objectives

Participants are able to:

1. Explain the TCFD four-pillar framework and the three recommended disclosures of its Risk Management pillar: how an institution identifies and assesses climate risk, how it manages it, and how both processes are integrated into its overall risk management.
2. Apply the TNFD LEAP approach to identify nature-related financial risks.
3. Integrate climate risk into Enterprise Risk Management (ERM).
4. Score an institution's climate risk-management maturity with the module's teaching rubric.
5. Compare regulatory approaches to TCFD implementation across the Association of Southeast Asian Nations (ASEAN).

The Module 4 / Module 5 boundary

TCFD and TNFD serve here as **risk assessment** tools: their Risk Management pillar and the processes for identifying and assessing risk. Their disclosure and reporting dimensions, together with IFRS S1 and IFRS S2 of the International Sustainability Standards Board (ISSB), belong to Module 5.

2.1 Standardised climate disclosure

Users of climate-related disclosures cited inconsistencies in disclosure practices and non-comparable reporting as major obstacles to using climate-related information in investment, lending and insurance underwriting decisions[1]. The Financial Stability Board (FSB) established

[1]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. Final Report, June 2017. Financial Stability Board. Section A, Introduction.

the Task Force on Climate-related Financial Disclosures (TCFD) in December 2015[2], and the recommendations followed in June 2017[3], presented by Michael Bloomberg on behalf of the Task Force to Mark Carney as Chairman of the FSB[4]. In June 2021 the Group of Seven (G7) finance ministers and central bank governors supported moving towards mandatory climate-related financial disclosures based on the TCFD framework[5]. The TCFD disbanded in October 2023, and the FSB asked the IFRS Foundation to take over monitoring companies' climate-related disclosures[6]; IFRS S2 is effective for annual reporting periods beginning on or after 1 January 2024[7].

2.2 The TCFD four pillars

The TCFD organises its recommendations in four pillars. **Governance** assigns board and management responsibility. **Strategy** identifies risks and opportunities over the short, medium, and long term, their impact on the business and its financial planning, and the resilience of the strategy under different climate scenarios, including a 2 °C or lower scenario[8]. **Risk Management** has three recommended disclosures: the processes for identifying and assessing climate risk, the processes for managing it, and how both are integrated into overall risk management[9]. **Metrics and Targets** disclose the metrics in use; Scope 1, Scope 2 and, if appropriate, Scope 3 emissions, where a bank's Scope 3 includes its financed emissions; and targets with performance against them[10]. Carbon intensity and Climate Value-at-Risk (Climate VaR) are two of the metrics a bank discloses under this pillar.

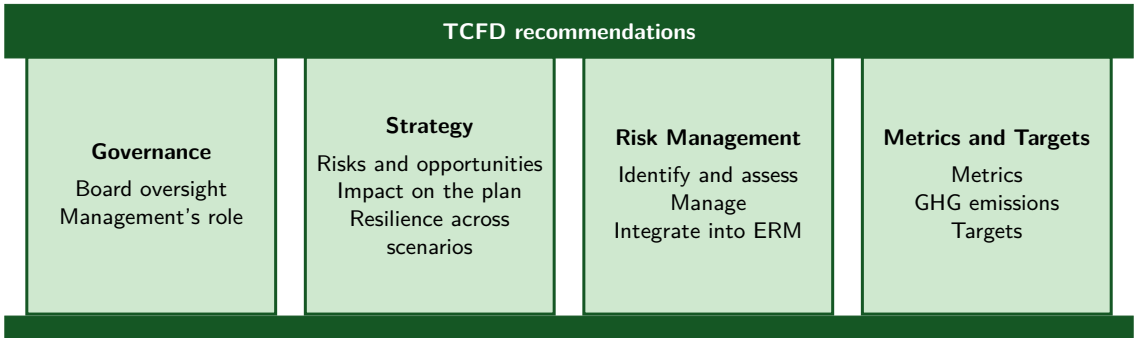


Figure 2.1: The four pillars of the TCFD recommendations: governance, strategy, risk management, and metrics and targets.

[2]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. Final Report, June 2017. Financial Stability Board. Section A, Introduction.

[3]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. Final Report, June 2017. Financial Stability Board.

[4]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. Final Report, June 2017. Financial Stability Board. Letter from Michael R. Bloomberg, 15 June 2017.

[5]G7 Finance Ministers and Central Bank Governors (2021). Communique, London, 5 June 2021, paragraph 4. GOV.UK.

[6]TCFD. Task Force on Climate-related Financial Disclosures website, notice of October 2023. fsb-tcfd.org.

[7]IFRS Foundation. IFRS S2 Climate-related Disclosures, standard page, ifrs.org.

[8]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, the recommendations and recommended disclosures of Figure 4 of the Final Report, as set out on the TCFD recommendations page, fsb-tcfd.org.

[9]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, the recommendations and recommended disclosures of Figure 4 of the Final Report, as set out on the TCFD recommendations page, fsb-tcfd.org.

[10]TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, the recommendations and recommended disclosures of Figure 4 of the Final Report, as set out on the TCFD recommendations page, fsb-tcfd.org.

Table 2.1: The TCFD four pillars

Pillar	Scope	Key outputs
Governance	Responsibility for climate risk	Board mandate, committee structure, management roles
Strategy	Effect of climate on the business, strategy and financial planning	Scenario analysis, resilience assessment, horizon mapping
Risk Management	Processes to identify, assess and manage climate risk	Risk register, stress tests, risk-appetite thresholds, credit integration
Metrics and Targets	Measures of exposure and progress against targets	Greenhouse gas (GHG) emissions, Weighted Average Carbon Intensity (WACI), Climate VaR, net-zero targets

2.3 The three disclosures of the Risk Management pillar

The Risk Management pillar holds a bank's day-to-day climate risk processes. It has three recommended disclosures: how the bank identifies and assesses climate risk, how it manages it, and how both processes are integrated into its overall risk management. **Identify and assess**: map physical and transition exposures across business lines and geographies, run scenario screening, keep a climate risk register inside the enterprise risk register, quantify likelihood and impact, prioritise against other risks with consistent scoring, and stress test under multiple scenarios of the Network for Greening the Financial System (NGFS), producing heatmaps and scenario-adjusted estimates of the probability of default (PD) and loss given default (LGD). **Manage**: set risk-appetite thresholds, embed climate into credit approval, investment, and underwriting decisions, and monitor effectiveness. **Integrate**: run the climate processes inside the enterprise risk framework the bank already has.

2.4 Integrating climate into Enterprise Risk Management

Climate risk belongs inside the existing ERM. The principle is to use the same machinery: the same risk-appetite framework, the same risk register, the same committee structure, and the same escalation processes. In practice a bank adds, say, "physical flood risk to the mortgage portfolio" as a line item in its credit risk register, scored on the same likelihood-impact matrix, reviewed by the same committee, and bounded by the same appetite limits. Only the climate line item is new.

The Basel Committee's 2022 principles for climate-related financial risks run 1 to 12 on how banks should manage those risks and 13 to 18 on how prudential supervisors should review them[11]. Principle 4 asks banks to incorporate climate-related financial risks into their internal control frameworks across the three lines of defence. In the first line of defence, climate-related risk assessments may be undertaken at client onboarding, credit application and credit review; the second line, the risk function, assesses and monitors climate-related risk independently and challenges the first line's assessment; the third line, the internal audit function, gives independent review and objective assurance of the first two lines[12].

[11] BCBS (2022). Principles for the effective management and supervision of climate-related financial risks. Basel Committee on Banking Supervision, June 2022.

[12] BCBS (2022). Principles for the effective management and supervision of climate-related financial risks. Basel Committee on Banking Supervision, June 2022, Principle 4, paragraphs 20 to 22, page 4.

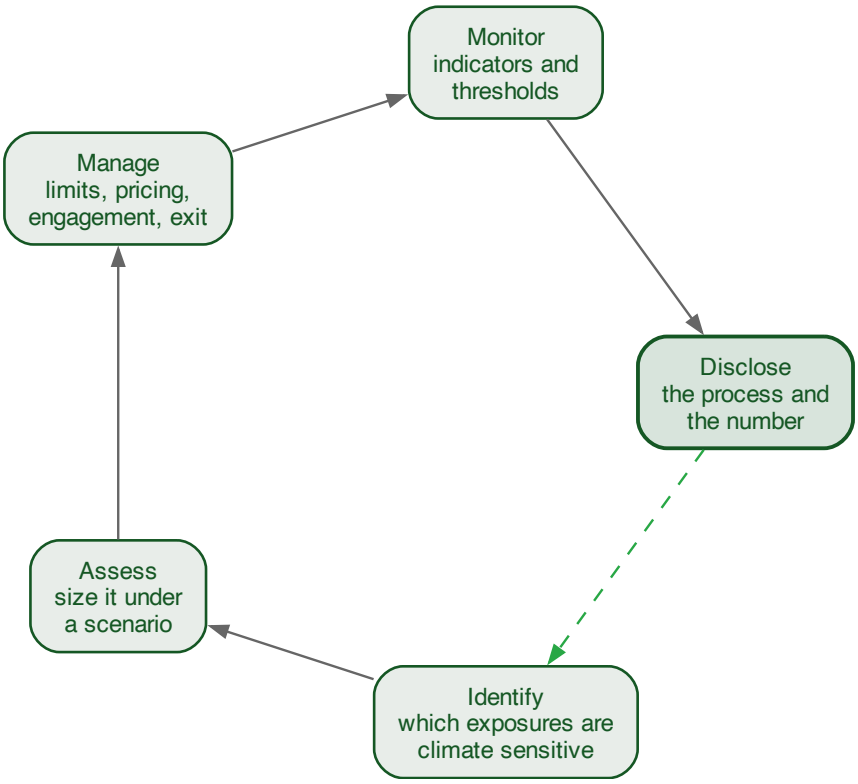


Figure 2.2: Identify, assess, manage and monitor form the risk cycle; the dashed edge runs from disclosure back to identification.

2.5 From climate to nature: TNFD and LEAP

Climate is only one dimension of environmental risk. The World Economic Forum (2020) estimates that $44 trillion of economic value generation, more than half of the world's total gross domestic product (GDP), is moderately or highly dependent on nature and its services[13]. The Sundaland biodiversity hotspot lies in Southeast Asia[14]. The Taskforce on Nature-related Financial Disclosures (TNFD) published its recommendations in September 2023 with four pillars, risk and impact management among them[15]. Its **LEAP** approach has four phases: Locate the interfaces with nature, Evaluate dependencies and impacts on nature, Assess nature-related risks and opportunities, and Prepare to respond to them[16]. The TNFD defines nature-related risks as potential threats to an organisation that arise from its and wider society's dependencies and impacts on nature, and classes them as physical, transition or systemic risks[17]. Nature-related dependencies and impacts are location specific and need local, context-specific assessment[18]; the Integrated Biodiversity Assessment Tool (IBAT) helps locate an organisation's interfaces with

[13] World Economic Forum (2020). Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy. New Nature Economy Report, January 2020.
[14] Critical Ecosystem Partnership Fund. Hotspots defined, cepf.net.
[15] TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023.
[16] TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023.
[17] TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023.
[18] TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023.

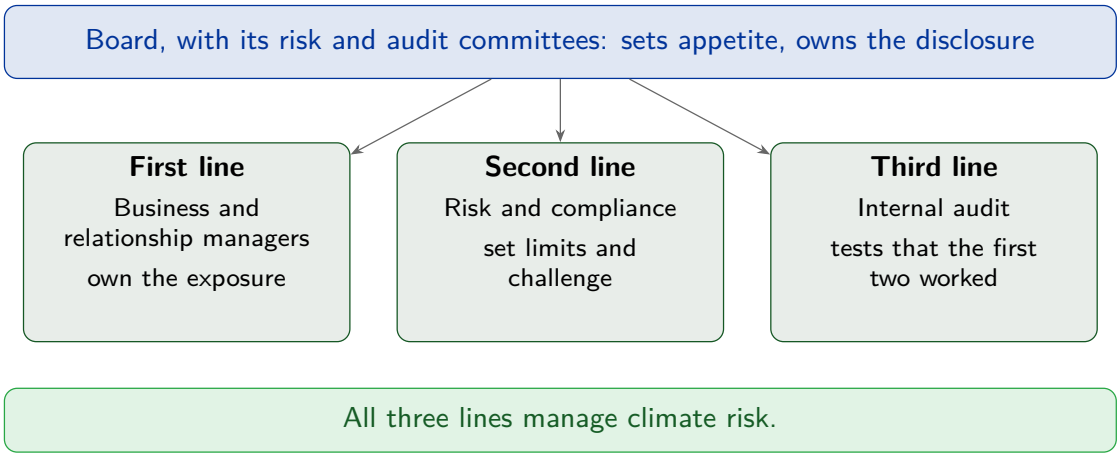


Figure 2.3: The three lines of defence under the board. All three manage climate risk.

nature[19], and the Exploring Natural Capital Opportunities, Risks and Exposure (ENCORE) tool helps identify which activities and assets warrant assessment[20]. The TNFD specifies no single metric for the state of nature, because none captures all its dimensions[21].

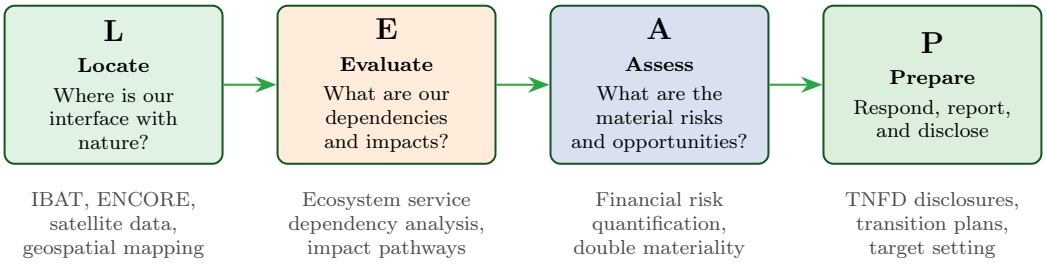


Figure 2.4: The four LEAP phases of the TNFD, from locating an organisation's interfaces with nature to preparing its response, with the tools used in each phase.

Table 2.2: TCFD and TNFD compared

Dimension	TCFD (climate)	TNFD (nature)
Established	December 2015 (FSB); recommendations 2017	2021; recommendations 2023
Risk assessment	Scenario-based (NGFS)	Spatial, location-based (LEAP)
Key metric	Tonnes of CO2 equivalent, tCO2e (globally fungible)	No single metric
Regulatory status	IFRS S2 effective from 1 January 2024	Voluntary adoption

The TNFD was launched in 2021[22], and it encourages and supports voluntary adoption of its

[19]TNFD (2023). Guidance on the identification and assessment of nature-related issues: the LEAP approach, version 1.1, October 2023.
[20]TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023.
[21]TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023.
[22]TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023. Section 1.2.

recommendations[23]. Deforestation accelerates climate change and climate change accelerates biodiversity loss, so a bank assesses climate and nature risk together.

2.6 Quantifying maturity

The module's teaching rubric scores risk-management maturity on four dimensions (identify, assess, manage, integrate), each from 0 to 3, for a total from 0 to 12: 0 to 3 absent, 4 to 6 basic, 7 to 9 developing, 10 to 12 advanced. Applying it to a hypothetical Thai commercial bank gives identification 2, assessment 1 (qualitative only, limited scenario work), management 2 (sector policies but no portfolio steering), and integration 1 (reported separately from the main ERM), a total of 6 out of 12, that is *basic*. The bank's two lowest dimensions are assessment and integration: NGFS scenario analysis raises assessment, and a board risk-appetite statement that names climate risk raises integration.

ASEAN case: Bank of Thailand, from the 2011 floods to a disclosure policy statement

Thailand's 2011 floods caused about $46.5 billion in damage and losses[a], and the manufacturing sector bore roughly 70 percent of the total after six industrial estates in Ayutthaya and Pathum Thani flooded[b]. In a policy statement of 15 February 2023 the Bank of Thailand (BOT) asks financial institutions to disclose climate-related information in line with internationally accepted standards such as the TCFD recommendations[c], and the BOT evaluates their progress against the statement from 2024 onwards[d]. In Singapore the Monetary Authority of Singapore (MAS) issued guidelines on environmental risk management in December 2020 with a transition period of 18 months[e], and Vietnam has required environmental risk management in bank lending since 1 June 2023 under Circular No. 17/2022/TT-NHNN of the State Bank of Vietnam (SBV)[f]. In the Philippines the Bangko Sentral ng Pilipinas (BSP) issued its Sustainable Finance Framework as Circular No. 1085 on 29 April 2020[g], and the framework asks banks to convey their sustainability objectives and policies to investors, clients and other stakeholders through disclosures in the Annual Report[h].

[a] World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning.

[b] World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Overview, page 2.

[c] Bank of Thailand (2023). Policy Statement of the Bank of Thailand Re: Internalizing Environmental and Climate Change Aspects into Financial Institution Business, 15 February 2023. Financial Institutions Strategy Department. Unofficial translation.

[d] Bank of Thailand (2023). Policy Statement of the Bank of Thailand Re: Internalizing Environmental and Climate Change Aspects into Financial Institution Business, 15 February 2023. Financial Institutions Strategy Department. Unofficial translation.

[e] Monetary Authority of Singapore (2020). Response to Feedback Received on Proposed Guidelines on Environmental Risk Management (Banks), 8 December 2020.

[f] State Bank of Vietnam (2022). Circular No. 17/2022/TT-NHNN of 23 December 2022 guiding environmental risk management in credit extension by credit institutions and foreign bank branches. English translation: LuatVietnam.

[g] Diokno, B. E. (2020). Integrating sustainability in corporate strategy: BSP sustainable finance framework. Speech by the Governor of the Bangko Sentral ng Pilipinas, 28 October 2020. BIS Central bankers' speeches, 10 December 2020.

[h] Diokno, B. E. (2020). Integrating sustainability in corporate strategy: BSP sustainable finance framework. Speech by the Governor of the Bangko Sentral ng Pilipinas, 28 October 2020. BIS Central bankers' speeches, 10 December 2020.

[23] TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023.

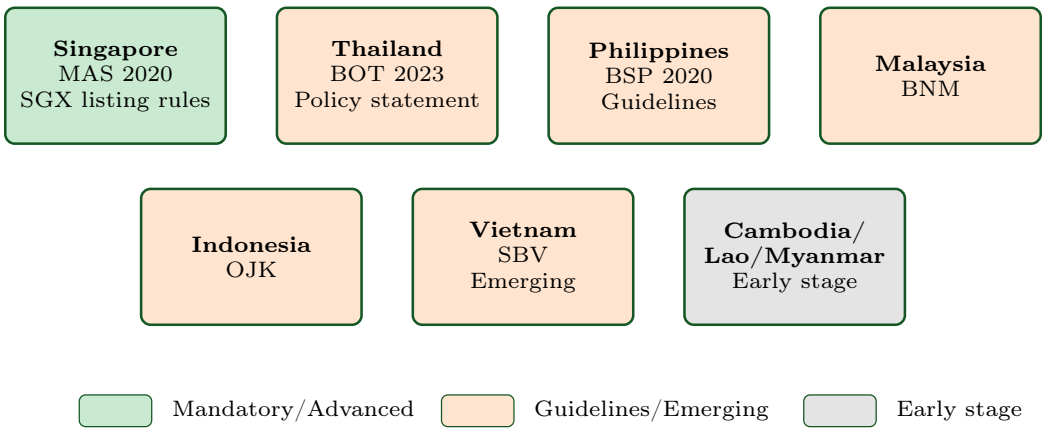


Figure 2.5: TCFD adoption across nine ASEAN economies in three supervisory stages: mandatory or advanced, guidelines or emerging, and early stage. SGX is the Singapore Exchange, BNM is Bank Negara Malaysia, and OJK is Otoritas Jasa Keuangan of Indonesia.

PhD extension: the awareness-action gap

Krueger, Sautner, and Starks (2020, *Review of Financial Studies*) surveyed 439 institutional investors[a] and found that many of them, especially the larger, longer-horizon and environmental, social and governance (ESG) oriented ones, prefer risk management and engagement to divestment as the response to climate risk[b]. The awareness-action gap is the distance between such stated preferences and portfolio allocations. Whether the gap has narrowed since mandatory disclosure regimes took effect, and how large it is for ASEAN investors, are open questions.

[a]Krueger, P., Sautner, Z., and Starks, L. T. (2020). The Importance of Climate Risks for Institutional Investors. Review of Financial Studies, 33(3), 1067 to 1111. ECGI Finance Working Paper.

[b]Krueger, P., Sautner, Z., and Starks, L. T. (2020). The Importance of Climate Risks for Institutional Investors. Review of Financial Studies, 33(3), 1067 to 1111. ECGI Finance Working Paper.

Key takeaways

- The TCFD has four pillars, and the Risk Management pillar has three recommended disclosures: how the bank identifies and assesses climate risk, how it manages it, and how both processes are integrated into its overall risk management.
- Climate risk belongs inside the existing ERM: same appetite, register, committee, and escalation.
- The TNFD extends the four pillars to nature; its LEAP approach evaluates dependencies and impacts on nature, which are location specific, to assess nature-related risks.
- Maturity can be scored 0 to 12 on the module's teaching rubric; the hypothetical Thai bank scores 6, basic, with its two lowest scores in assessment (limited scenario work) and integration (reported outside the main ERM).

Chapter 3

Scenario Analysis and Climate Modeling

The NGFS publishes seven reference scenarios, and their end-of-century warming runs from 1.1 °C in Low Demand to 3.0 °C in Current Policies.

Scenario analysis turns a climate pathway, such as a tripling of carbon prices by 2035 or warming of 3 °C, into a portfolio loss. The Strategy pillar of the Task Force on Climate-related Financial Disclosures (TCFD) asks a bank to describe the resilience of its strategy under such scenarios.

Learning objectives

Participants are able to:

1. Explain what a scenario states under deep uncertainty, where the probability distribution itself is unknown.
2. Describe the seven NGFS reference scenarios and select the ones that matter for the Association of Southeast Asian Nations (ASEAN).
3. Trace the five-stage transmission chain from a climate pathway to portfolio losses.
4. Calibrate sectoral shocks to the probability of default (PD) and loss given default (LGD) from scenario variables.
5. Outline what integrated assessment models (IAMs) do and why the choice of damage function matters.

3.1 Scenarios under deep uncertainty

Climate outcomes resist prediction: the system has non-linear dynamics and tipping points, outcomes depend on policy choices not yet made, and the uncertainty is deep, with no probability attached to any path. Risk has known probabilities; deep uncertainty means the probability distribution itself is unknown. Scenarios respond to this by offering structured explorations of plausible futures: internally consistent "what if" stories about climate, policy, and technology that let an institution stress test against several pathways and look for vulnerabilities that persist across all of them. The goal is a strategy that survives every pathway in the set. Climate scenarios evolved from the Special Report on Emissions Scenarios (SRES), accepted by Working Group III of the Intergovernmental Panel on Climate Change (IPCC) in 2000[1], through the

[1]IPCC (2000). Special Report on Emissions Scenarios, Summary for Policymakers. Nakicenovic, N. and Swart, R. (eds.).

Representative Concentration Pathways (RCPs) of van Vuuren et al. (2011)[2] and the Shared Socioeconomic Pathways (SSPs) of Riahi et al. (2017)[3], to the NGFS scenarios for the financial sector, whose socio-economic assumptions follow SSP2[4].

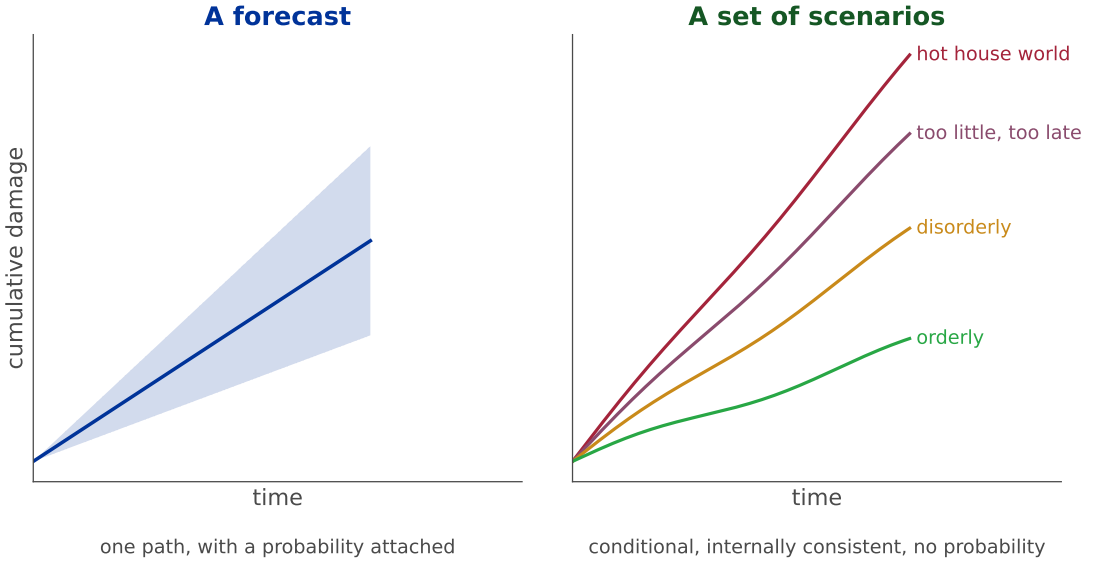


Figure 3.1: A forecast is one path with a probability attached; a scenario set is a family of conditional paths with none.

3.2 The NGFS scenarios

The Network of Central Banks and Supervisors for Greening the Financial System (NGFS), founded in 2017 at the Paris One Planet Summit[5], counts Bank Indonesia, the Bank of Thailand, Bank Negara Malaysia and the Bangko Sentral ng Pilipinas (BSP) among its members[6], and publishes climate scenarios for financial supervision. The current release, results version 5.0 of November 2024, provides seven reference scenarios in four categories: orderly transition, disorderly transition, hot world (Hot House World in the scenario narratives of the same release), and too little, too late[7]. The NGFS released annual vintages from Phase I (2020) to Phase V (2024)[8], and the next is due in 2026 under a two-year design cycle[9], so a scenario table without a version number cannot be checked: Phase IV added Fragmented World and Low Demand and

[2]van Vuuren, D.P., Edmonds, J., Kainuma, M. et al. (2011). The representative concentration pathways: an overview. Climatic Change 109, 5-31.

[3]Riahi, K. et al. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change 42, 153-168.

[4]NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V). Annex A.

[5]NGFS. Origin and Purpose. Network of Central Banks and Supervisors for Greening the Financial System.

[6]NGFS. Membership, list of members, Asia-Oceania. ngfs.net.

[7]NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V). Box 1, NGFS Scenario framework, page 9.

[8]NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V).

[9]NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V).

discontinued the Divergent Net Zero scenario[10].

Table 3.1: The seven NGFS scenarios of results version 5.0, November 2024, with end-of-century warming averaged across the three NGFS models.

Scenario	Category	End-of-century warming
Low Demand	Orderly	1.1 °C
Net Zero 2050	Orderly	1.4 °C
Below 2 °C	Orderly	1.8 °C
Delayed Transition	Disorderly	1.7 °C
Nationally Determined Contributions (NDCs)	Hot house world	2.3 °C
Current Policies	Hot house world	3.0 °C
Fragmented World	Too little, too late	2.4 °C

The same source gives each scenario's peak: Net Zero 2050 peaks at 1.7 °C and ends the century at 1.4 °C[11]. Carbon prices and impacts on gross domestic product (GDP) are model outputs: the same scenario run through a different integrated assessment model gives a different number, and the spread is wide enough that a single tabulated value misleads. For Net Zero 2050 the modelled global carbon price reaches $500 to $1,250 per tonne by 2050, in 2010 dollars, a two-and-a-half-fold spread across models for one scenario in one year[12]. Quote a range and its model, or pull the pathway live from the NGFS Scenario Explorer; do not quote a slide.

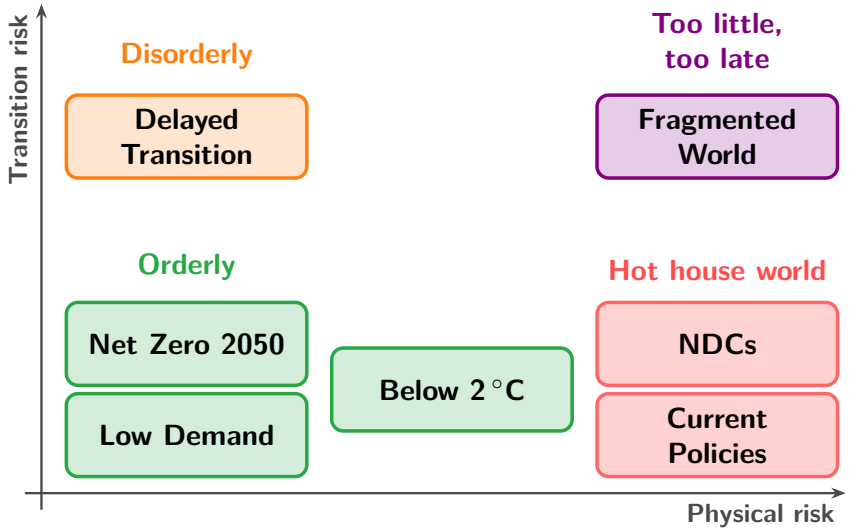


Figure 3.2: The seven NGFS scenarios placed by physical and transition risk. The orderly scenarios sit low on both, Delayed Transition high on transition risk, NDCs and Current Policies high on physical risk, and Fragmented World high on both.

ASEAN and physical risk

Orderly scenarios assume that ambitious climate policies are introduced early and become gradually more stringent, so physical and transition risks both stay relatively subdued[a]. Disorderly scenarios assume that climate policies are delayed or divergent across countries

[10]NGFS (2023). NGFS Scenarios for central banks and supervisors, Phase IV, November 2023.
[11]NGFS (2024). NGFS long-term scenarios for central banks and supervisors, November 2024 (Phase V), Scenarios at a glance (1/2), page 10.
[12]NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V). Net Zero 2050 scenario narrative.

and sectors, so physical risk stays subdued and transition risk is high, as carbon prices rise sharply and abruptly[b]. Hot house world scenarios assume that some jurisdictions implement some policies but that global efforts are insufficient to halt significant global warming, so they hold the least transition cost and the most physical damage[c]. Chronic physical risk is the main source of risk in the NGFS scenarios of November 2024[d], and the NGFS counts Asia among the regions most vulnerable to physical risks[e]. The Swiss Re Institute (2021) finds ASEAN economies hardest hit: with 3.2 °C of warming by mid-century, ASEAN GDP is 37.4 percent below a world without climate change, against 4.2 percent under the Paris target[f]. *Fragmented World*, the too little, too late case, assumes a late and uncoordinated transition, with uneven climate action across countries, so it holds high physical and high transition risk at once[g]. For a region that is physically exposed and also trade-exposed to other countries' carbon policy, Fragmented World belongs in an ASEAN stress test alongside the hot house world. Bolton et al. (2020) call climate tail risks "green swans": potentially extremely financially disruptive events that could be behind the next systemic financial crisis[h].

[a] NGFS (2024). NGFS Climate Scenarios Technical Documentation, version 5.0, November 2024, page 16.

[b] NGFS (2024). NGFS Climate Scenarios Technical Documentation, version 5.0, November 2024, page 17.

[c] NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024, page 35.

[d] NGFS (2024). NGFS long-term scenarios for central banks and supervisors, November 2024 (Phase V), Main results, Gross Domestic Product.

[e] NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V). Section 4, Fragmented World, GDP impact across jurisdictions.

[f] Swiss Re Institute (2021). The economics of climate change: no action not an option. April 2021, Key takeaways.

[g] NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024, page 49.

[h] Bolton, P., Despres, M., Pereira da Silva, L. A., Samama, F., and Svartzman, R. (2020). The green swan: central banking and financial stability in the age of climate change. Bank for International Settlements.

The International Energy Agency (IEA) publishes energy-sector scenarios in its World Energy Outlook: the Current Policies and Stated Policies scenarios are exploratory and the Net Zero Emissions by 2050 scenario is normative[13], and the 2025 edition leaves out the Announced Pledges scenario of earlier editions[14]. Use the NGFS set for portfolio-level stress testing and the IEA scenarios for energy-sector analysis.

3.3 The transmission chain

Every scenario analysis follows the same five-stage chain, and each stage adds model uncertainty:

1. **Climate pathway**: temperature, precipitation, extreme-event frequency.
2. **Macro variables**: GDP impact, carbon price, energy prices.
3. **Sector shocks**: output, employment, technology disruption.
4. **Counterparty**: revenue decline, cost increase, asset impairment.
5. **Portfolio losses**: changes in probability of default (PD) and loss given default (LGD), collateral loss, mark-to-market losses.

[13] IEA (2025). Global Energy and Climate Model: Understanding GEC Model scenarios. International Energy Agency.

[14] IEA (2025). Global Energy and Climate Model: Announced Pledges Scenario (APS). International Energy Agency.

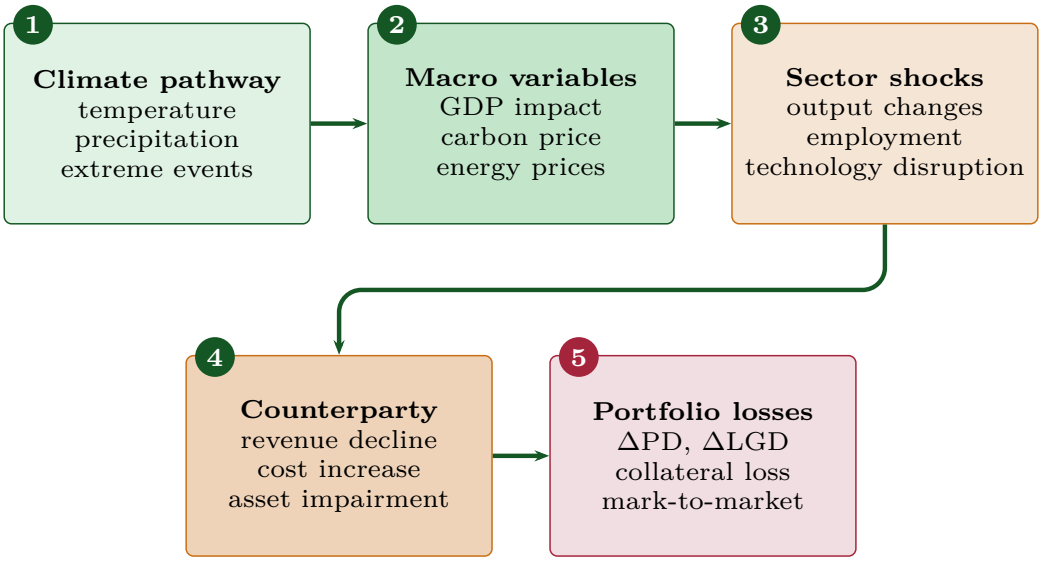


Figure 3.3: The five stages of the transmission chain, from climate pathway to portfolio losses. Each stage is a model, so each adds its own uncertainty to every stage after it.

As an ASEAN illustration, Philippine agriculture under a hot house world pathway runs from +2.5 °C, through a GDP deviation of about minus 8 percent, to a roughly 15 percent decline in rice yield.

3.4 Calibrating sectoral shocks

Two calibrations turn scenario variables into credit parameters. The PD shock scales GDP by a sector sensitivity:

$$\Delta PD_{sector} = -\gamma_{sector} \times \Delta GDP_{scenario},$$

in percentage points, where γ_{sector} is the sector's default sensitivity to output and the minus sign turns a fall in output into a rise in defaults. For Philippine agriculture under a hot house world pathway, with $\Delta GDP = -8$ percent and $\gamma_{agriculture} = 1.5$, this gives a rise of 12 percentage points in the default probability. The LGD adjustment captures the uninsured share of physical damage:

$$LGD_{climate} = LGD_{base} + (1 - \text{insurance coverage}) \times \text{physical damage rate},$$

where insurance coverage is the insured share of physical damage and the physical damage rate applies to the collateral, so an agricultural loan with a base LGD of 45 percent, 30 percent insurance coverage and a 25 percent damage rate has $LGD_{climate} = 45 + 0.70 \times 25 = 62.5$ percent. The LGD adjustment raises LGD by 17.5 percentage points, from 45 to 62.5 percent, and the PD shock raises PD by 12 percentage points. Per unit of exposure, the PD rise at the base LGD adds $0.12 \times 0.45 = 0.054$ to expected loss, the LGD rise at the base PD adds $0.175 \times PD_{base}$, and the two rises together add a further $0.12 \times 0.175 = 0.021$. The LGD rise adds more than the PD rise only where the base PD exceeds 31 percent. Take a sample Philippine bank under a disorderly scenario, with sector weights in percent and PD shocks in percentage points of energy 10 and 15, agriculture 25 and 8, manufacturing 20 and 5, real estate 15 and 3, and services 30 and 2. Its portfolio-weighted PD increase is 5.55 percentage points, which on a $2 billion book at the 62.5 percent climate-adjusted LGD implies about $69.4 million in additional expected credit losses from the PD rise; the LGD rise adds a further 17.5 percent of the base PD times the book. The LGD belongs in that step: a PD rise multiplied by exposure alone gives the amount entering default, and only the loss identity of Chapter 1 turns it into a loss.

3.5 Quantifying uncertainty

Within one scenario, a Monte Carlo simulation over uncertain model parameters gives a fan chart: the central line is the median of the simulated paths, and the shaded bands, the 25th to 75th and the 10th to 90th percentiles, widen with the horizon as uncertainty compounds. The percentiles are conditional on the scenario, and a bank reads its losses from the lower tail of the fan.

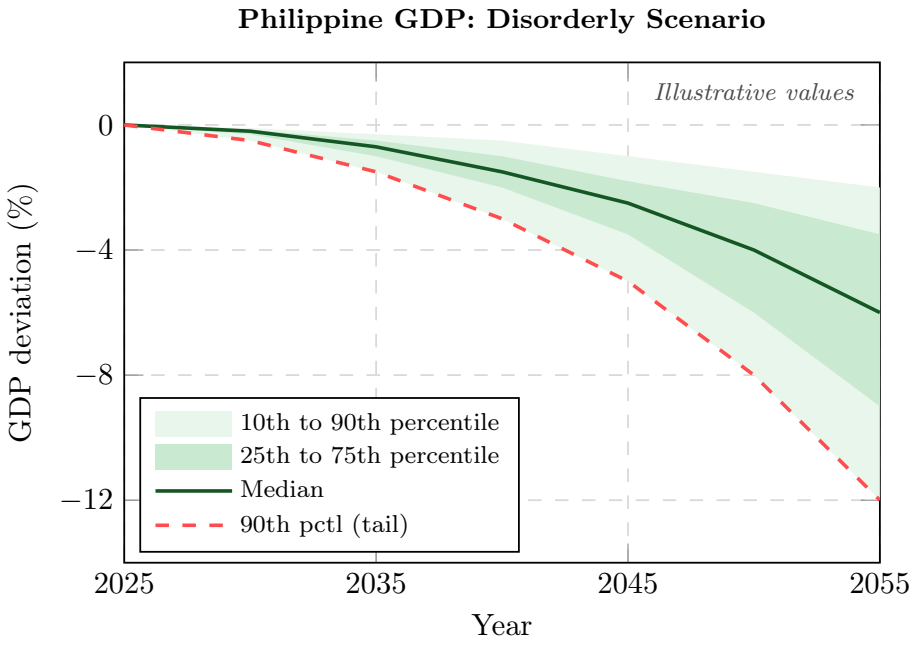


Figure 3.4: Philippine GDP deviation from baseline under a disorderly scenario, 2025 to 2055: the median of the simulated paths and two percentile bands that widen with the horizon. Illustrative values.

3.6 Integrated assessment models, carbon budgets and damage functions

The numbers behind every NGFS scenario come from a chain of models. The NGFS runs three integrated assessment models (IAMs), REMIND-MAgPIE, GCAM and MESSAGEix-GLOBIOM, and one macroeconomic model, NiGEM[15]. Each IAM couples an economic, an energy and a climate module and turns a policy path into energy use, emissions and land use. NiGEM turns the transition and the physical shocks into GDP, interest rates and prices. Physical damages feed back into the transition pathways only in REMIND-MAgPIE's runs with integrated damages[16].

DICE (the Dynamic Integrated Climate-Economy model) is a single-region teaching model. The three NGFS models make different structural assumptions, so the same scenario name can yield different numbers. The carbon budget constraint, $\sum_t E_t \leq B_{1.5}$, holds cumulative emissions below the budget consistent with a temperature limit; if annual CO2 emissions from 2020 to 2030 stayed at the 2019 level, the resulting cumulative emissions would almost exhaust the remaining

[15]NGFS (2024). NGFS Climate Scenarios Technical Documentation, version 5.0, November 2024, page 11.
[16]NGFS (2024). NGFS Climate Scenarios Technical Documentation, version 5.0, November 2024, page 22.

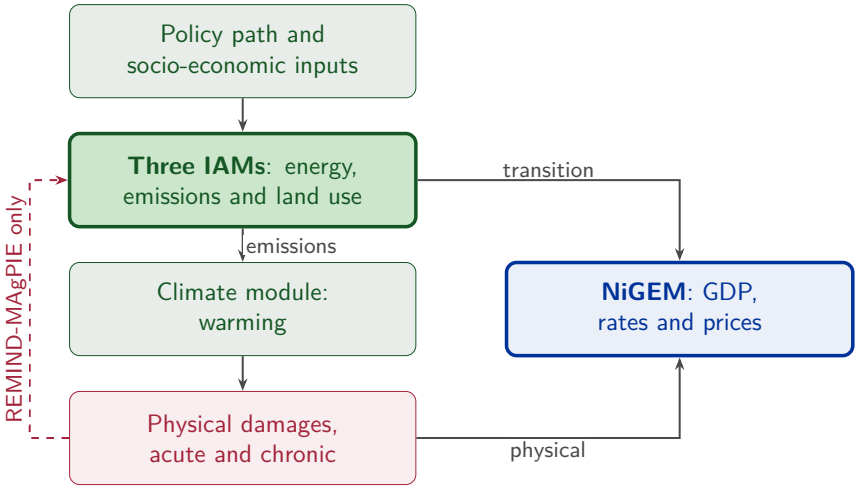


Figure 3.5: The NGFS model chain. Three IAMs turn a policy path into energy use, emissions and land use, a climate module turns emissions into warming, and NiGEM turns the transition and the physical shocks into GDP, interest rates and prices. The dashed return from damages to the IAMs exists only in REMIND-MAgPIE's runs.

carbon budget for 1.5 °C at a 50 percent likelihood[17], so every year of delay raises the rate at which emissions must fall afterwards. The damage function, often written $D(T) = aT^2/(1+bT^2)$ with warming T and calibrated parameters a and b, translates temperature into GDP loss: at the same level of warming, published estimates of the GDP loss differ several-fold depending on whose damage function is used.

PhD extension: discount rates and the limits of IAMs

The Stern-Nordhaus debate turns on the discount rate in the Ramsey equation $r = \delta + \eta g$, where δ is the pure rate of time preference, η the elasticity of marginal utility and g the growth rate of consumption per head. Stern's low rate implies a high social cost of carbon and urgent action; Nordhaus's higher rate implies a much lower cost and gradual action. The difference comes from an ethical choice about the weight of future generations. Weitzman (2009) argues that fat-tailed catastrophic risk should dominate cost-benefit analysis, and Pindyck (2013) warns that IAMs create an illusion of precision. For ASEAN, physical damages arrive in the near term, where the choice of discount rate moves their present value less.

ASEAN case: Philippine typhoons and the cubic wind-damage law

An average of about 20 tropical cyclones a year occur in the Philippine region, and 8 or 9 of them cross the country[a]. The IPCC projects that the proportion of intense tropical cyclones (Category 4 to 5) and the peak wind speeds of the most intense ones increase with global warming[b]. Typhoon Haiyan, known locally as Yolanda, made landfall in November 2013 as one of the strongest typhoons ever recorded; official estimates put its damages and losses at $13 billion, 90 percent of them borne by the private sector and largely uninsured[c]. Emanuel (2005) notes that the monetary loss in wind storms rises roughly as the cube of the wind speed[d], $Damage \propto v^3$, so a quarter more wind speed implies roughly twice the damage ($1.25^3 \approx 1.95$). Policy responses include climate-adjusted capital buffers, crop-insurance loan conditions to cut LGD, and concentration caps on typhoon-corridor lending.

[a] PAGASA. Tropical Cyclone Information. Philippine Atmospheric, Geophysical and Astronomical Ser-

[17] IPCC (2023). Climate Change 2023: Synthesis Report, Summary for Policymakers, B.5.3.

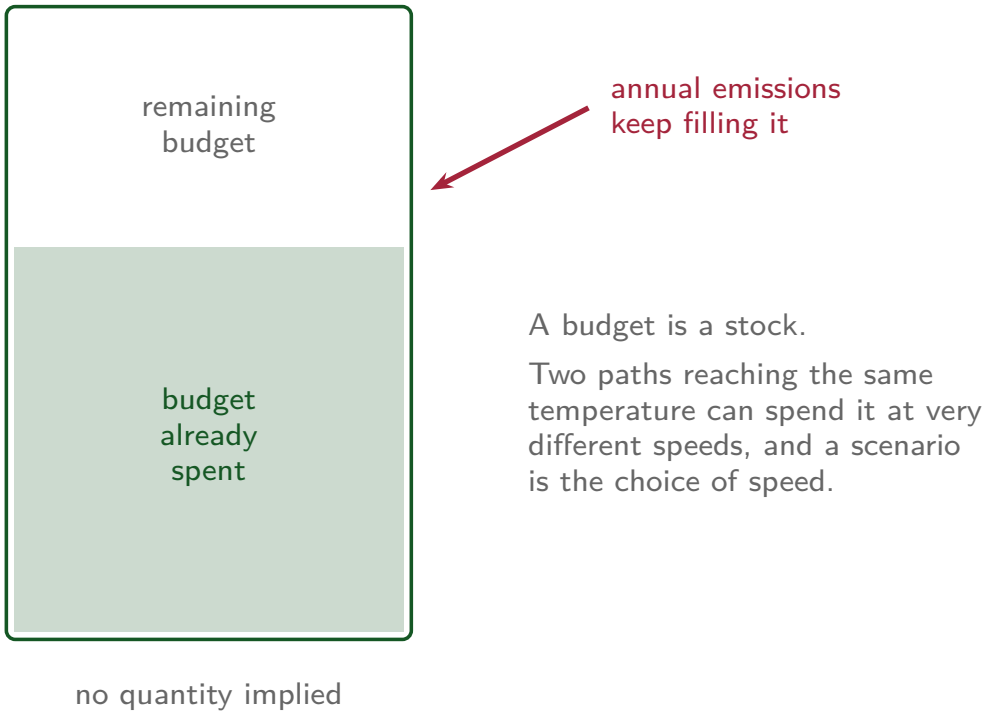


Figure 3.6: A carbon budget is a stock: two pathways reaching the same temperature spend the same fixed quantity at different speeds, and a scenario is a choice of speed. The size of the remaining budget is contested, so the stock is drawn without a scale.

vices Administration, DOST.

[b]IPCC (2021). Climate Change 2021: The Physical Science Basis, Summary for Policymakers, B.2.4.

[c]World Bank (2021). Philippines Financial Sector Assessment Program: Climate Change and Environmental Risks and Opportunities, Technical Note, Box 1.

[d]Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436, 686-688. Copy hosted by Appalachian State University course readings.

Key takeaways

- Scenarios are internally consistent explorations of plausible futures under deep uncertainty, with no probability attached to any path.
- The NGFS provides seven reference scenarios in four categories (version 5.0, November 2024). Chronic physical risk is the main source of risk in them, and the NGFS counts Asia among the regions most vulnerable to physical risks; Fragmented World, the too little, too late case, is high on physical and transition risk at once.
- The five-stage transmission chain links climate pathway to portfolio loss; calibrate with $\Delta PD = -\gamma\,\Delta GDP$ and the uninsured-damage LGD adjustment.
- The damage function turns warming into GDP loss, and published damage functions differ several-fold at the same warming, so report the range across them.

Chapter 4

Carbon Metrics and Climate Value-at-Risk

CDP, formerly the Carbon Disclosure Project, finds that the emissions associated with financial institutions' investing, lending and underwriting are on average more than 700 times their direct emissions[1].

Carbon metrics measure the emissions a portfolio finances: Greenhouse Gas (GHG) scopes, financed emissions, the Weighted Average Carbon Intensity (WACI), data quality scores and alignment metrics. Climate Value-at-Risk (Climate VaR) converts a climate scenario into a loss of portfolio value. In an illustrative Vietnamese bank, coal has the highest carbon intensity and agriculture the larger Climate VaR, about $281 million against about $74 million.

Learning objectives

Participants are able to:

1. Distinguish Scope 1, 2, and 3 emissions and compute financed emissions with the attribution formula of the Partnership for Carbon Accounting Financials (PCAF).
2. Calculate and benchmark a portfolio's Weighted Average Carbon Intensity (WACI).
3. Read PCAF data quality scores and report a metric with its score.
4. Decompose Climate VaR into physical and transition components and compute each.
5. Explain the carbon premium and why exposure size can dominate carbon intensity.

4.1 Financed emissions

Financed emissions are the Scope 1 and Scope 2 emissions of investees and borrowers attributed to the lender, which the Greenhouse Gas Protocol files under Scope 3, category 15, Investments[2]. PCAF standardises how financed emissions are computed. Its attribution formula is

$$FE_i = \frac{Outstanding_i}{EVIC_i} \times Emissions_i,$$

[1] CDP (2021). Finance sector's funded emissions over 700 times greater than its own. Press release, 28 April 2021.

[2] GHG Protocol (2011). Corporate Value Chain (Scope 3) Accounting and Reporting Standard. WRI and WBCSD, September 2011. Table 5.4, page 37; page 51; glossary, page 140.

where $Outstanding_i$ is the bank's loan to borrower i, $EVIC_i$ is the borrower's Enterprise Value Including Cash, the ratio $Outstanding_i/EVIC_i$ is the attribution factor, and $Emissions_i$ is the borrower's absolute emissions[3]. For a Vietnamese steel company with a $50 million loan, $500 million EVIC and 200,000 tonnes of carbon dioxide equivalent (tCO2e) of emissions, the bank is attributed $\frac{50}{500} \times 200{,}000 = 20{,}000$ tCO2e. The attribution factor ensures each lender is responsible only for its share.

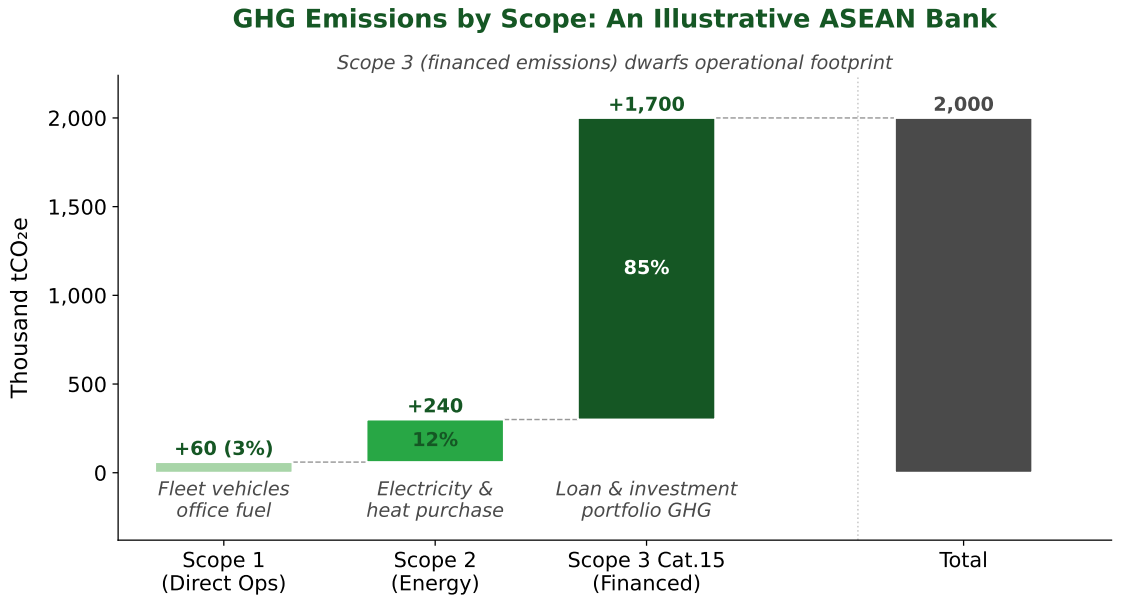


Figure 4.1: Scope 1, Scope 2 and financed emissions (Scope 3, category 15) of an illustrative bank in the Association of Southeast Asian Nations (ASEAN). Financed emissions are 85 percent of the total; at CDP's average ratio the Scope 1 and Scope 2 bars would be too small to see.

4.2 Weighted Average Carbon Intensity

WACI measures a portfolio's exposure to carbon-intensive companies, in tCO2e per $ million of revenue[4], and the Task Force on Climate-related Financial Disclosures (TCFD) asks asset owners to disclose it for each fund or investment strategy[5]:

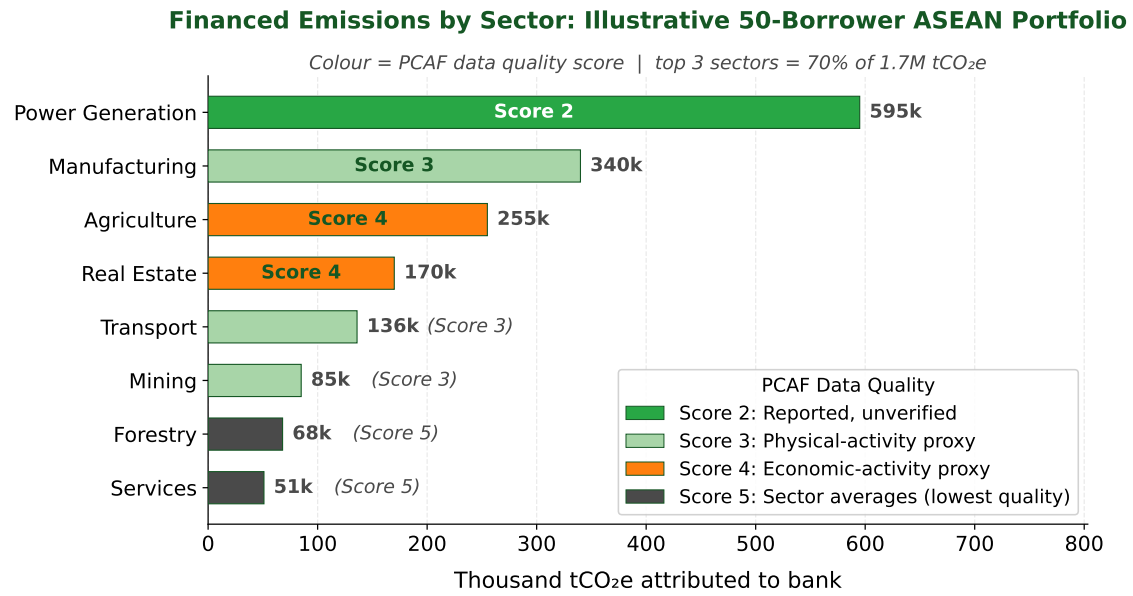
$$WACI = \sum_i w_i \times \frac{Emissions_i}{Revenue_i},$$

where w_i is the portfolio weight and the ratio is carbon intensity in tCO2e per $ million of revenue, so doubling every holding leaves WACI unchanged. An illustrative three-company portfolio of a power utility (40 percent weight, intensity 800), a manufacturer (35 percent, 200), and a tech firm (25 percent, 15) has $WACI = 0.40 \times 800 + 0.35 \times 200 + 0.25 \times 15 \approx 394$ tCO2e per $ million of revenue, and the utility alone contributes about 81 percent of that despite being

[3]PCAF (2022). The Global GHG Accounting and Reporting Standard, Part A: Financed Emissions. Second Edition, December 2022. Section 5.2, Business loans and unlisted equity, page 70.

[4]TCFD (2021). Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures, October 2021. Table 3, Common Carbon Footprinting and Exposure Metrics, page 52.

[5]TCFD (2021). Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures, October 2021. Supplemental Guidance for Asset Owners, page 42.



Assumed teaching example, not measured data: Illustrative 50-borrower portfolio, not a real bank.
https://digital-ai-finance.github.io/Green-Finance/module4-lesson4-carbon-metrics/

Figure 4.2: Financed emissions by sector of the same illustrative ASEAN bank, whose 50 borrowers account for 1,700 thousand tCO2e. Power generation, manufacturing and agriculture make up 70 percent. Colour gives the PCAF data quality score.

40 percent of value. Coal provided 44 percent of ASEAN electricity generation in 2023 and fossil fuels 74 percent[6]. The benchmark to compare against is the reporting institution's own book.

4.3 Data quality and alignment

PCAF grades each figure with a data quality score from 1, the highest, to 5, the lowest: score 1 means verified emissions reported by the company[7] and score 5 means emission factors for the borrower's sector per unit of revenue or of assets[8]. Report the data quality score and the uncertainty range alongside every metric. Three alignment tools answer different questions. The Paris Agreement Capital Transition Assessment (PACTA) measures the alignment of financial portfolios with climate scenarios[9]. The Transition Pathway Initiative (TPI) assesses companies on Management Quality and Carbon Performance, two complementary metrics[10]. Companies and financial institutions can have their targets validated by SBTi Services, a subsidiary of the Science Based Targets initiative (SBTi)[11]. An illustrative ASEAN bank portfolio with an Implied Temperature Rise of 2.8 °C lies in the partial-alignment band, 2.0 to 3.0 °C.

[6]Ember (2024). ASEAN's clean power pathways: 2024 insights. Power sector in 2023.
[7]PCAF (2022). The Global GHG Accounting and Reporting Standard, Part A: Financed Emissions. Second Edition, December 2022. Pages 19, 52 and 53; Table 5-3, page 57.
[8]PCAF (2022). The Global GHG Accounting and Reporting Standard, Part A: Financed Emissions. Second Edition, December 2022. Table 5-3, options 3b and 3c, page 57.
[9]RMI. PACTA: Measure the alignment of financial portfolios with climate scenarios. Paris Agreement Capital Transition Assessment, RMI.
[10]Transition Pathway Initiative Centre, London School of Economics. Corporate assessments, TPI online tool.
[11]Science Based Targets initiative. How it works: setting science-based targets.

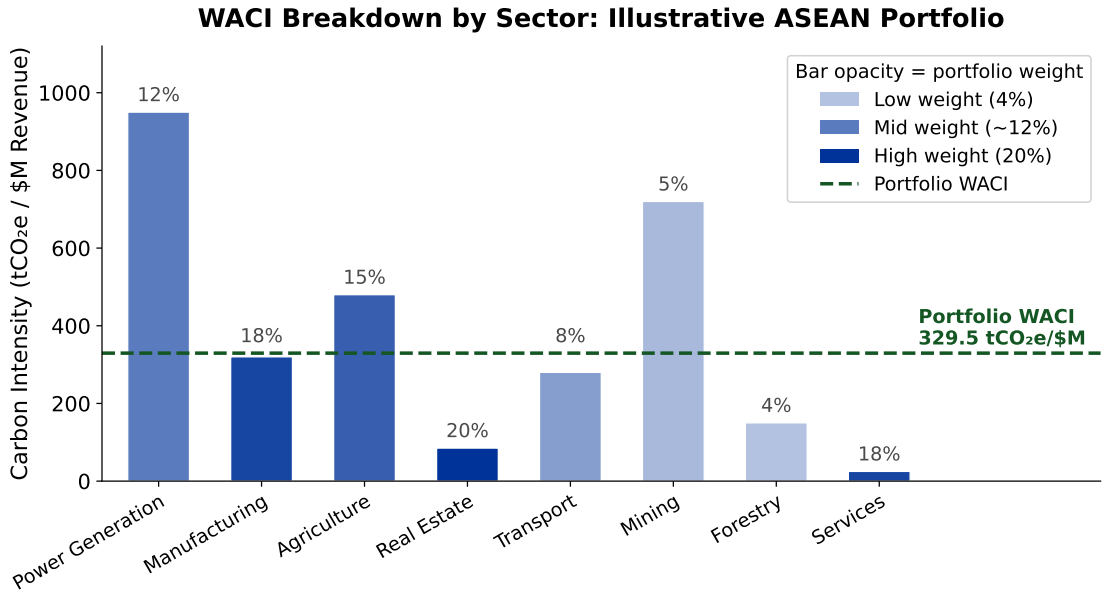


Figure 4.3: WACI of an illustrative eight-sector ASEAN portfolio, 329.5 tCO2e per $ million of revenue. Power generation, 12 percent of the portfolio weight, contributes the largest share.

4.4 Climate Value-at-Risk

Climate VaR measures the impact of climate-related risks and opportunities on the market value of an asset or a portfolio under a specified climate scenario[12], as the expected loss of portfolio value,

$$\text{Climate VaR} = Portfolio_{t_0} - \mathbb{E}[Portfolio_{t_T} \mid Scenario]\,,$$

so an illustrative portfolio of $2 billion expected to be worth $1.62 billion under a hot house world pathway to 2050 has a Climate VaR of $380 million, or 19 percent. Value-at-Risk is a quantile of a loss distribution at a stated confidence level, over days. Climate VaR is a loss conditional on one named scenario, over years to decades, with no probability attached to the scenario, and it splits into physical and transition components. Operationally,

$$\text{Climate VaR} = \sum_i Exposure_i \times \Delta PD_i \times LGD_i,$$

evaluated separately for the physical channel (climate-adjusted default and uninsured collateral loss) and the transition channel (carbon pricing, stranded assets, technology displacement), where ΔPD_i is the scenario's rise in the probability of default (PD) and LGD_i the loss given default (LGD) in the scenario. For the Mekong Delta rice portfolio of Chapter 1 the sum gives $6.8 million against the $7.6 million rise in expected loss; the difference is the higher LGD on the defaults the bank expected anyway. A Vietnamese rice borrower with $10 million exposure, default probability rising by 8 percentage points from 5 to 13 percent, and LGD of 65 percent contributes $\$10\text{M} \times 0.08 \times 0.65 = \$520{,}000$ of physical Climate VaR. A coal borrower with $20 million exposure, default probability rising from 3 to 18 percent under a $75 carbon price, and LGD of 55 percent contributes $\$20\text{M} \times 0.15 \times 0.55 = \$1.65\text{M}$ of transition Climate VaR.
Under Net Zero 2050 the transition channel leads, $45 million against $12 million; under a hot house world pathway the physical channel leads, $38 million against $8 million. A single Climate

[12]UNEP FI (2019). Changing Course: A comprehensive investor guide to scenario-based methods for climate risk assessment, in response to the TCFD, page 38.

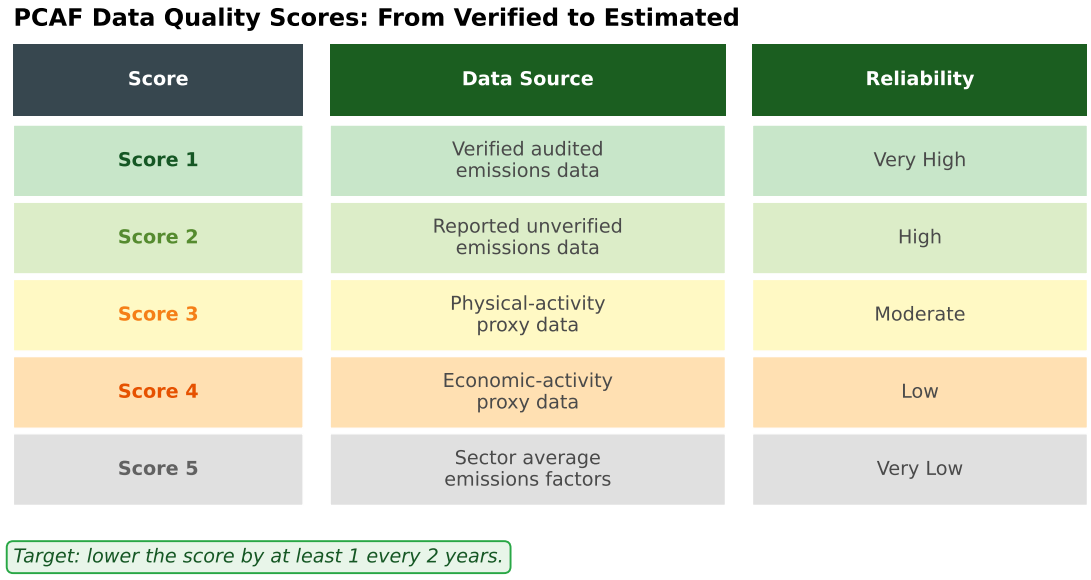


Figure 4.4: The PCAF data quality scores, from verified emissions reported by the company to emission factors for the borrower's sector.

VaR figure hides the scenario that produced it, so an assessment reports both channels under several scenarios.

4.5 The carbon premium

The carbon beta β_{carbon} of a factor model measures whether markets price transition risk:

$$R_i = \alpha + \beta_{mkt} R_m + \beta_{carbon}\, CarbonIntensity_i + \varepsilon_i.$$

A positive β_{carbon} means investors demand a carbon premium, a higher return for holding carbon-intensive assets. Bolton and Kacperczyk (2021, *Journal of Financial Economics*) find such a premium in the *US* cross-section: a one-standard-deviation increase in the level of Scope 1 emissions is associated with about 1.8 percent higher annualised returns, and in the change of emissions with about 3.1 percent[13]. Their post-Paris comparison is a caution: the premium does look larger after 2015, but the rise is mostly due to new firms entering the sample, and excluding those new firms leaves it insignificant[14]. The same authors later extend the result to a cross-section of over 14,400 firms in 77 countries, published in 2023[15].

ASEAN case: the Vietnam agriculture-coal Climate VaR inversion

Illustrative worked example. An illustrative Vietnamese bank with $30 billion in assets has 18 percent of its book in agriculture ($5.4 billion) and 3 percent in coal and power ($0.9 billion). Its loans finance 2,130 thousand tCO2e. Coal is 3 percent of loans and 17 percent of the carbon footprint; agriculture is 18 percent of loans and 38 percent of the footprint.

[13]Bolton, P. and Kacperczyk, M. (2021). Do Investors Care about Carbon Risk? Journal of Financial Economics 142(2), 517-549. NBER Working Paper 26968.
[14]Bolton, P. and Kacperczyk, M. (2021). Do Investors Care about Carbon Risk? Journal of Financial Economics 142(2), 517-549. NBER Working Paper 26968.
[15]Bolton, P. and Kacperczyk, M. (2023). Global Pricing of Carbon-Transition Risk. The Journal of Finance 78(6), 3677-3754. NBER Working Paper 28510.

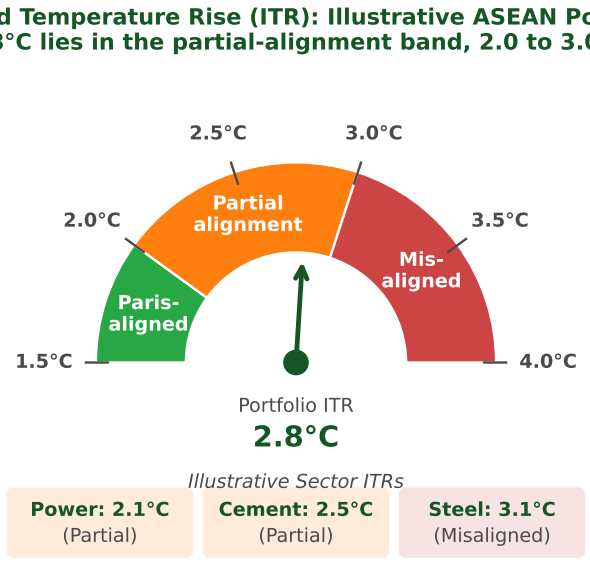


Figure 4.5: Implied Temperature Rise of an illustrative ASEAN portfolio, 2.8 °C, on a scale from 1.5 to 4.0 °C, with three illustrative sector values.

Agriculture's physical Climate VaR is about $281 million ($5.4B × 0.08 × 0.65), whereas coal's transition Climate VaR is about $74 million ($0.9B × 0.15 × 0.55). Two drivers explain the inversion: agriculture is much the larger book, and the Mekong Delta faces coastal and river erosion, sea-level rise and saltwater intrusion[a].

[a] World Bank (2022). New World Bank Group Report Proposes Path for Vietnam to Address Climate Risks While Sustaining Robust Economic Growth. Press release, 1 July 2022.

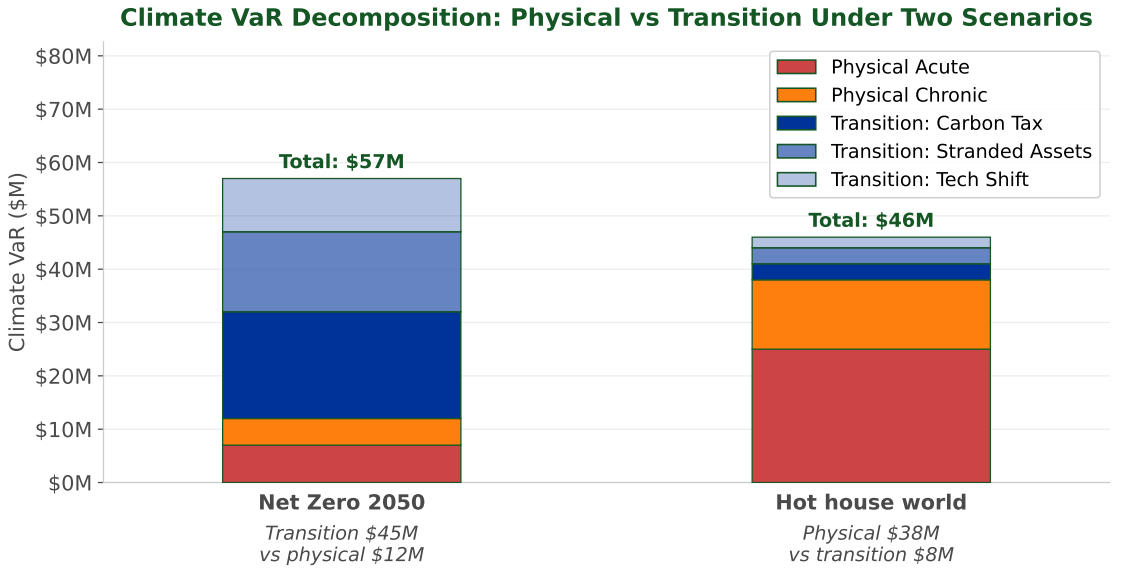
Carbon intensity and Climate VaR rank coal and agriculture in opposite order

In the Vietnam case coal has the highest carbon intensity and agriculture the larger Climate VaR, because agriculture's exposure is 6 times coal's. Financed emissions per dollar lent and Climate VaR rank agriculture and coal in opposite order.

Key takeaways

- Almost all of a bank's emissions are financed emissions, on CDP's evidence on average more than 700 times its direct emissions[16]; PCAF attributes them by the outstanding-over-EVIC factor.
- WACI weights each holding's carbon intensity by its share of the portfolio; the benchmark to compare against is the reporting institution's own book.
- Report the PCAF data quality score and the uncertainty range with every carbon figure.
- Climate VaR splits into physical and transition channels; the dominant channel depends on the scenario.

[16] CDP (2021). Finance sector's funded emissions over 700 times greater than its own. Press release, 28 April 2021.

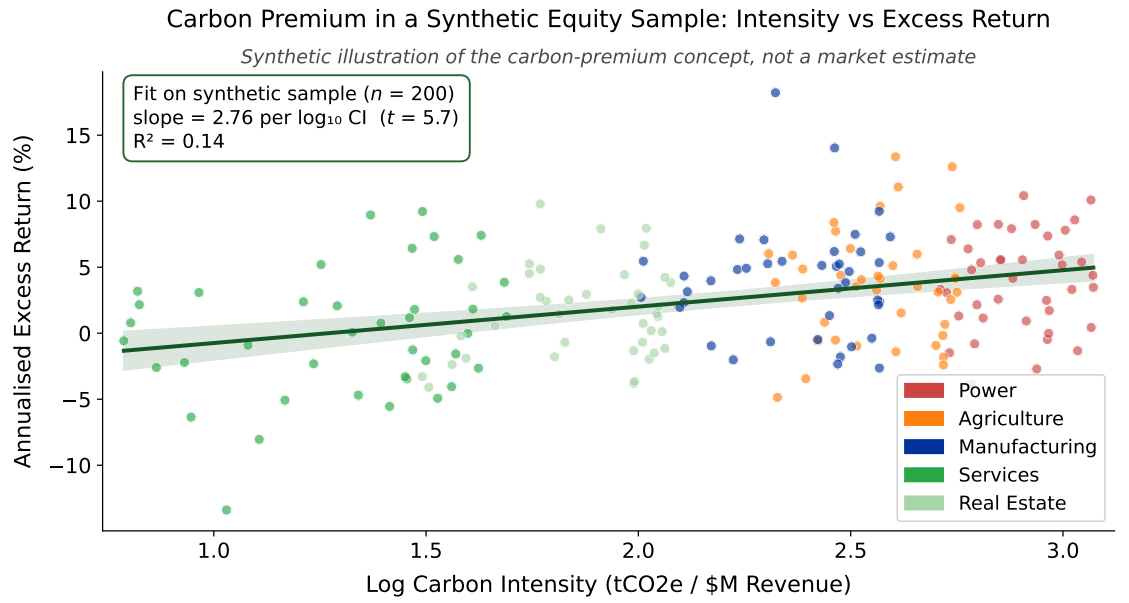


Assumed teaching example, not measured data: Illustrative Climate VaR scenario, not an NGFS-published result.

https://digital-ai-finance.github.io/Green-Finance/module4-lesson4-carbon-metrics/

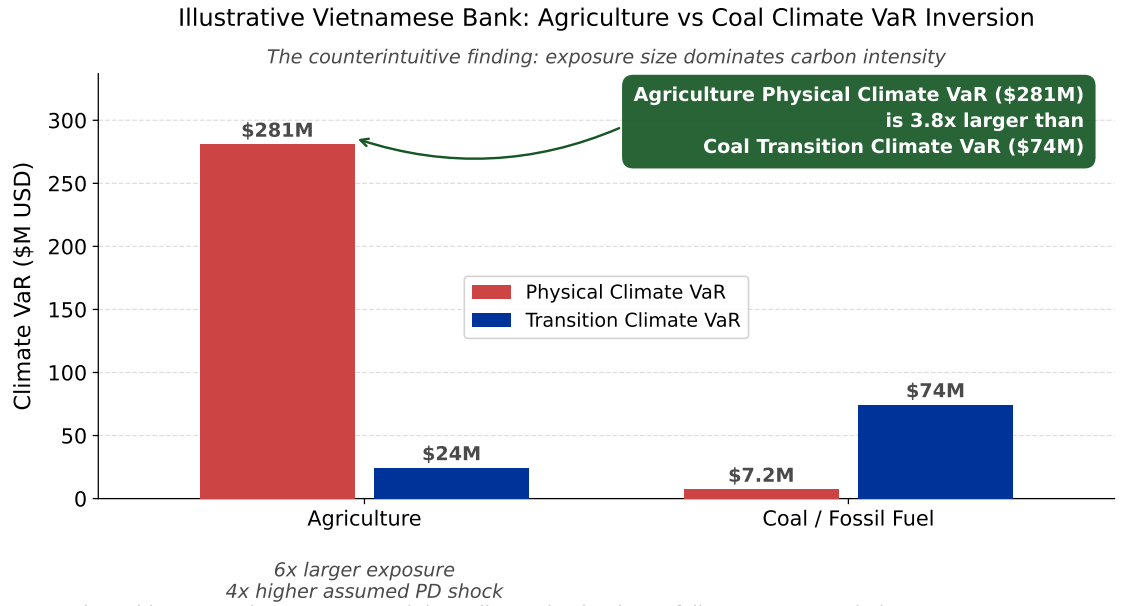
Figure 4.6: Which Climate VaR component dominates depends on the scenario: transition under Net Zero 2050, physical under the hot house world.

- Exposure size can outweigh carbon intensity, as the agriculture-coal inversion shows.



Assumed teaching example, not measured data: Synthetic sample, not market data.
https://digital-ai-finance.github.io/Green-Finance/module4-lesson4-carbon-metrics/

Figure 4.7: A synthetic cross-section of 200 firms in five sectors, with a carbon premium built into the data. The scatter around the fitted line shows a tendency across many firms, and the line belongs to this sample.



Assumed teaching example, not measured data: Illustrative bank portfolio, not measured Vietnamese sector data.
https://digital-ai-finance.github.io/Green-Finance/module4-lesson4-carbon-metrics/

Figure 4.8: Agriculture physical Climate VaR far exceeds coal transition Climate VaR for the illustrative Vietnamese bank.

Chapter 5

Climate Stress Testing

The 2022 climate stress test of the European Central Bank (ECB) covered 104 significant banks[1].

Climate stress testing applies the Climate VaR of Chapter 4 to the whole balance sheet and tests whether the bank can absorb climate losses and still meet its capital requirements.

Learning objectives

Participants are able to:

1. Explain how a climate stress test differs from a traditional one.
2. Describe the five design elements of a climate stress test.
3. Convert scenario variables into shocks to the probability of default (PD) and loss given default (LGD), and compute post-stress capital.
4. Contrast top-down and bottom-up, and static and dynamic, approaches.
5. Interpret the exercises of the Bank of Thailand (BOT), the ECB and the Bank of England, and the capacity gaps across the Association of Southeast Asian Nations (ASEAN).

5.1 Five design elements of a climate stress test

A climate stress test assesses whether an institution can absorb climate-related losses while maintaining regulatory capital under plausible but severe scenarios. It differs from a traditional exercise on every axis: the horizon is multi-decadal, the uncertainty is deep, the data is novel and proxy-based, and the scope is economy-wide. A climate stress test has five design elements in sequence. **Scenario selection** picks pathways of the Network for Greening the Financial System (NGFS) or bespoke physical events. **Exposure mapping** assigns each loan, bond and holding to the sectors and places the scenario strikes. **Transmission to the risk parameters** raises PD and LGD and can move exposure at default (EAD). **Loss estimation** separates expected loss, met by provisions, from unexpected loss, met by capital. **Capital impact** deducts losses from capital, raises risk-weighted assets (RWA) through downgrades, and compares the capital ratio with the minimum and the buffer.

[1] European Central Bank (2022). ECB banking supervision launches 2022 climate risk stress test. Press release, 8 July 2022.

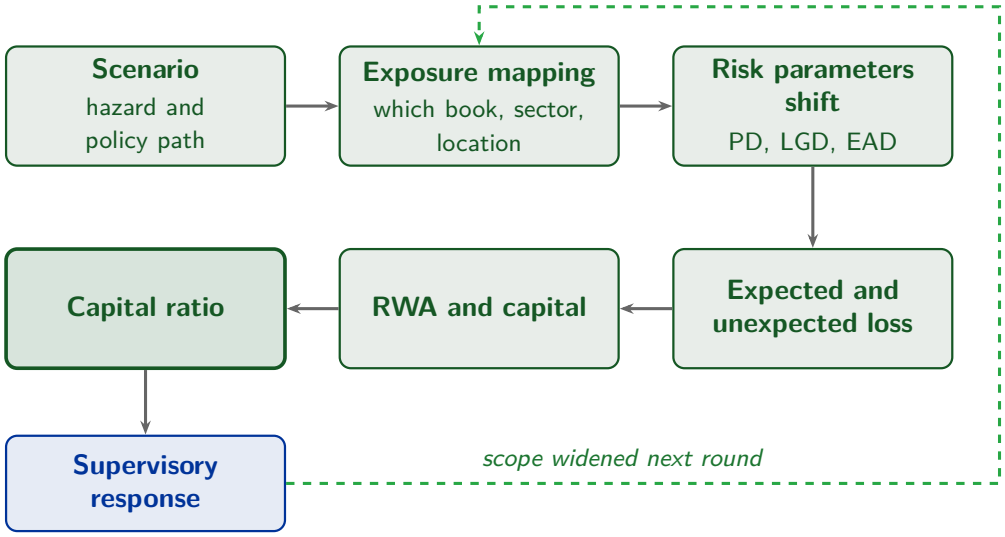


Figure 5.1: The five design elements drawn as six stages, from the scenario to the capital ratio, and the supervisory response, which widens the scope of the next round.

5.2 Supervisory climate stress tests

In a 2022 survey by the Financial Stability Board (FSB) and the NGFS, financial authorities reported 67 climate scenario analysis exercises, 35 of them completed[2]. The ECB's 2022 climate risk stress test covered 104 significant banks[3]. The Bank of England's 2021 Climate Biennial Exploratory Scenario (CBES) explored the financial risks posed by climate change for the largest UK banks and insurers[4]. The pilot climate risk stress test of the Hong Kong Monetary Authority (HKMA), launched in January 2021, covered 20 major retail banks and 7 branches of international banking groups, 80 percent of the sector's lending, and the participating banks assessed their climate risk exposures under its scenarios[5]. The Monetary Authority of Singapore (MAS) conducted a climate scenario analysis for selected key banks and insurers as part of its 2022 Industry-Wide Stress Test[6]. The World Bank and the Bank of Thailand studied how floods affect the economy and banks with a flood scenario for Bangkok and neighbouring provinces, informed by past events like the 2011 floods[7]. Their analysis of bank-level data puts 41 percent of banks' corporate lending in districts with high riverine flood risk, with the Chao Phraya River among the most significant sources of that risk[8], and the Bank of Thailand requested banks to use the scenarios provided by the World Bank to evaluate their own climate risk assessment systems[9].

For a single bank the result reduces to one number, the post-stress capital adequacy ratio (CAR), judged against the Basel III floor: a minimum total capital ratio of 8.0 percent plus a capital

[2]FSB and NGFS (2022). Climate Scenario Analysis by Jurisdictions: Initial findings and lessons. Financial Stability Board and Network for Greening the Financial System, 15 November 2022.

[3]European Central Bank (2022). ECB banking supervision launches 2022 climate risk stress test. Press release, 8 July 2022.

[4]Bank of England (2022). Results of the 2021 Climate Biennial Exploratory Scenario (CBES). 24 May 2022.

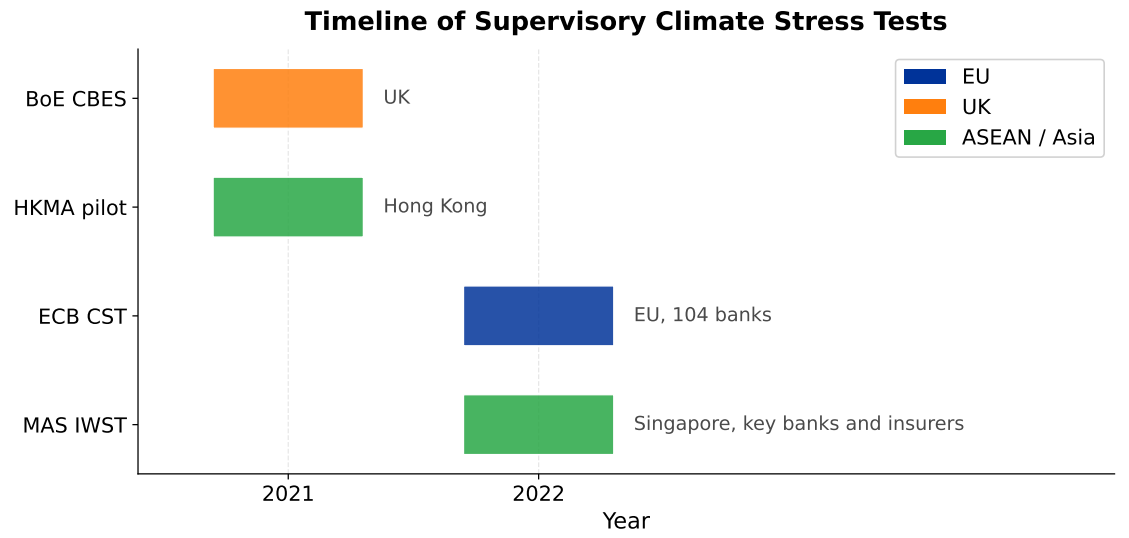
[5]Hong Kong Monetary Authority (2021). HKMA publishes the results of the pilot climate risk stress test. Press release, 30 December 2021.

[6]Monetary Authority of Singapore (2022). Financial Stability Review, November 2022. Special Feature 1.

[7]Dolk, M., Dunz, N., Lesage, F., Nie, O. and Pollitt, H. (2025). Assessing and managing natural disaster risks for the financial sector in Thailand. World Bank blog, All About Finance, 2 June 2025.

[8]Dolk, M., Dunz, N., Lesage, F., Nie, O. and Pollitt, H. (2025). Assessing and managing natural disaster risks for the financial sector in Thailand. World Bank blog, All About Finance, 2 June 2025.

[9]Dolk, M., Dunz, N., Lesage, F., Nie, O. and Pollitt, H. (2025). Assessing and managing natural disaster risks for the financial sector in Thailand. World Bank blog, All About Finance, 2 June 2025.



Each exercise is placed at the year its source states: Bank of England 2021 CBES, HKMA pilot launched January 2021, ECB 2022 climate risk stress test, MAS 2022 Industry-Wide Stress Test. Source: ECB Banking Supervision, press release, 8 July 2022: ECB Banking Supervision launches 2022 climate risk stress test.

https://digital-ai-finance.github.io/Green-Finance/module4-lesson5-climate-stress-testing/

Figure 5.2: Supervisory climate stress tests by year: the Bank of England, the HKMA, the ECB and the MAS.

conservation buffer of 2.5 percent, that is 10.5 percent[10]. A bank below 10.5 percent is inside the capital conservation buffer, and capital distribution constraints, on dividends and bonuses among others[11], apply to it until it rebuilds capital[12]. A bank that falls below the minimum itself is in breach. The ECB's 2022 climate risk stress test had no direct capital implications for the supervised banks[13], and the Bank of England stated that the CBES would not be used to set capital requirements related to climate risk[14].

5.3 Transmission, loss, and capital

Scenario variables enter the credit model as multipliers. A simple specification scales the baseline default rate, $PD_{climate} = PD_{base}\,(1 + \text{stress multiplier})$, so Thai agriculture with a 5.0 percent baseline and a flood-driven multiplier of 0.80 reaches 9.0 percent; loss given default adds a physical-damage uplift, $LGD_{climate} = LGD_{base} + \Delta_{physical}$, taking 45 percent to 65 percent. Expected loss is then $EL = PD \times LGD \times EAD$ summed across sectors. For a five-sector Thai bank with 500 billion Thai baht (THB) of exposure under Delayed Transition, climate stress roughly doubles expected loss from about THB 6.5 billion to THB 14.1 billion, with agriculture contributing THB 3.6 billion of the THB 7.6 billion increase, 48 percent of it, and 42 percent of the stressed loss, from 20 percent of the exposure.

In the network model of Battiston et al. (2017), second-round losses arise through interbank exposures and can be comparable in magnitude to first-round losses[15].

[10] BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Basel Committee on Banking Supervision, Annex 1: Calibration of the capital framework.

[11] BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Paragraph 132(a).

[12] BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Paragraph 129.

[13] European Central Bank (2022). 2022 climate risk stress test. ECB Banking Supervision, July 2022.

[14] Bank of England (2022). Results of the 2021 Climate Biennial Exploratory Scenario (CBES). 24 May 2022.

[15] Battiston, S., Mandel, A., Monasterolo, I., Schuetze, F., and Visentin, G. (2017). A climate stress-test of

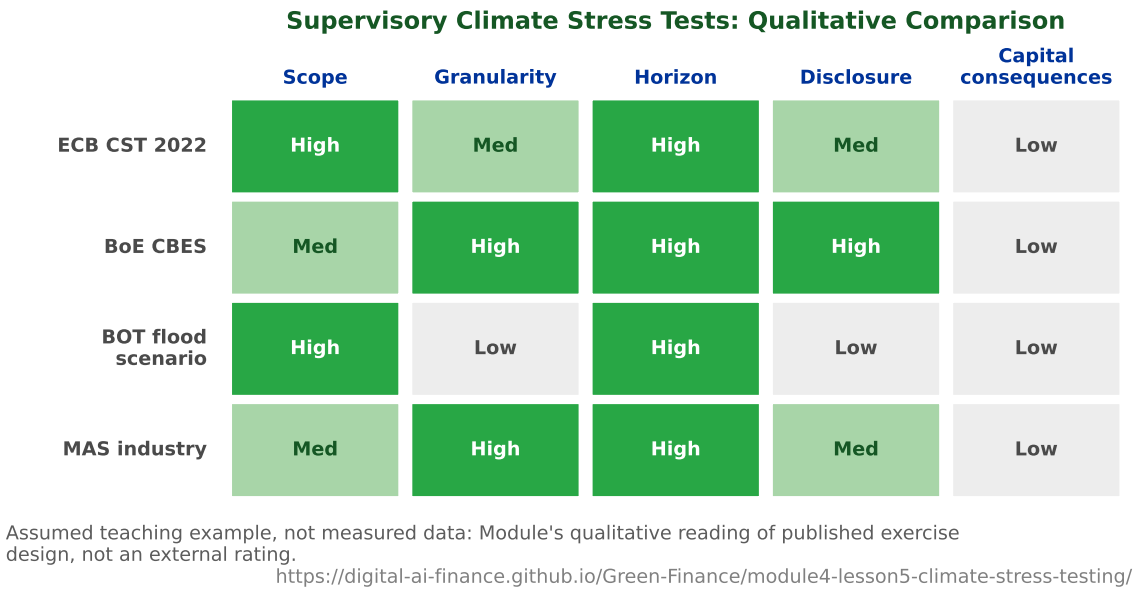


Figure 5.3: Four supervisory exercises rated High, Medium or Low on five design dimensions. The ratings are illustrative, and all four exercises rate Low on capital consequences.

Post-stress capital adequacy is

$$CAR_{post} = \frac{RegCapital - ClimateLosses}{RWA}.$$

Here *ClimateLosses* are the scenario's losses across all channels, an assumed THB 18.5 billion for the worked bank. The loan book's credit expected loss of THB 14.1 billion is one part of that total, and the remaining THB 4.4 billion is the assumed loss through the market and operational risk channels, taken as one sum. The formula holds risk-weighted assets fixed. A scenario that downgrades borrowers raises their risk weights, so a full test also raises RWA, and the ratio falls further. A bank with THB 71 billion of capital and THB 500 billion of risk-weighted assets has a pre-stress CAR of 14.2 percent. The Basel III floor requires 10.5 percent of THB 500 billion, THB 52.5 billion, so the bank absorbs THB 18.5 billion of climate losses before it reaches the floor, and a loss of that size leaves zero headroom. The Bank of Thailand sets a minimum of 8.5 percent and the same 2.5 percent buffer, 11 percent in all, which requires THB 55 billion of capital and leaves THB 16 billion of headroom. After the loss of THB 18.5 billion the bank stands at 10.5 percent, 0.5 percentage points below the Bank of Thailand's 11 percent and above its 8.5 percent minimum, inside the Bank of Thailand's 2.5 percent buffer.

5.4 Top-down, bottom-up, static and dynamic designs

Three modelling choices change results. Around half of the climate scenario exercises the FSB and the NGFS surveyed in 2022 were *top-down*, run by the authority, an approach that increases the consistency and comparability of the results[16]. *Bottom-up* exercises, in which the institutions submit their own projections, were often used to understand how individual institutions would respond to the scenarios[17], and some exercises adopted a hybrid approach that combines the

the financial system. Nature Climate Change, 7, 283 to 288. Published article as hosted by the Stanford Energy Modeling Forum; the nature.com page is paywalled.

[16]FSB and NGFS (2022). Climate Scenario Analysis by Jurisdictions: Initial findings and lessons. Financial Stability Board and Network for Greening the Financial System, 15 November 2022.

[17]FSB and NGFS (2022). Climate Scenario Analysis by Jurisdictions: Initial findings and lessons. Financial Stability Board and Network for Greening the Financial System, 15 November 2022.

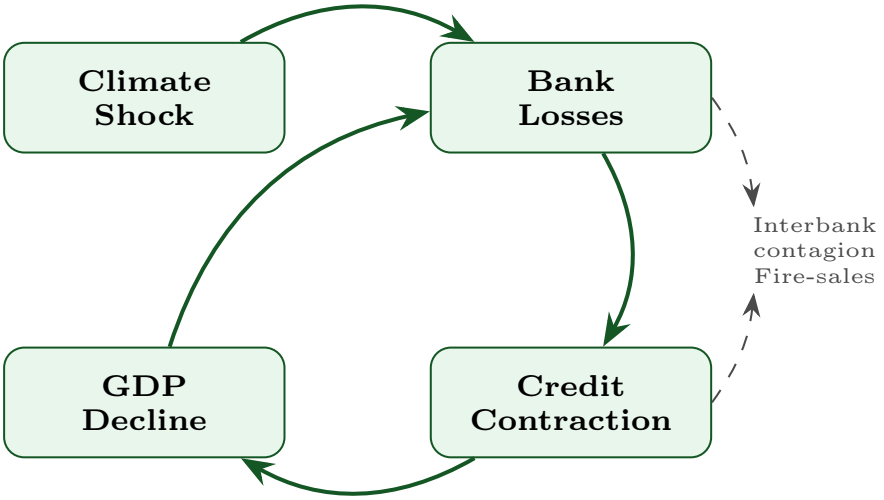


Figure 5.4: Second-round effects: climate losses cut bank capital, tighter capital cuts credit supply, the credit contraction lowers gross domestic product (GDP), and weaker borrowers raise bank losses again.

two[18]. Approximately 80 percent of the surveyed exercises adopted a *static balance sheet*[19]. The ECB based all its 2022 projections except the long-term paths on a static balance sheet[20], and the Bank of England's CBES held balance sheets fixed as they stood at end-2020, noting that the responses of banks and insurers over time may mitigate some of the losses projected[21]. In the worked bank, a *dynamic* balance sheet that lets the bank rebalance cuts losses by an assumed 15 to 30 percent. Finally, authorities surveyed by the FSB judge their measures of exposure likely understated, in many cases because the metrics do not capture *second-round effects* or climate non-linearities[22]; Battiston et al. (2017) take a network approach to trace how climate policy risk can propagate through the financial system[23]. The ECB's 2022 exercise had three modules, and in the third, a bottom-up stress test, the 41 banks that provided projections put combined credit and market risk losses at around EUR 70 billion[24]. The ECB wrote in the same report that "for a number of reasons this estimate significantly understates the actual risk"[25].

PhD extension: the limits of current climate stress tests

Acharya et al. (2023) review the climate stress scenarios regulators use and call for treating many transition risks as dynamic policy choices, incorporating feedback loops between climate change and the economy, and exploring compound risk scenarios in which climate risks co-occur with other risks[a]. They also discuss market-based climate stress tests, built from publicly available data, to complement existing stress testing frameworks[b]. The ECB gives

[18]FSB and NGFS (2022). Climate Scenario Analysis by Jurisdictions: Initial findings and lessons. Financial Stability Board and Network for Greening the Financial System, 15 November 2022.
[19]FSB and NGFS (2022). Climate Scenario Analysis by Jurisdictions: Initial findings and lessons. Financial Stability Board and Network for Greening the Financial System, 15 November 2022.
[20]European Central Bank (2022). 2022 climate risk stress test. ECB Banking Supervision, July 2022.
[21]Bank of England (2022). Results of the 2021 Climate Biennial Exploratory Scenario (CBES). 24 May 2022.
[22]FSB and NGFS (2022). Climate Scenario Analysis by Jurisdictions: Initial findings and lessons. Financial Stability Board and Network for Greening the Financial System, 15 November 2022.
[23]Battiston, S., Mandel, A., Monasterolo, I., Schuetze, F., and Visentin, G. (2017). A climate stress-test of the financial system. Nature Climate Change, 7, 283 to 288.
[24]European Central Bank (2022). 2022 climate risk stress test. ECB Banking Supervision, July 2022.
[25]European Central Bank (2022). 2022 climate risk stress test. ECB Banking Supervision, July 2022.

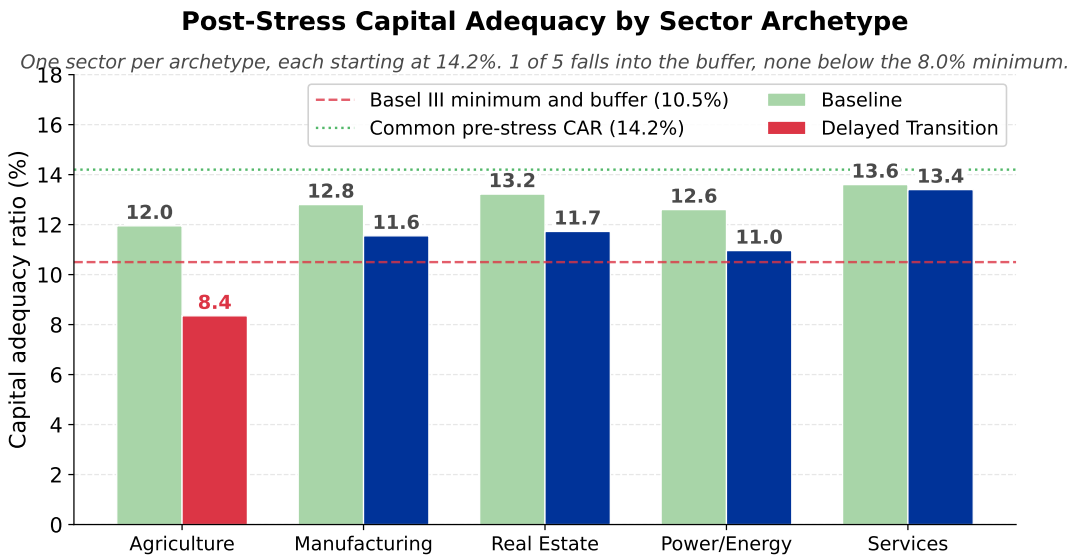


Figure 5.5: Capital ratio of five single-sector archetypes of the worked Thai bank, each starting at 14.2 percent, at baseline and under Delayed Transition. The agriculture archetype falls below 10.5 percent, into the buffer, and stays above the 8.0 percent minimum. The archetypes hold no provisions, so all expected loss falls on capital.

four reasons its own 2022 estimate understates the risk: the scenarios carry no economic downturn, the data and modelling are at a preliminary stage, no supervisory overlays were applied, and the exposures in scope are around one-third of the banks' total[c]. The ECB asks that its 30-year loss projections be read as a qualitative yardstick for the direction of travel[d].

[a] Acharya, V. V., Berner, R., Engle, R. F., Jung, H., Stroebel, J., Zeng, X. and Zhao, Y. (2023). Climate Stress Testing. Annual Review of Financial Economics 15, 291-326. NBER Working Paper 31097, April 2023.

[b] Acharya, V. V., Berner, R., Engle, R. F., Jung, H., Stroebel, J., Zeng, X. and Zhao, Y. (2023). Climate Stress Testing. Annual Review of Financial Economics 15, 291-326. NBER Working Paper 31097, April 2023.

[c] European Central Bank (2022). 2022 climate risk stress test. ECB Banking Supervision, July 2022.

[d] European Central Bank (2022). 2022 climate risk stress test. ECB Banking Supervision, July 2022.

ASEAN case: the Thailand 2011 floods scaled to 2050

The 2011 Thailand floods caused about $46.5 billion in damage and losses[a]. The manufacturing sector bore roughly 70 percent of the total, after six industrial estates in Ayutthaya and Pathum Thani flooded from mid-October to November 2011[b]. The flood scenario the World Bank built with the Bank of Thailand, for Bangkok and neighbouring provinces, is informed by past events like the 2011 floods[c]. The illustrative calibration: assume that under a hot house world pathway to 2050 floods of the 2011 kind become 2.5 times more frequent with a 1.3 times severity uplift, so an assumed 0.9 percentage-point sector shock to the non-performing-loan ratio scales to $0.9 \times 2.5 \times 1.3 \approx 2.9$ percentage points. Applied sector by sector to a bank's loan book, the scaled shocks give the stressed losses, and the capital identity turns them into a post-stress ratio. This projection is a hot house world

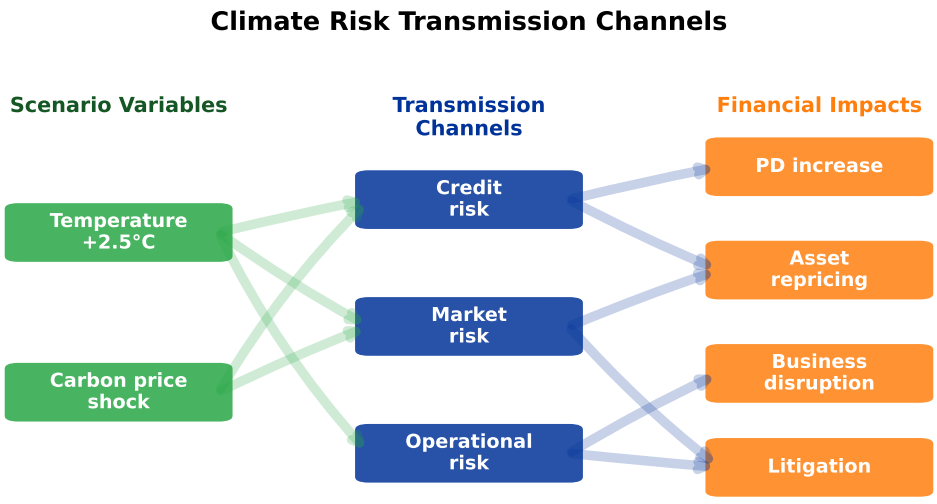


Figure 5.6: How two scenario variables reach three risk channels and four financial impacts. The arrows all have one width, and the diagram gives no sizes.

case, separate from the worked Thai bank, which runs Delayed Transition.

[a]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning.

[b]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Overview, page 2.

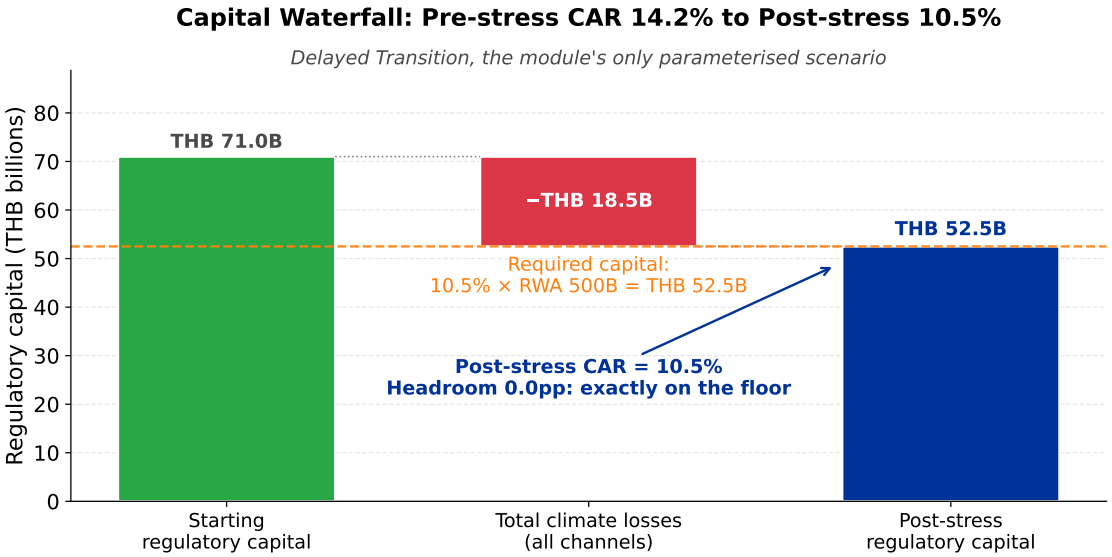
[c]Dolk, M., Dunz, N., Lesage, F., Nie, O. and Pollitt, H. (2025). Assessing and managing natural disaster risks for the financial sector in Thailand. World Bank blog, All About Finance, 2 June 2025.

5.5 The ASEAN capacity-building agenda

ASEAN supervisors share five gaps in stress-testing practice. Data infrastructure is thin, and borrower-level emissions registries linked to loan books are missing. Methodology is unharmonised: different proxies give different PD shocks for the same portfolio, and an ASEAN-wide protocol would align them. Physical-risk models, such as platforms built on a geographic information system (GIS), are outside bank systems. Balance sheets are static, and dynamic modules can be phased in. Second-round effects are omitted, and agent-based network models can add them.

Key takeaways

- Climate stress tests look forward over decades under deep uncertainty; the five design elements run from scenario to capital impact.
- For a single bank the headline output is post-stress CAR, judged against the Basel III minimum-plus-buffer floor.



Assumed teaching example, not measured data: Illustrative bank, not a real institution. Source: BCBS, Basel III: A global regulatory framework for more resilient banks and banking systems (rev. June 2011), para 96 fn.

https://digital-ai-finance.github.io/Green-Finance/module4-lesson5-climate-stress-testing/

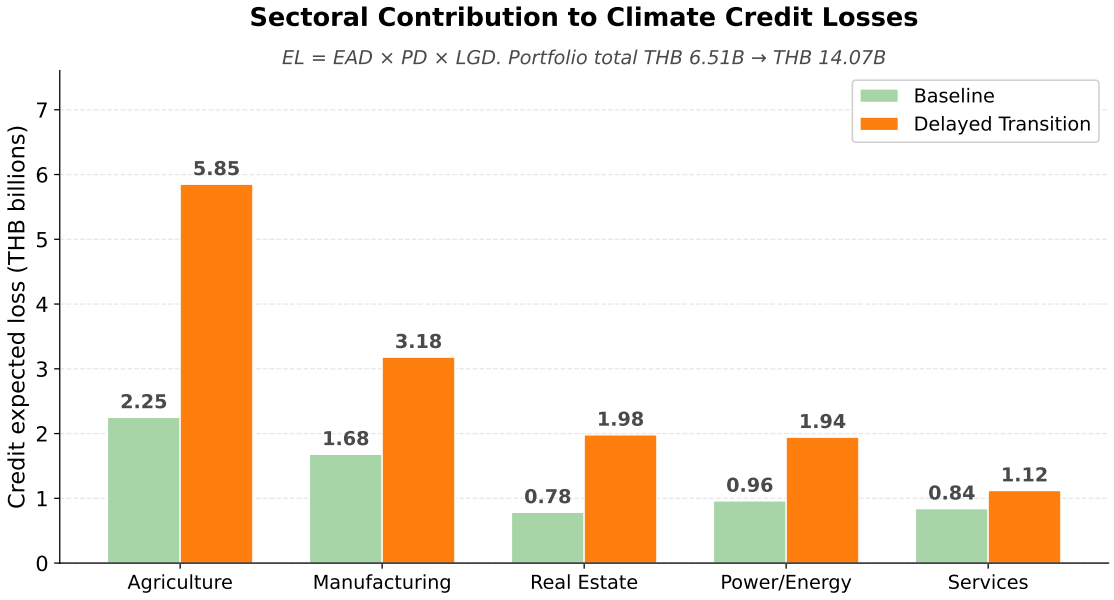
Figure 5.7: Capital falls from THB 71 billion to THB 52.5 billion, the capital the Basel III floor of 10.5 percent requires; the Bank of Thailand's 11 percent requires THB 55 billion.

- The ECB says its 2022 estimate significantly understates the actual risk[26], and authorities surveyed by the FSB and the NGFS judge their measures of exposure likely understated, in many cases because the metrics do not capture second-round effects[27].
- The NGFS counts Asia among the regions most vulnerable to physical risks[28]. In the worked Thai bank under Delayed Transition, agriculture holds 42 percent of the stressed credit loss from a fifth of the exposure.

[26]European Central Bank (2022). 2022 climate risk stress test. ECB Banking Supervision, July 2022.

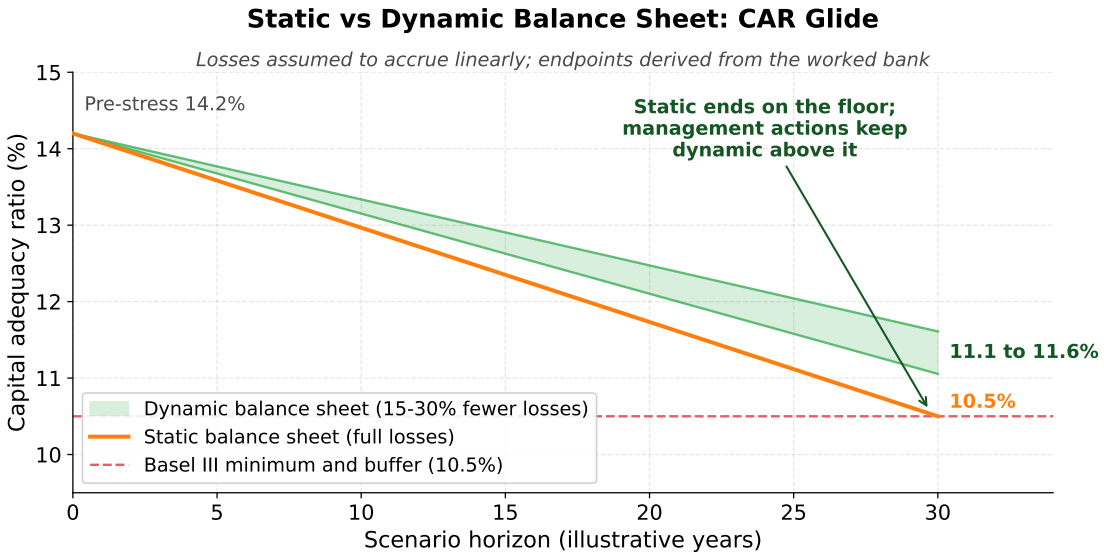
[27]FSB and NGFS (2022). Climate Scenario Analysis by Jurisdictions: Initial findings and lessons. Financial Stability Board and Network for Greening the Financial System, 15 November 2022.

[28]NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V). Section 4, Fragmented World, GDP impact across jurisdictions.



Assumed teaching example, not measured data: Illustrative bank, not a real institution.
https://digital-ai-finance.github.io/Green-Finance/module4-lesson5-climate-stress-testing/

Figure 5.8: Credit expected loss by sector, baseline against Delayed Transition. The book's total rises from THB 6.5 billion to THB 14.1 billion; agriculture, a fifth of the book, rises from THB 2.25 billion to THB 5.85 billion, the largest share of the rise.



Assumed teaching example, not measured data: Illustrative management actions, not a modelled or supervisory result; Illustrative bank, not a real institution. Source: BCBS, Basel III: A global regulatory framework for more resilient banks and banking systems (rev. June 2011), para 96 fn.
https://digital-ai-finance.github.io/Green-Finance/module4-lesson5-climate-stress-testing/

Figure 5.9: The worked bank under a static balance sheet ends at 10.5 percent; with 15 to 30 percent fewer losses, a dynamic balance sheet ends between 11.1 and 11.6 percent.

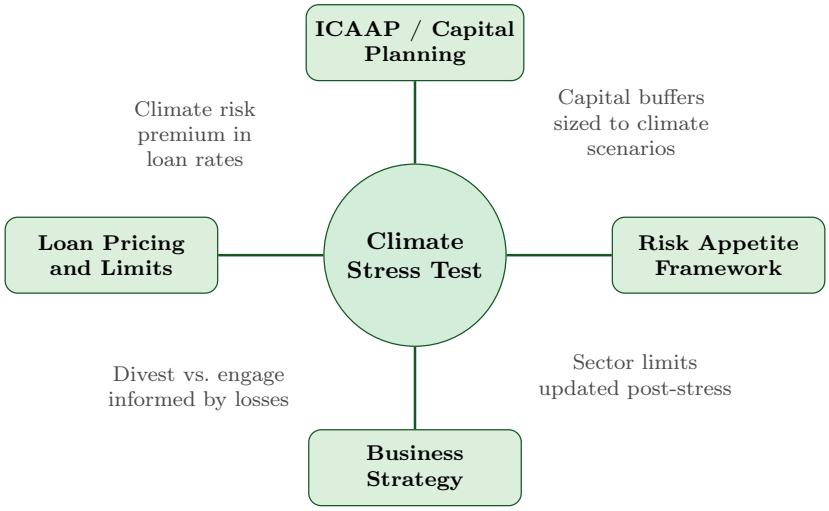
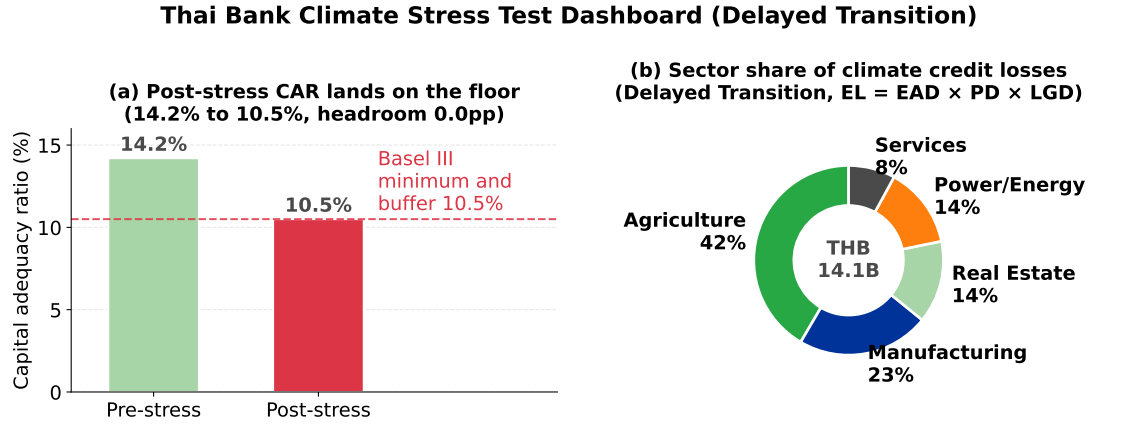


Figure 5.10: Four uses of a stress-test result: the internal capital adequacy assessment process (ICAAP) and capital planning, the risk appetite framework, loan pricing and limits, and business strategy.



Assumed teaching example, not measured data: Illustrative bank, not a real institution. Source: BCBS, Basel III: A global regulatory framework for more resilient banks and banking systems (rev. June 2011), para 96 fn.

https://digital-ai-finance.github.io/Green-Finance/module4-lesson5-climate-stress-testing/

Figure 5.11: The illustrative Thai bank under Delayed Transition, a case separate from the hot house world flood projection: its capital ratio falls from 14.2 to 10.5 percent, and agriculture holds 42 percent of the stressed credit loss, the largest sector share.

Chapter 6

ASEAN Climate Vulnerability

About 20 tropical cyclones a year occur in the Philippine region, and 8 or 9 of them cross the country[1].

In the three decades before 2020, disasters in Southeast Asia affected more than 400 million people and caused losses of more than $136 billion[2]. The region faces rising seas, intensifying typhoons, prolonged droughts and coral bleaching at the same time. In 2023 the ten member states of the Association of Southeast Asian Nations (ASEAN) had 676.6 million people[3], and the Network of Central Banks and Supervisors for Greening the Financial System (NGFS) counts Asia among the regions most vulnerable to physical risks[4]. In the definition of the Intergovernmental Panel on Climate Change (IPCC), risk results from dynamic interactions between climate-related hazards and the exposure and vulnerability of the affected human or ecological system[5]. The risk identity multiplies the three terms,

$$\text{Risk} = \text{Hazard} \times \text{Exposure} \times \text{Vulnerability},$$

so risk is zero when any one term is zero, and ASEAN scores high on all three terms.

Learning objectives

Participants are able to:

1. Apply the hazard-exposure-vulnerability framework to Vietnam, Thailand, and the Philippines.
2. Decompose the index of the Notre Dame Global Adaptation Initiative (ND-GAIN) into vulnerability and readiness.
3. Explain the ASEAN adaptation finance gap, why its size is contested, and which instruments address it.
4. Outline the empirical methods used to study climate and finance in the region.
5. Run an integrated country stress test and read its capital implications.

[1] PAGASA. Tropical Cyclone Information. Philippine Atmospheric, Geophysical and Astronomical Services Administration, DOST.

[2] World Bank (2026). Southeast Asia Disaster Risk Insurance Facility (SEADRIF): Strengthening Financial Resilience in Southeast Asia (P170913). Implementation Completion and Results Report ICR00681, corrigendum of 30 January 2026.

[3] ASEAN Secretariat (2024). ASEAN Key Figures 2024, Vol. 7, December 2024.

[4] NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V). Section 4, Fragmented World, GDP impact across jurisdictions.

[5] IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary, entry Risk, page 2921.

6.1 Hazard, exposure and vulnerability in ASEAN

The three terms of the risk identity reinforce each other in Southeast Asia, where all three are high at once. The *hazard* is tropical: typhoons, monsoon flooding, sea-level rise, and coral bleaching arrive together. The *exposure* is large: long coastlines and much of the population living in coastal and delta zones. The *vulnerability* is high: most ASEAN countries have paid for disaster response from government budgets and donor aid after the event, and the larger economies have limited catastrophe insurance penetration[6], so a shock that a wealthier and better-insured economy absorbs is one this region borrows against.

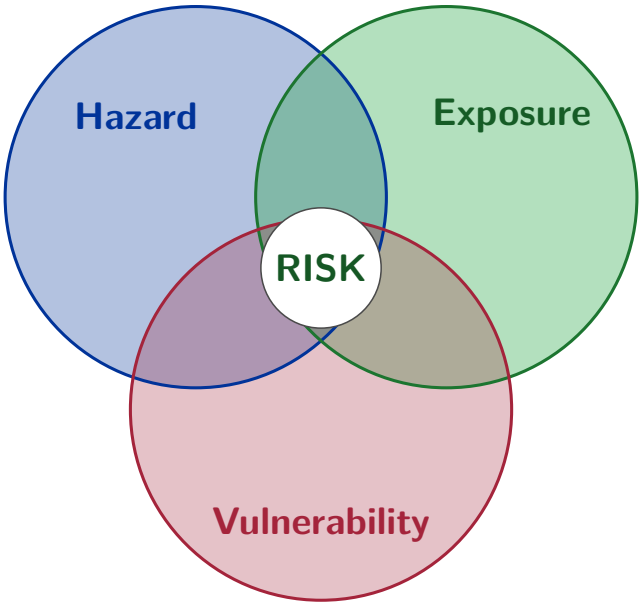


Figure 6.1: Risk results from the interaction of hazard, exposure and vulnerability. A typhoon over open ocean is a hazard and a risk to no bank, and a bank chooses its exposure through where it lends. Adaptation finance buys down vulnerability.

6.2 Three country profiles

Table 6.1 compares the three countries on five dimensions. **Vietnam** faces compound physical risk: two forecasting models in the World Bank's 2022 country report put its economic losses from climate change at 12 to 14.5 percent of gross domestic product (GDP) a year by 2050[7]. Almost half of the Mekong Delta would be inundated by a sea-level rise of 75 to 100 centimetres above the 1980 to 1999 average, which would raise salinity and end the production of some crops[8]. Agribank's agricultural and rural loans make up over 70 percent of its total loans, by its own account[9]. Circular No. 17/2022/TT-NHNN of the State Bank of Vietnam (SBV), on environmental risk management in credit extension, took effect on 1 June 2023[10]. **Thailand**

[6] World Bank (2026). Southeast Asia Disaster Risk Insurance Facility (SEADRIF): Strengthening Financial Resilience in Southeast Asia (P170913). Implementation Completion and Results Report ICR00681, corrigendum of 30 January 2026.

[7] World Bank Group (2022). Vietnam Country Climate and Development Report, July 2022.

[8] World Bank Group (2022). Vietnam Country Climate and Development Report, July 2022.

[9] Agribank (Vietnam Bank for Agriculture and Rural Development). About Agribank, corporate page, figures as of 30 September 2019.

[10] State Bank of Vietnam (2022). Circular No. 17/2022/TT-NHNN of 23 December 2022 guiding environmental risk management in credit extension by credit institutions and foreign bank branches. English translation: LuatVietnam.

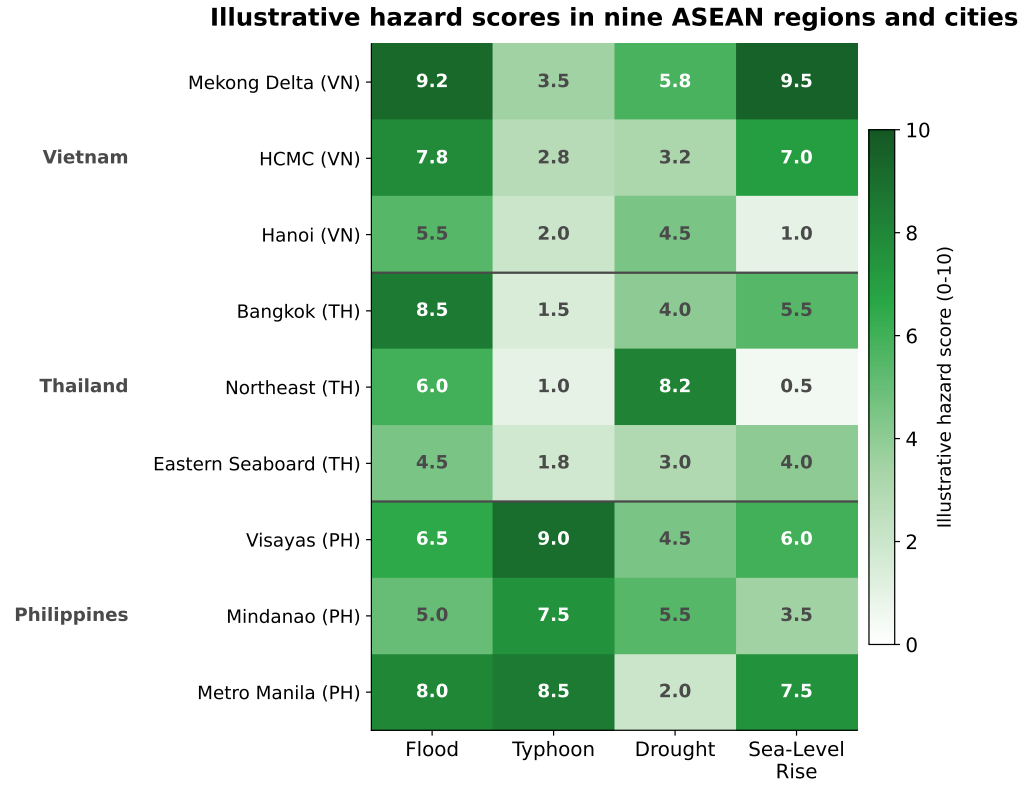


Figure 6.2: Illustrative hazard scores for flood, typhoon, drought and sea-level rise in nine regions and cities of Vietnam, Thailand and the Philippines. A national score averages regions that face different hazards.

spans urban subsidence and flood (the 2011 floods caused about $46.5 billion in damage and losses[11]) and drought. The Bank for Agriculture and Agricultural Cooperatives (BAAC) holds an excess loan-loss allowance against farm borrowers whose repayment is uncertain because of drought, falling farm prices and economic slowdown[12]. The World Bank and the Bank of Thailand built a flood scenario for Bangkok and neighbouring provinces, informed by the 2011 floods[13], and the Bank of Thailand requested banks to use the scenarios provided by the World Bank to evaluate their own climate risk assessment systems[14]. **The Philippines** lies in a region with an average of about 20 tropical cyclones a year, 8 or 9 of which cross the country[15]. Its central bank, the Bangko Sentral ng Pilipinas (BSP), issued the Sustainable Finance Framework as Circular No. 1085 on 29 April 2020[16], and the framework asks banks to convey their sustainability objectives and policies to investors, clients and other stakeholders

[11]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning.

[12]Bank for Agriculture and Agricultural Cooperatives (2025). Annual Report 2024 (fiscal year to 31 March 2025).

[13]Dolk, M., Dunz, N., Lesage, F., Nie, O. and Pollitt, H. (2025). Assessing and managing natural disaster risks for the financial sector in Thailand. World Bank blog, All About Finance, 2 June 2025.

[14]Dolk, M., Dunz, N., Lesage, F., Nie, O. and Pollitt, H. (2025). Assessing and managing natural disaster risks for the financial sector in Thailand. World Bank blog, All About Finance, 2 June 2025.

[15]PAGASA. Tropical Cyclone Information. Philippine Atmospheric, Geophysical and Astronomical Services Administration, DOST.

[16]Diokno, B. E. (2020). Integrating sustainability in corporate strategy: BSP sustainable finance framework. Speech by the Governor of the Bangko Sentral ng Pilipinas, 28 October 2020. BIS Central bankers' speeches, 10 December 2020.

through disclosures in the Annual Report[17].

Table 6.1: Three ASEAN countries compared on five dimensions, ranked without scores.

Dimension	Vietnam	Thailand	Philippines
Primary hazard	Sea-level rise, delta flooding	Subsidence-flood, drought	Typhoons, recurrent
Annual losses	Moderate and rising	Episodic but severe	Highest of the three
Insurance penetration	Thin	Deepest of the three	Thin
ND-GAIN standing	Vulnerable, low readiness	Least vulnerable, highest readiness	Vulnerable, low readiness
Regulatory stage	SBV circular 2023	Bank of Thailand and World Bank flood scenario	BSP framework 2020

The ND-GAIN index separates *vulnerability* (exposure, sensitivity, and adaptive capacity across life-supporting sectors) from *readiness* (economic, governance, and social capacity to act)[18]. ND-GAIN's vulnerability score includes exposure, so it spans two terms of the risk identity. In the identity, vulnerability is the propensity or predisposition to be adversely affected, including sensitivity to harm and lack of capacity to cope and adapt[19]. Vietnam and the Philippines both score as vulnerable with low readiness. Thailand is the least vulnerable of the three and leads on governance and economic readiness. The distance between a country's vulnerability and its readiness sets its adaptation priorities.

6.3 The adaptation finance gap

Mitigation alone cannot protect ASEAN, because substantial warming and sea-level rise are already locked in, so adaptation is necessary whatever the mitigation path. Global climate finance averaged almost $1.3 trillion a year in 2021/2022[20], of which adaptation drew $63 billion, about 5 percent of the total, against estimated needs of $212 billion a year by 2030 for developing countries alone[21].

Published estimates of the ASEAN adaptation gap differ by close to an order of magnitude, depending on whether they cover Asia or Southeast Asia, adaptation alone or climate finance combined, an annual gap or a total need, and which baseline year is used. One widely repeated pairing of need against mobilised finance quotes an Asia-wide need estimate as an ASEAN one. A regional gap figure is usable only with its scope, its source and its year.

The instruments to close the gap fall into market-based tools (catastrophe bonds with parametric or indemnity triggers, resilience bonds and parametric insurance) and public or multilateral capital (the Green Climate Fund, whose Board is to balance the allocation of resources between adaptation and mitigation activities[22], and the Adaptation Fund). In November 2019 the World Bank issued two tranches of catastrophe bonds that insured the Philippines against

[17]Diokno, B. E. (2020). Integrating sustainability in corporate strategy: BSP sustainable finance framework. Speech by the Governor of the Bangko Sentral ng Pilipinas, 28 October 2020. BIS Central bankers' speeches, 10 December 2020.

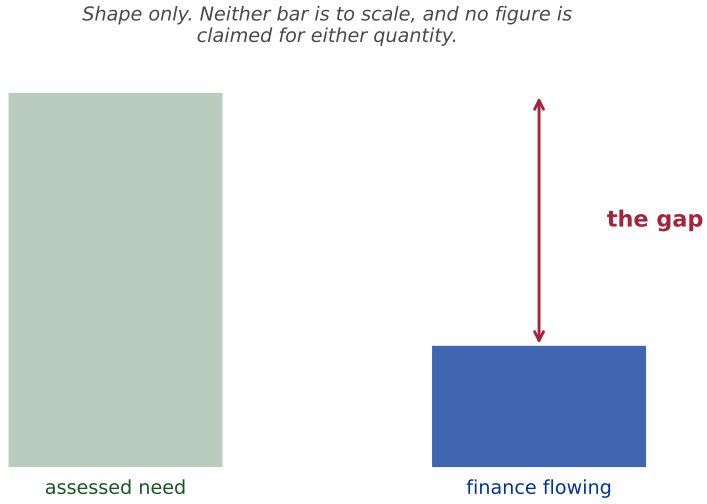
[18]University of Notre Dame Global Adaptation Initiative. ND-GAIN Country Index: Methodology.

[19]IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary, page 2927.

[20]Climate Policy Initiative (2023). Global Landscape of Climate Finance 2023. Press release, November 2023.

[21]Climate Policy Initiative (2023). Global Landscape of Climate Finance 2023. Press release, November 2023.

[22]Green Climate Fund. Governing Instrument for the Green Climate Fund, paragraph 50.



Assumed teaching example, not measured data: Shape only: neither bar is to scale and no quantity is claimed for either.
https://digital-ai-finance.github.io/Green-Finance/module4-lesson6-asean-climate-vulnerability/

Figure 6.3: The relationship the cited figures describe, drawn without asserting its size. The gap's direction is documented; its size would need a need and a flow measured at one scope by one source.

earthquakes and tropical cyclones for three years, for up to $225 million[23]. The Southeast Asia Disaster Risk Insurance Facility (SEADRIF), established in 2018 and launched in 2020, offers ASEAN countries market-based risk transfer products[24]. Parametric instruments pay on a measured trigger such as wind speed, so the money arrives in days. Blended finance links the two families. It places a thin layer of concessional first-loss capital below a guarantee or mezzanine layer and a majority senior commercial tranche, so public money absorbs the first losses and private capital prices the rest. Blended finance is judged by the private capital each public dollar mobilises. National pledges depend on international finance: the Philippines' first nationally determined contribution (NDC), of April 2021, commits to a 75 percent reduction and avoidance of projected emissions for 2020 to 2030, of which 2.71 percent is unconditional[25], and Vietnam's 2022 update targets 15.8 percent below business as usual when domestically supported and 43.5 percent when internationally supported[26]. The just-transition principle requires that adaptation reach coastal communities, smallholder farmers and informal workers as well as large corporates.

PhD extension: empirical methods for climate and finance in ASEAN

The empirical toolkit is standard applied econometrics adapted to climate data. Panel fixed-effects models, $NPL_{it} = \alpha + \beta_1 ClimateEvent_{it} + \cdots + \gamma_i + \delta_t + \varepsilon_{it}$, isolate the within-country effect of disasters on bank asset quality (Nie, Regelink and Wang, 2023, find in Philippine regional data for 2011 to 2018 that a 1 percentage point rise in the typhoon damage ratio, damage over regional GDP, could raise the non-performing-loan ratio by

[23]World Bank Treasury (2022). Case study: The Philippines: Transferring the Cost of Severe Natural Disasters to Capital Markets.

[24]World Bank (2026). Southeast Asia Disaster Risk Insurance Facility (SEADRIF): Strengthening Financial Resilience in Southeast Asia (P170913). Implementation Completion and Results Report ICR00681, corrigendum of 30 January 2026.

[25]UNDP Climate Promise. Philippines: key highlights from the NDC (first NDC, April 2021).

[26]UNDP Climate Promise. Viet Nam: key highlights from the NDC (updated NDC, November 2022).

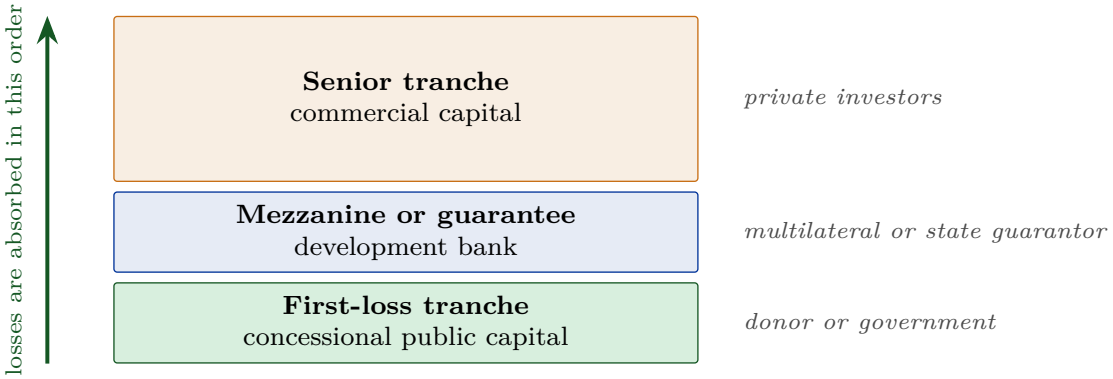


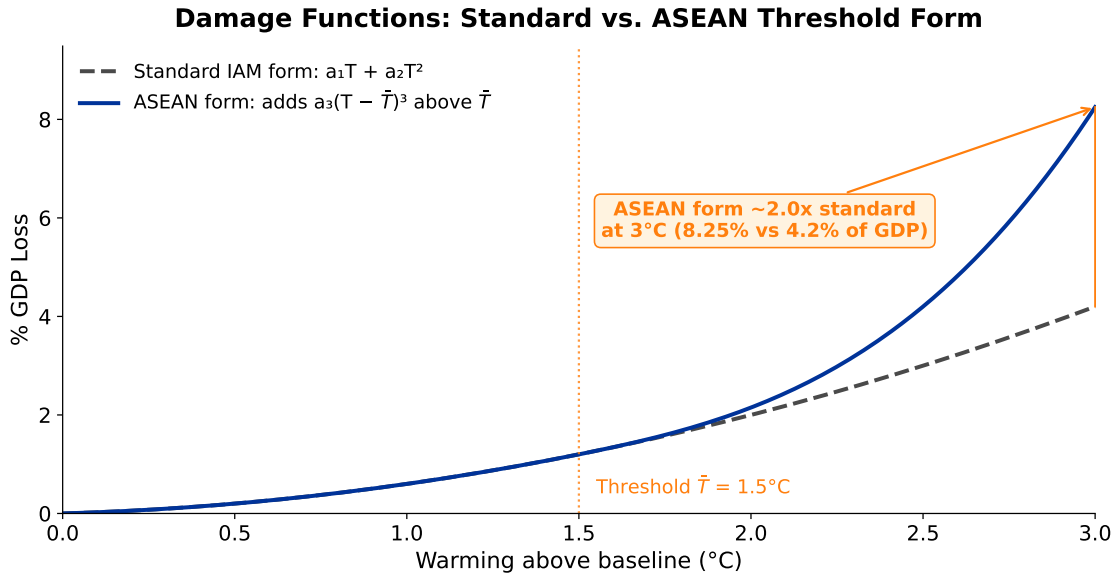
Figure 6.4: The blended-finance stack, drawn as an order of loss. Tranche sizes vary by deal; first-loss capital absorbs losses before the mezzanine layer, and the mezzanine layer before the senior tranche.

as much as 2.3 percent[a]). Difference-in-differences evaluates disclosure rules such as the BSP's Sustainable Finance Framework of 2020. Instrumental-variable designs address the endogeneity of where adaptation finance is allocated, and geographic information system (GIS) models overlay hazard grids onto geocoded loan books. An illustrative damage function adds a threshold term, $D(T) = a_1 T + a_2 T^2 + a_3 \mathbf{1}(T > \bar{T})(T - \bar{T})^3$, to represent tropical tipping points. Cross-border spatial panels capture the contagion seen when the 2011 Thai floods disrupted regional supply chains.

[a]Nie, O., Regelink, M. and Wang, D. (2023). Banking Sector Risk in the Aftermath of Climate Change and Environmental-Related Natural Disasters. Policy Research Working Paper 10326, World Bank, February 2023.

ASEAN case: a Category 5 typhoon stress test for the Philippine banking system

Illustrative worked example. Universal and commercial banks held 93.9 percent of the Philippine banking system's total assets in March 2024[a]. Uptake of the free crop insurance of the Philippine Crop Insurance Corporation was 37 percent among the subsistence farmers on the national farm register (RSBSA), the World Bank found in 2023[b]. The scenario is a Haiyan-class Category 5 typhoon (Chapter 3) making landfall in Central Visayas. It raises each sector's default probability by an assumed share of that sector's own baseline: agriculture by 80 percent, real estate by 40 percent, services and tourism by 25 percent, manufacturing by 15 percent and all other lending by 5 percent. Weighted by each sector's share of the loan book, $r_{portfolio} = \sum_i w_i r_i$, the shocks are assumed to give a relative increase of about 22.6 percent for the book. The example states no sector weights, and the weighted sum equals the book's rise when the sectors start from one default rate. The capital calculation starts from a measured number: the Philippine banking system's actual solo capital adequacy ratio in December 2023, 16.6 percent[c]. Three assumed deductions, in percentage points of the ratio, take it to 13.5 percent: 1.8 for new provisions on the extra defaults, 0.9 for the rise in risk-weighted assets as borrowers are downgraded, and 0.4 for market losses on securities. That leaves 3.5 percentage points above the BSP's minimum of 10 percent. The Philippine rule differs from the Basel III figures of Chapter 5 in its minimum: under Circular No. 781 of 2013 the BSP sets 10 percent against Basel III's 8.0 percent and adds the same 2.5 percent conservation buffer for universal and commercial



Assumed teaching example, not measured data: Illustrative damage function, not a calibration: the deck states these parameters are unestimated.
https://digital-ai-finance.github.io/Green-Finance/module4-lesson6-asean-climate-vulnerability/

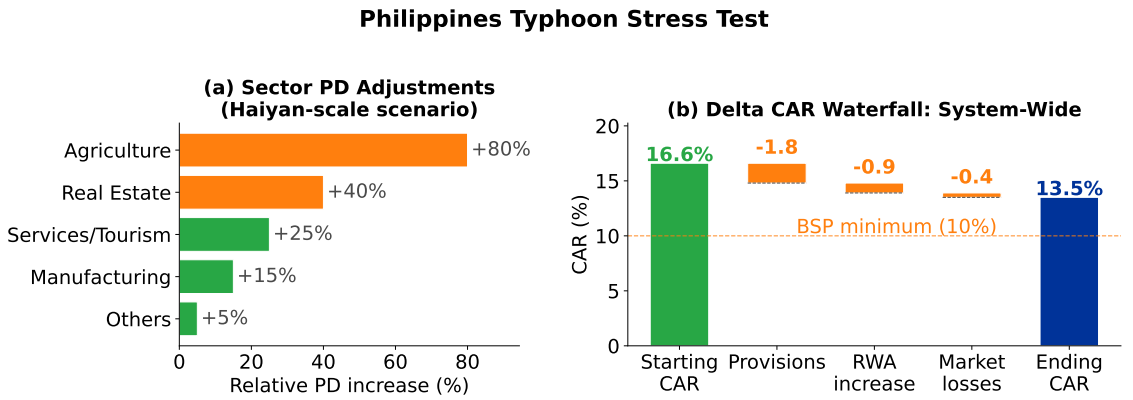
Figure 6.5: A standard quadratic damage function against one with an illustrative ASEAN threshold term at 1.5 °C. At 3.0 °C of warming the standard form gives 4.2 percent of GDP and the threshold form 8.25 percent.

banks, 12.5 percent in all[d], which the system's 13.5 percent clears by 1 percentage point. The buffer binds universal and commercial banks only, and the system ratio also covers thrift and rural banks. National minimums differ, so a bank that clears one supervisor's floor may not clear another's, and a cross-border comparison of post-stress ratios compares each against its own floor. A system ratio can hide banks below the minimum: a bank whose book is mostly Visayas agriculture takes the agriculture shock on most of its loans. Three policy responses follow: mandatory bank-level climate stress testing, portfolio-level parametric crop cover, and a blended-finance facility for resilient infrastructure, each designed under the just-transition principle.

[a]Bangko Sentral ng Pilipinas, Report on Recent Trends in the Philippine Financial System, Issue No. 2024-03, as of March 2024.
[b]World Bank (2023). Reforming Agricultural Insurance in the Philippines. Policy note.
[c]Bangko Sentral ng Pilipinas. Report on Recent Trends in the Philippine Financial System, Issue No. 2024-03.
[d]Bangko Sentral ng Pilipinas (2013). Circular No. 781, 15 January 2013: Basel III Implementing Guidelines on Minimum Capital Requirements. Full text: Supreme Court E-Library.

6.4 Three regional gaps

Chapter 5 named the gaps in stress-testing practice; three more are regional: finance, capacity and coordination. Adaptation finance falls short of need (**finance**). Climate stress tests and adaptation programmes need specialist staff in supervisors and banks (**capacity**). No ASEAN-wide stress-test protocol exists despite cross-border transmission (**coordination**). Module 5 covers reporting climate risk through IFRS S1 and IFRS S2 of the International Sustainability Standards Board (ISSB), the EU Corporate Sustainability Reporting Directive (CSRD) and the EU Sustainable Finance Disclosure Regulation (SFDR).



Assumed teaching example, not measured data: Illustrative stress scenario, not a BSP exercise.
Source: Bangko Sentral ng Pilipinas, Report on Recent Trends in the Philippine Financial System, Issue No. 2024-03.

https://digital-ai-finance.github.io/Green-Finance/module4-lesson6-asean-climate-vulnerability/

Figure 6.6: The Philippine system's capital ratio falls from 16.6 to 13.5 percent, 3.5 percentage points above the BSP minimum of 10 percent and 1 percentage point above 12.5 percent with the buffer.

Key takeaways

- In the IPCC's definition, risk results from the interaction of hazard, exposure and vulnerability; the risk identity multiplies the three, and ASEAN scores high on all three.
- ND-GAIN separates vulnerability from readiness; the distance between them sets adaptation priorities.
- Adaptation finance falls short of need, and published estimates of the regional gap differ by close to an order of magnitude; blended finance and parametric instruments are the main mechanisms proposed to close it.
- In the Philippine stress test the system's capital ratio stays above the BSP minimum with its buffer, and a system ratio can hide banks below the minimum.
- Module 4 manages climate risk; Module 5 reports it.

Reading List

Standards and frameworks

- TCFD (2017). *Recommendations of the Task Force on Climate-related Financial Disclosures*. Final Report, June 2017. Financial Stability Board.
  Four thematic areas: governance, strategy, risk management, and metrics and targets.
- TCFD (2021). *Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures*, October 2021.
  Carbon footprinting metrics, weighted average carbon intensity among them.
- TNFD (2023). *Recommendations of the Taskforce on Nature-related Financial Disclosures*. September 2023.
  Four disclosure pillars and the LEAP approach: Locate, Evaluate, Assess and Prepare.
- IFRS Foundation. *IFRS S2 Climate-related Disclosures*. International Sustainability Standards Board (ISSB), `ifrs.org`, accessed 26 September 2026.
  The ISSB's climate standard, effective for annual periods from 1 January 2024.
- BCBS (2022). *Principles for the effective management and supervision of climate-related financial risks*. Basel Committee on Banking Supervision, June 2022.
  Eighteen principles: 1 to 12 for banks, 13 to 18 for prudential supervisors.
- PCAF (2022). *The Global GHG Accounting and Reporting Standard, Part A: Financed Emissions*, second edition, December 2022. Partnership for Carbon Accounting Financials.
  Attribution factors and data quality scores, from 1, the highest, to 5, the lowest.
- RMI. *PACTA: Measure the alignment of financial portfolios with climate scenarios*. Paris Agreement Capital Transition Assessment, RMI, `pacta.rmi.org`, accessed 26 September 2026.
  Open-source software that measures portfolio alignment with climate scenarios.

Scenarios and climate modelling

- NGFS (2025). *NGFS Scenarios: narratives and key findings*. November 2025, on results version 5.0 of November 2024 (Phase V). Network of Central Banks and Supervisors for Greening the Financial System.
  The seven Phase V scenarios in four categories, and the narrative of each.
- van Vuuren, D. P., Edmonds, J., Kainuma, M., et al. (2011). The representative concentration pathways: an overview. *Climatic Change*, 109, 5 to 31.
  The four Representative Concentration Pathways and how they were developed.
- Riahi, K., et al. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: an overview. *Global Environmental Change*, 42, 153 to 168.

The pathways, SSP2 among them, whose assumptions all NGFS scenarios share.

- Bolton, P., Despres, M., Pereira da Silva, L. A., Samama, F., and Svartzman, R. (2020). *The Green Swan: Central Banking and Financial Stability in the Age of Climate Change*. Bank for International Settlements.
  Climate tail risks as green swans for central banks and financial stability.
- IPCC (2023). *Climate Change 2023: Synthesis Report, Summary for Policymakers*. Intergovernmental Panel on Climate Change.
  The remaining carbon budgets for 1.5 °C and 2 °C.
- Nordhaus, W. (2017). Revisiting the social cost of carbon. *PNAS*, 114(7), 1518 to 1523.
  The social cost of carbon from the Dynamic Integrated Climate-Economy (DICE) model.
- Weitzman, M. (2009). On modeling and interpreting the economics of catastrophic climate change. *Review of Economics and Statistics*, 91(1), 1 to 19.
  Fat-tailed catastrophic risk in cost-benefit analysis of climate policy.
- Howard, P., and Sterner, T. (2017). Few and not so far between: a meta-analysis of climate damage estimates. *Environmental and Resource Economics*, 68(1), 197 to 225.
  Published estimates of climate damage pooled in one meta-analysis.
- IEA (2025). *Global Energy and Climate Model: Understanding GEC Model scenarios*. International Energy Agency, `iea.org`, accessed 26 September 2026.
  Current Policies, Stated Policies and Net Zero Emissions by 2050 scenarios.

Carbon metrics and asset pricing

- Bolton, P., and Kacperczyk, M. (2021). Do investors care about carbon risk? *Journal of Financial Economics*, 142(2), 517 to 549.
  A carbon premium in US stock returns, for the level and for the change of emissions.
- Sautner, Z., van Lent, L., Vilkov, G., and Zhang, R. (2023). Firm-level climate change exposure. *Journal of Finance*, 78(3), 1449 to 1498.
  Each firm's exposure to climate change, measured from earnings conference calls.
- Dietz, S., Bowen, A., Dixon, C., and Gradwell, P. (2016). Climate value at risk of global financial assets. *Nature Climate Change*, 6, 676 to 679.
  Expected and tail Climate Value-at-Risk (Climate VaR) of global financial assets.
- UNEP FI (2019). *Changing Course: A comprehensive investor guide to scenario-based methods for climate risk assessment, in response to the TCFD*. United Nations Environment Programme Finance Initiative.
  Climate VaR: the effect of climate-related risks and opportunities on market value.

Stress testing and systemic risk

- European Central Bank (2022). *2022 climate risk stress test*. ECB Banking Supervision, July 2022.
  Design and results, and four reasons the loss estimate understates the risk.
- Bank of England (2022). *Results of the 2021 Climate Biennial Exploratory Scenario (CBES)*. 24 May 2022.
  The financial risks of climate change for the largest UK banks and insurers.

- Acharya, V. V., Berner, R., Engle, R. F., Jung, H., Stroebel, J., Zeng, X., and Zhao, Y. (2023). Climate stress testing. *Annual Review of Financial Economics*, 15, 291 to 326.
  Stress scenarios, compound risks and market-based climate stress tests.
- Battiston, S., Mandel, A., Monasterolo, I., Schuetze, F., and Visentin, G. (2017). A climate stress-test of the financial system. *Nature Climate Change*, 7, 283 to 288.
  How climate policy risk propagates through a network of financial exposures.
- Krueger, P., Sautner, Z., and Starks, L. T. (2020). The importance of climate risks for institutional investors. *Review of Financial Studies*, 33(3), 1067 to 1111.
  A survey of 439 institutional investors on how they respond to climate risk.

ASEAN, adaptation, and methods

- World Bank Group (2022). *Vietnam Country Climate and Development Report*, July 2022.
  Vietnam's losses from climate change and the Mekong Delta under sea-level rise.
- IPCC (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary.
  The definitions of risk, hazard, exposure and vulnerability.
- Green Climate Fund. *Governing Instrument for the Green Climate Fund*.
  The Fund's rules, among them a balance between adaptation and mitigation.
- Nie, O., Regelink, M., and Wang, D. (2023). *Banking Sector Risk in the Aftermath of Climate Change and Environmental-Related Natural Disasters*. Policy Research Working Paper 10326, World Bank, February 2023.
  Typhoon damage and non-performing loans in Philippine regions, 2011 to 2018.
- Kelejian, H. H., and Prucha, I. R. (1998). A generalized spatial two-stage least squares procedure for estimating a spatial autoregressive model with autoregressive disturbances. *The Journal of Real Estate Finance and Economics*, 17(1), 99 to 121.
  A two-stage least squares estimator for spatial autoregressive models.
- Coles, S. G. (2001). *An Introduction to Statistical Modeling of Extreme Values*. Springer.
  Classical extreme value theory and models, and threshold models.
- McNeil, A. J., Frey, R., and Embrechts, P. (2015). *Quantitative Risk Management: Concepts, Techniques and Tools*, revised edition. Princeton University Press.
  Value-at-Risk, expected shortfall and extreme value theory for financial risk.

Regulatory sources and data

- Bank of Thailand (2023). *Policy Statement of the Bank of Thailand Re: Internalizing Environmental and Climate Change Aspects into Financial Institution Business* (Standard Practice), February 2023.
  Environmental and climate change aspects in Thai financial institutions' business.
- MAS (2020). *Guidelines on Environmental Risk Management (Banks)*, December 2020. Monetary Authority of Singapore.
  Environmental risk management for banks, with a transition period of 18 months.
- Bangko Sentral ng Pilipinas (2020). Circular No. 1085, *Sustainable Finance Framework*, 29 April 2020.
  Sustainability objectives and policies of banks, disclosed in the annual report.

- State Bank of Vietnam (2022). *Circular No. 17/2022/TT-NHNN of 23 December 2022 guiding environmental risk management in credit extension by credit institutions and foreign bank branches*, in force from 1 June 2023. English translation: LuatVietnam.
  Environmental risk management in bank lending in Vietnam.
- World Bank (2026). *Southeast Asia Disaster Risk Insurance Facility (SEADRIF): Strengthening Financial Resilience in Southeast Asia* (P170913). Implementation Completion and Results Report ICR00681, corrigendum of 30 January 2026.
  SEADRIF, a regional platform for market-based disaster risk transfer since 2020.
- NGFS Scenario Explorer, hosted by the International Institute for Applied Systems Analysis (IIASA), version 5 of the NGFS scenarios, November 2024 (Phase V): `data.ene.iiasa.ac.at/ngfs`, accessed 26 September 2026.
  The data of the Phase V scenarios.
- EM-DAT (2026). *EM-DAT, the Emergency Events Database*. Centre for Research on the Epidemiology of Disasters (CRED), UCLouvain, Brussels, Belgium, `www.emdat.be`, accessed 26 September 2026.
  Occurrence and impacts of mass disasters worldwide since 1900.
- University of Notre Dame Global Adaptation Initiative. *ND-GAIN Country Index: Methodology*. `gain.nd.edu`, accessed 26 September 2026.
  Country scores for vulnerability across six sectors, and for readiness.

Appendix A

ASEAN Case Study: Thailand Insurance-Sector Catastrophe Tail Risk

Terminology note: CVaR here denotes Conditional Value-at-Risk in the actuarial sense, the expected loss beyond a Value-at-Risk threshold, a different measure from the Climate VaR of Chapters 4 and 5. The loss distribution, the insurer's balance sheet and the reinsurance terms of the case are illustrative teaching values.

A.1 Background

Thailand's life and non-life insurers face catastrophe risk mainly from flooding: flood is the country's largest catastrophic risk, while earthquake and windstorm risk are present but relatively low[1]. The 2011 Central Thailand floods followed rainfall from successive monsoons and a series of dam breaches[2], and caused about $46.5 billion[3] in damage and losses. Only part of that loss was insured: the World Bank's preliminary estimate put insured losses in the areas already flooded at 109.9 to 165.7 billion Thai baht (THB)[4]. The governing question is whether current capital and reinsurance arrangements are adequate to withstand a major catastrophe given climate acceleration.

Table A.1: Where the insured part of two Thai catastrophes sat. Insurance follows insurable assets, and few homes have cover.

Event or asset	Year	Insured loss, and where it sat
Indian Ocean tsunami	2004	Insured-loss estimates up to $500 million, concentrated in tourist resorts
Central Thailand floods	2011	Preliminary insured losses of THB 109.9 to 165.7 billion, 85 percent on industrial estates
Private dwellings	2011	Fewer than 1 percent insured against natural disasters

[1]World Bank, GFDRR, ASEAN Secretariat and UNISDR (2012). Advancing Disaster Risk Financing and Insurance in ASEAN Member States: Framework and Options for Implementation, Appendices, June 2012. Thailand PCRI market profile.

[2]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Vol. 1, Overview.

[3]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning.

[4]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Vol. 2, Final report. Royal Thai Government and World Bank.

Insurance follows insurable assets. The insured part of the 2004 tsunami loss sat in tourist resorts, which typically have insurance cover[5]. The 2011 floods inundated industrial estates whose firms usually held property cover for building and contents that included floods, and some of those firms had also bought business interruption insurance[6]; 85 percent of the preliminary insured loss of 2011 sat on the industrial estates[7]. In 2011 fewer than 1 percent of Thai private dwellings were insured against natural disasters[8]. The uninsured part of a catastrophe loss is the protection gap, and in emerging and less developed countries insured losses are less than 10 percent of total damages[9]. For the 2011 floods around 95 percent of the claims were reinsured abroad[10], so the solvency of Thai insurers depends on reinsurance markets outside the country. The Office of Insurance Commission (OIC) lets the Registrar impose measures on a non-life insurer whose capital adequacy ratio falls below 140 percent[11], and it requires each non-life insurer's own risk and solvency assessment to include a catastrophe scenario and a reverse stress test[12].

A.2 Method: from hazard to solvency

The assessment runs in four steps: hazard, loss, tail risk, and capital and reinsurance.

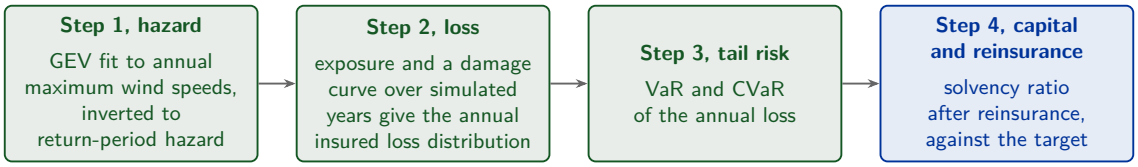


Figure A.1: Four steps from a fitted wind-speed distribution to an insurer's solvency ratio after reinsurance.

Step 1, hazard. Fit a Generalised Extreme Value (GEV) distribution to historical maximum wind speeds (or flood depths),

$$F(v) = \exp\left\{ - \left[1 + \xi \left(\frac{v-\mu}{\sigma} \right) \right]^{-1/\xi} \right\},$$

where μ is the location, $\sigma > 0$ the scale and ξ the shape, for $1 + \xi(v-\mu)/\sigma > 0$; a positive ξ indicates heavy tails. Invert the fitted distribution to obtain return-period hazard levels.

Step 2, loss. Map hazard to financial loss through exposure (insured building value by district) and a vulnerability damage curve (for example zero damage below 30 m/s rising to

[5]World Bank, GFDRR, ASEAN Secretariat and UNISDR (2012). Advancing Disaster Risk Financing and Insurance in ASEAN Member States: Framework and Options for Implementation, Appendices, June 2012. Thailand PCRI market profile.

[6]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Vol. 2, Final report. Royal Thai Government and World Bank.

[7]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Vol. 2, Final report. Royal Thai Government and World Bank.

[8]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Vol. 2, Final report. Royal Thai Government and World Bank.

[9]BCBS (2021). Climate-related risk drivers and their transmission channels. Basel Committee on Banking Supervision, April 2021, page 30, citing Munich Re (2020).

[10]World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Vol. 2, Final report. Royal Thai Government and World Bank.

[11]Office of Insurance Commission (2018). Registrar's Order No. 48/2561 Re: Required Disclosure of Financial Standing and Operating Results of Non-life Insurance Companies. English translation.

[12]Office of Insurance Commission (2019). Notification of the Insurance Commission re: Criteria, Methods, and Conditions for Governing Enterprise Risk Management and Own Risk and Solvency Assessment of Non-life Insurance Companies B.E. 2562. Unofficial translation.

about 90 percent above 50 m/s), then simulate many synthetic years (a Monte Carlo of, say, 10,000 scenarios) to obtain a distribution of annual insured losses.

Step 3, tail risk. Summarise the tail with Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR),

$$VaR(\alpha) = \min\{L : P(\text{Loss} \le L) \ge \alpha\}, \qquad CVaR(\alpha) = \mathbb{E}[\text{Loss} \mid \text{Loss} \ge VaR(\alpha)].$$

CVaR is the average of losses beyond the VaR threshold, so it measures the depth of the tail.

Step 4, capital and reinsurance. Compare capital to the tail estimate through a solvency ratio (total capital over required capital) and choose a reinsurance structure that holds the stressed solvency ratio above target at least cost.

Indicative results

The case assumes a 1-in-100-year insured loss of roughly $5 to $7 billion and a 1-in-250-year loss of about $10 to $15 billion. An assumed climate adjustment of plus 5 to 8 percent in intensity by 2050 lifts the 1-in-100-year figure to about $7 to $9 billion. The 1-in-100-year loss rises by 29 to 40 percent for a 5 to 8 percent rise in intensity, because the damage relation is convex. A large non-life insurer with $2.5 billion of capital against required capital of $1.5 billion has a solvency ratio of 167 percent in normal times; a 1-in-100-year event with about $1 billion of net loss after reinsurance takes it to 100 percent, below the 140 percent at which the OIC Registrar may impose measures. Reinsurance and capital buffers are the two levers that move that ratio.

A.3 Discussion questions

1. Thai Meteorological Department records list Tropical Storm Harriet of 1962 as the deadliest cyclone to hit Thailand and Gay of 1989 as the only typhoon known to have hit it[13]. Is so short a record of direct landfalls adequate to fit an extreme-value distribution, and how sensitive is VaR to the distribution chosen?

2. A 5 to 8 percent rise in intensity need not map to a 5 to 8 percent rise in VaR; why might the tail response be larger?

3. If several Asian countries face major events at once, reinsurance capacity may be scarce; how should an insurer plan for tail risk if reinsurance is unavailable at the moment of crisis?

4. Does an implicit government backstop after disasters cause insurers to underprice risk?

5. How would you modify the loss model to capture compound events, a cyclone arriving during the monsoon?

6. In 2011 fewer than 1 percent of Thai private dwellings were insured against natural disasters[14]. Should catastrophe insurance be mandated or remain voluntary?

[13] Al Jazeera (2019). Tropical cyclone heads for southern Thailand. 2 January 2019. News report citing Thai Meteorological Department records.

[14] World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Vol. 2, Final report. Royal Thai Government and World Bank.

Appendix B

Module 4 Assessment

B.1 Part 1: Multiple-choice questions

Select one answer per question.

1. Which of the following is not one of the three top-level categories of climate-related financial risk?
   (a) Physical (b) Transition (c) Liability (d) Regulatory

2. Which risk of a bank does the literature on climate risk drivers study most, according to the Basel Committee (2021)?
   (a) Credit (b) Market (c) Operational (d) Liquidity

3. Medium-term climate risk runs over three to ten years. For which book is it the relevant horizon?
   (a) Trading books (b) Corporate loan books (c) Pension funds (d) Sovereign bonds

4. Double materiality, as in the EU Corporate Sustainability Reporting Directive (CSRD), requires assessing:
   (a) Only how climate affects the firm (b) Both directions (c) Only how the firm affects climate (d) Materiality at a short and a long horizon

5. A loan book with an exposure at default (EAD) of \$200 million, a base probability of default (PD) of 4 percent, a base loss given default (LGD) of 50 percent, a climate sensitivity $\beta_{climate}$ of 0.25 per degree and a physical LGD uplift of 10 percentage points has, at $\Delta T = 2\,^{\circ}\mathrm{C}$ of warming, a climate-adjusted expected loss of:
   (a) \$4.0 million (b) \$4.8 million (c) \$6.0 million (d) \$7.2 million

6. A bank in the Mekong Delta holds 25 percent of its book in agriculture and 15 percent in real estate, both directly exposed to physical risk; the share of its book directly exposed, and the type of hazard that dominates in the Delta, are:
   (a) 25 percent, chronic (b) 40 percent, acute (c) 40 percent, chronic (d) 60 percent, chronic

7. Which pillar of the Task Force on Climate-related Financial Disclosures (TCFD) has three recommended disclosures: how a bank identifies and assesses climate risk, how it manages it, and how both processes are integrated into its overall risk management?
   (a) Governance (b) Strategy (c) Metrics and Targets (d) Risk Management

8. The nature risk-assessment process of the Taskforce on Nature-related Financial Disclosures (TNFD) is called:
   (a) PCAF (b) WACI (c) LEAP (d) PACTA

9. In Module 4, TCFD and TNFD are used for risk assessment; their disclosure requirements belong to:
(a) Module 5 (b) Module 1 (c) Module 2 (d) Module 3

10. A bank brings physical flood risk to its mortgage portfolio into its Enterprise Risk Management (ERM). Which element of the ERM is new?
(a) The climate line item in the risk register (b) The risk-appetite framework and limits
(c) The committee that reviews the register (d) The escalation process for limit breaches

11. On the module's teaching rubric, a bank that scores 3 for identification, 2 for assessment, 2 for management and 1 for integration has a total and a maturity band of:
(a) 2, absent (b) 6, basic (c) 8, basic (d) 8, developing

12. Which supervisor issued its Sustainable Finance Framework as a circular in April 2020, asking banks to disclose their sustainability objectives and policies in the Annual Report?
(a) Bank of Thailand (b) State Bank of Vietnam (c) Monetary Authority of Singapore
(d) Bangko Sentral ng Pilipinas

13. Under deep uncertainty, a climate scenario is:
(a) the most likely path of the climate (b) a forecast with its probability stated (c) a conditional path with no probability attached (d) the median of many simulated paths

14. Which scenario category of the Network for Greening the Financial System (NGFS) assumes climate policies that are delayed or divergent across countries and sectors, so that physical risk stays subdued and transition risk is high as carbon prices rise sharply and abruptly?
(a) Orderly (b) Disorderly (c) Hot house world (d) Too little, too late

15. Asia is among the regions most vulnerable to physical risks. Which NGFS scenario category holds the most physical risk?
(a) Orderly (b) Disorderly (c) Net Zero 2050 (d) Hot house world

16. In the five-stage transmission chain from a climate pathway to portfolio losses, which stage comes between the macro variables and the counterparty?
(a) Sector shocks (b) Climate pathway (c) Portfolio losses (d) Scenario selection

17. If a sector's default sensitivity to output is $\gamma = 1.5$ and the scenario lowers gross domestic product (GDP) by 8 percent, the modelled rise in default probability, $\Delta PD = -\gamma \times \Delta GDP$, is:
(a) 8 percentage points (b) 12 percentage points (c) 18 percentage points (d) 20 percentage points

18. An agricultural loan with a base LGD of 45 percent, insurance covering 60 percent of physical damage and a physical damage rate of 20 percent on its collateral has a climate-adjusted LGD of:
(a) 8 percent (b) 53 percent (c) 57 percent (d) 65 percent

19. In an integrated assessment model (IAM), the damage function translates:
(a) emissions into warming (b) a policy path into energy use and emissions (c) a loss of GDP into default probabilities (d) warming into a loss of GDP

20. For a bank, the overwhelming majority of emissions fall under:
(a) Scope 1, own operations (b) Scope 3, category 15 (c) Scope 2, bought energy (d) Scope 3, category 1

21. In the weighted average carbon intensity (WACI), each company's emissions are divided by its:

(a) Total assets (b) Market capitalisation (c) Revenue (d) Enterprise value including cash (EVIC)

22. On the data quality scale of the Partnership for Carbon Accounting Financials (PCAF), financed emissions computed from emission factors for the borrower's sector per unit of revenue score:
(a) 1, the highest quality (b) 1, the lowest quality (c) 5, the lowest quality (d) 5, the highest quality

23. A borrower with $20 million of exposure, whose default probability rises from 4 to 10 percent under a scenario and whose LGD is 50 percent, contributes a Climate Value-at-Risk (Climate VaR) of:
(a) $0.6 million (b) $1.0 million (c) $1.2 million (d) $2.0 million

24. In the Chapter 4 case of an illustrative Vietnamese bank with $30 billion of assets, which book and channel had the larger Climate VaR?
(a) Coal, transition (b) Coal, physical (c) Agriculture, transition (d) Agriculture, physical

25. Which pairing of horizon and uncertainty describes a climate stress test?
(a) Multi-decadal horizon, known probabilities (b) Horizon of a few years, deep uncertainty
(c) Multi-decadal horizon, deep uncertainty (d) Horizon of a few years, known probabilities

26. Which design element of a climate stress test separates expected loss, met by provisions, from unexpected loss, met by capital?
(a) Exposure mapping (b) Loss estimation (c) Transmission to the risk parameters (d) Capital impact

27. The Basel III minimum capital adequacy ratio (CAR) including the capital conservation buffer is:
(a) 4.5 percent (b) 8.0 percent (c) 10.5 percent (d) 13.0 percent

28. For a single bank, the headline output of a climate stress test is the:
(a) Post-stress CAR (b) Portfolio WACI (c) Implied temperature rise (d) Financed emissions

29. A bank that holds 71 billion Thai baht (THB) of capital against THB 500 billion of risk-weighted assets (RWA) and loses THB 18.5 billion under a climate scenario has, with RWA held fixed, a capital adequacy ratio after the loss of:
(a) 3.7 percent (b) 10.5 percent (c) 10.9 percent (d) 14.2 percent

30. An exercise in which the authority runs one model over all banks and holds their balance sheets fixed is:
(a) top-down and static (b) top-down and dynamic (c) bottom-up and static (d) bottom-up and dynamic

31. Which statement on capital requirements holds for the 2022 climate risk stress test of the European Central Bank (ECB) and the Bank of England's 2021 Climate Biennial Exploratory Scenario (CBES)?
(a) Both set capital requirements for climate risk (b) Only the ECB's test set capital requirements (c) Neither set capital requirements for climate risk (d) Only the CBES set capital requirements

32. The risk identity of Chapter 6 is Risk equals Hazard times Exposure times:
(a) Vulnerability (b) Insurance (c) Emissions (d) Volatility

33. The index of the Notre Dame Global Adaptation Initiative (ND-GAIN) separates vulnerability from:
(a) exposure (b) hazard (c) insurance penetration (d) readiness

34. In a blended-finance stack, which layer does the concessional public money take?
(a) The mezzanine or guarantee layer (b) The first-loss layer (c) The senior commercial tranche (d) An equal share of every layer

35. Which empirical design evaluates the effect of a new disclosure rule on banks?
(a) Panel fixed effects (b) Instrumental variables (c) Difference-in-differences (d) Hazard-grid overlays

36. The solo capital adequacy ratio of the Philippine banking system was 16.6 percent in December 2023[1]. An assumed typhoon scenario deducts 1.8 percentage points for new provisions, 0.9 for the rise in risk-weighted assets and 0.4 for market losses. The Bangko Sentral ng Pilipinas (BSP) sets a floor of 12.5 percent for universal and commercial banks, its 10 percent minimum plus the 2.5 percent conservation buffer of Circular No. 781[2]. The stressed ratio exceeds that floor, in percentage points, by:
(a) 1.0 (b) 2.3 (c) 3.5 (d) 4.1

B.2 Part 2: Applied exercise on a Thai insurer's solvency

A Thai non-life insurer holds total capital of $2.5 billion against required capital of $1.5 billion, and its solvency ratio is total capital over required capital. Its target is 140 percent, the capital adequacy ratio below which the Registrar of the Office of Insurance Commission (OIC) may impose measures on a non-life insurer[3].

1. Compute the insurer's solvency ratio in normal conditions.

2. A 1-in-100-year catastrophe produces an industry insured loss of about $6 billion; after reinsurance the insurer's net share is about $1 billion. Compute the post-event capital and the post-event solvency ratio, and compare the ratio with the target.

3. Before excess-of-loss cover the insurer's share of the 1-in-100-year loss is $2 billion. Option A covers $1 billion of loss above an attachment point of $0.25 billion at a premium of 4 percent of that limit, Option B covers $3 billion of loss above the same attachment point at 7 percent of its limit, and the third choice buys no cover. Each premium is an annual cost paid from premium income, so it leaves the post-event capital unchanged. Compute the post-event solvency ratio under each of the three choices, name the cheapest choice that meets the target, and state its annual premium.

4. An assumed climate adjustment raises intensity by 5 to 8 percent and lifts the assumed 1-in-100-year industry loss from about $5 to $7 billion to about $7 to $9 billion. Discuss, in one paragraph, whether the regulator should require additional capital now or wait for greater certainty, referencing the deep-uncertainty argument of Chapter 3.

B.3 Grading rubric

The four dimensions count equally, and the mark is the sum of the four band scores, out of 16.

[1] Bangko Sentral ng Pilipinas. Report on Recent Trends in the Philippine Financial System, Issue No. 2024-03.
[2] Bangko Sentral ng Pilipinas (2013). Circular No. 781, 15 January 2013: Basel III Implementing Guidelines on Minimum Capital Requirements. Full text: Supreme Court E-Library.
[3] Office of Insurance Commission (2018). Registrar's Order No. 48/2561 Re: Required Disclosure of Financial Standing and Operating Results of Non-life Insurance Companies. English translation.

Dimension	Excellent (4)	Competent (3)	Developing (2)	Beginning (1)
Technical, questions 1 to 3	All results right, 167 percent; $1.5 billion and 100 percent; 33, 100 and 150 percent; every step shown	All results right, one step not shown	Questions 1 and 2 right, question 3 incomplete	Question 1 right at most
Critical, question 3	Option B, the only choice at or above 140 percent; its $210 million premium is paid every year against a loss expected once in a hundred years	Option B, with both premiums stated	Option B, without the ratios behind it	Option A or no cover
Understanding, question 4	The deep-uncertainty argument of Chapter 3: waiting for certainty is itself a choice with tail consequences	Deep uncertainty named, with a conclusion for capital	Deep uncertainty named, with no conclusion	The assumed intensity rise treated as a known probability
Communication, all questions	Every step and unit stated; the paragraph of question 4 follows from its evidence	Steps and units stated, with one gap	Results stated without their steps	Results without steps or units

Answer key (Part 1)

1:(d), 2:(a), 3:(b), 4:(b), 5:(d), 6:(c), 7:(d), 8:(c), 9:(a), 10:(a), 11:(d), 12:(d), 13:(c), 14:(b), 15:(d), 16:(a), 17:(b), 18:(b), 19:(d), 20:(b), 21:(c), 22:(c), 23:(a), 24:(d), 25:(c), 26:(b), 27:(c), 28:(a), 29:(b), 30:(a), 31:(c), 32:(a), 33:(d), 34:(b), 35:(c), 36:(a).

Part 1 working

- Question 5: $PD_{climate} = 0.04 \times (1 + 2 \times 0.25) = 0.06$ and $LGD_{climate} = 0.50 + 0.10 = 0.60$, so $EL_{climate} = 0.06 \times 0.60 \times \$200$ million = \$7.2 million.
- Question 6: agriculture and real estate hold $25+15 = 40$ percent of the book, and the Delta's dominant hazard is chronic: sea-level rise, subsidence and salt water intrusion.
- Question 11: the total is $3 + 2 + 2 + 1 = 8$ out of 12, in the band from 7 to 9, developing.
- Question 17: $\Delta PD = -1.5 \times (-8) = 12$ percentage points.
- Question 18: $LGD_{climate} = 45 + (1 - 0.60) \times 20 = 53$ percent.
- Question 23: the contribution is \$20 million $\times (0.10 - 0.04) \times 0.50 = \$0.6$ million.
- Question 29: $(71 - 18.5)/500 = 0.105$, a ratio of 10.5 percent.
- Question 36: $16.6 - 1.8 - 0.9 - 0.4 = 13.5$ percent, and $13.5 - 12.5 = 1.0$ percentage point.

Part 2 worked answers

1. Solvency ratio = $2.5/1.5 \approx 1.67$, that is about 167 percent.
2. Post-event capital = $2.5 - 1.0 = 1.5$ billion, so the post-event ratio is $1.5/1.5 = 1.0$, that is 100 percent: capital equals required capital, and the ratio is below the 140 percent target.
3. With no cover the insurer retains the whole \$2 billion loss, so capital falls to $2.5-2.0 = 0.5$ billion and the ratio to $0.5/1.5 \approx 0.33$, about 33 percent. Option A costs $0.04 \times \$1{,}000$ million = \$40 million a year; the insurer retains $0.25 + (2.0 - 0.25 - 1.0) = 1.0$ billion, and the ratio is $1.5/1.5 = 1.0$, 100 percent. Option B costs $0.07 \times \$3{,}000$ million = \$210 million a year; the insurer retains the 0.25 billion below the attachment point, and the ratio is $(2.5 - 0.25)/1.5 = 1.5$, 150 percent. Option B is the only choice at or above the 140 percent target, so it is the answer, at \$210 million of premium income paid every year against a loss expected once in a hundred years.
4. A defensible answer notes that under deep uncertainty point probabilities are unreliable, so waiting for certainty is itself a choice with tail consequences; capital or reinsurance arranged before the event protects the insurer across the range of scenarios.

References

- ASEAN Secretariat (2024). ASEAN Key Figures 2024, Vol. 7, December 2024.
- ASEAN central banks and monetary authorities (2020). Report on the Roles of ASEAN Central Banks in Managing Climate and Environment-related Risks, 17 November 2020, page 11. Published by Bank Negara Malaysia.
- Acharya, V. V., Berner, R., Engle, R. F., Jung, H., Stroebel, J., Zeng, X. and Zhao, Y. (2023). Climate Stress Testing. Annual Review of Financial Economics 15, 291-326. NBER Working Paper 31097, April 2023.
- Agribank (Vietnam Bank for Agriculture and Rural Development). About Agribank, corporate page, figures as of 30 September 2019.
- Al Jazeera (2019). Tropical cyclone heads for southern Thailand. 2 January 2019. News report citing Thai Meteorological Department records.
- BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Basel Committee on Banking Supervision, Annex 1: Calibration of the capital framework.
- BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Introduction, paragraph 31.
- BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Paragraph 129.
- BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Paragraph 132(a).
- BCBS (2011). Basel III: A global regulatory framework for more resilient banks and banking systems, revised June 2011. Paragraphs 49 and 50, page 12.
- BCBS (2021). Climate-related risk drivers and their transmission channels. Basel Committee on Banking Supervision, April 2021, Executive summary, page 1.
- BCBS (2021). Climate-related risk drivers and their transmission channels. Basel Committee on Banking Supervision, April 2021, page 12.
- BCBS (2021). Climate-related risk drivers and their transmission channels. Basel Committee on Banking Supervision, April 2021, page 26.
- BCBS (2021). Climate-related risk drivers and their transmission channels. Basel Committee on Banking Supervision, April 2021, page 30, citing Munich Re (2020).
- BCBS (2021). Revisions to the Principles for the Sound Management of Operational Risk. Basel Committee on Banking Supervision, March 2021, section 3, paragraph 1, page 2.

- BCBS (2022). Principles for the effective management and supervision of climate-related financial risks. Basel Committee on Banking Supervision, June 2022, Principle 4, paragraphs 20 to 22, page 4.
- BCBS (2022). Principles for the effective management and supervision of climate-related financial risks. Basel Committee on Banking Supervision, June 2022.
- Bangko Sentral ng Pilipinas (2013). Circular No. 781, 15 January 2013: Basel III Implementing Guidelines on Minimum Capital Requirements. Full text: Supreme Court E-Library.
- Bangko Sentral ng Pilipinas, Report on Recent Trends in the Philippine Financial System, Issue No. 2024-03, as of March 2024.
- Bangko Sentral ng Pilipinas. Report on Recent Trends in the Philippine Financial System, Issue No. 2024-03.
- Bank for Agriculture and Agricultural Cooperatives (2025). Annual Report 2024 (fiscal year to 31 March 2025).
- Bank of England (2022). Results of the 2021 Climate Biennial Exploratory Scenario (CBES). 24 May 2022.
- Bank of England (2022). Results of the 2021 Climate Biennial Exploratory Scenario (CBES). Bank of England, 24 May 2022.
- Bank of Thailand (2023). Policy Statement of the Bank of Thailand Re: Internalizing Environmental and Climate Change Aspects into Financial Institution Business, 15 February 2023. Financial Institutions Strategy Department. Unofficial translation.
- Battiston, S., Mandel, A., Monasterolo, I., Schuetze, F., and Visentin, G. (2017). A climate stress-test of the financial system. Nature Climate Change, 7, 283 to 288.
- Battiston, S., Mandel, A., Monasterolo, I., Schuetze, F., and Visentin, G. (2017). A climate stress-test of the financial system. Nature Climate Change, 7, 283 to 288. Published article as hosted by the Stanford Energy Modeling Forum; the nature.com page is paywalled.
- Bolton, P. and Kacperczyk, M. (2021). Do Investors Care about Carbon Risk? Journal of Financial Economics 142(2), 517-549. NBER Working Paper 26968.
- Bolton, P. and Kacperczyk, M. (2023). Global Pricing of Carbon-Transition Risk. The Journal of Finance 78(6), 3677-3754. NBER Working Paper 28510.
- Bolton, P., Despres, M., Pereira da Silva, L. A., Samama, F., and Svartzman, R. (2020). The green swan: central banking and financial stability in the age of climate change. Bank for International Settlements.
- CDP (2021). Finance sector's funded emissions over 700 times greater than its own. Press release, 28 April 2021.
- Caldecott, B., Kruitwagen, L., Dericks, G., Tulloch, D. J., Kok, I., and Mitchell, J. (2016). Stranded Assets and Thermal Coal: An analysis of environment-related risk exposure. Smith School of Enterprise and the Environment, University of Oxford, January 2016, page 9.
- Carney, M. (2015). Breaking the tragedy of the horizon: climate change and financial stability. Speech at Lloyd's of London, 29 September 2015. Bank of England, page 4.

- Carney, M. (2015). Breaking the tragedy of the horizon: climate change and financial stability. Speech at Lloyd's of London, 29 September 2015. Bank of England. Full text: BIS Review r151009a.
- Climate Policy Initiative (2023). Global Landscape of Climate Finance 2023. Press release, November 2023.
- Critical Ecosystem Partnership Fund. Hotspots defined, cepf.net.
- Dietz, S., Bowen, A., Dixon, C., and Gradwell, P. (2016). Climate value at risk of global financial assets. Nature Climate Change, 6, 676 to 679.
- Diokno, B. E. (2020). Integrating sustainability in corporate strategy: BSP sustainable finance framework. Speech by the Governor of the Bangko Sentral ng Pilipinas, 28 October 2020. BIS Central bankers' speeches, 10 December 2020.
- Directive (EU) 2022/2464 of 14 December 2022 (Corporate Sustainability Reporting Directive, CSRD), Article 1(4), replacing Article 19a(1) of Directive 2013/34/EU. Text as signed: PE-CONS 35/22, Council of the European Union, 16 November 2022.
- Directive (EU) 2022/2464 of 14 December 2022 (Corporate Sustainability Reporting Directive, CSRD), recital 29. Text as signed: PE-CONS 35/22, Council of the European Union, 16 November 2022.
- Dolk, M., Dunz, N., Lesage, F., Nie, O. and Pollitt, H. (2025). Assessing and managing natural disaster risks for the financial sector in Thailand. World Bank blog, All About Finance, 2 June 2025.
- Emanuel, K. (2005). Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436, 686-688. Copy hosted by Appalachian State University course readings.
- Ember (2024). ASEAN's clean power pathways: 2024 insights. Power sector in 2023.
- European Central Bank (2022). 2022 climate risk stress test. ECB Banking Supervision, July 2022.
- European Central Bank (2022). ECB banking supervision launches 2022 climate risk stress test. Press release, 8 July 2022.
- European Commission, Taxation and Customs Union. Carbon Border Adjustment Mechanism.
- FSB and NGFS (2022). Climate Scenario Analysis by Jurisdictions: Initial findings and lessons. Financial Stability Board and Network for Greening the Financial System, 15 November 2022.
- FSB. About the FSB. Financial Stability Board.
- G7 Finance Ministers and Central Bank Governors (2021). Communique, London, 5 June 2021, paragraph 4. GOV.UK.
- GHG Protocol (2011). Corporate Value Chain (Scope 3) Accounting and Reporting Standard. WRI and WBCSD, September 2011. Table 5.4, page 37; page 51; glossary, page 140.
- GRI (2021). GRI 3: Material Topics 2021, Introduction, page 4. Global Reporting Initiative, effective 1 January 2023.

- Gerechtshof Den Haag (The Hague Court of Appeal), press release of 12 November 2024, Hague court denies claim for reduction in Shell's CO2 emissions.
- Global Affairs Canada. Canada and the G7. Government of Canada, holder of the 2025 G7 presidency.
- Green Climate Fund. Governing Instrument for the Green Climate Fund, paragraph 50.
- HKMA. The HKMA. Hong Kong Monetary Authority.
- Hong Kong Monetary Authority (2021). HKMA publishes the results of the pilot climate risk stress test. Press release, 30 December 2021.
- IEA (2025). Global Energy and Climate Model: Announced Pledges Scenario (APS). International Energy Agency.
- IEA (2025). Global Energy and Climate Model: Understanding GEC Model scenarios. International Energy Agency.
- IFRS Foundation (2023). IFRS S1 General Requirements for Disclosure of Sustainability-related Financial Information, paragraph 3. International Sustainability Standards Board (ISSB), June 2023.
- IFRS Foundation (2025). Jurisdictional snapshot: Singapore. Updated 12 June 2025.
- IFRS Foundation. IFRS 9 Financial Instruments, paragraphs 5.5.1 to 5.5.5. IFRS Standards, 2021 issued edition, Part A.
- IFRS Foundation. IFRS S2 Climate-related Disclosures, standard page, ifrs.org.
- IPCC (2000). Special Report on Emissions Scenarios, Summary for Policymakers. Nakicenovic, N. and Swart, R. (eds.).
- IPCC (2021). Climate Change 2021: The Physical Science Basis, Summary for Policymakers, B.2.4.
- IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary, entry Risk, page 2921.
- IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary, page 2908.
- IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary, page 2911.
- IPCC (2022). Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report, Annex II: Glossary, page 2927.
- IPCC (2023). Climate Change 2023: Synthesis Report, Summary for Policymakers, B.5.3.
- Krueger, P., Sautner, Z., and Starks, L. T. (2020). The Importance of Climate Risks for Institutional Investors. Review of Financial Studies, 33(3), 1067 to 1111. ECGI Finance Working Paper.
- Milieudefensie et al. v. Royal Dutch Shell plc, Hague District Court, 26 May 2021. Sabin Center Climate Change Litigation Databases.

- Minderhoud, P. S. J., Coumou, L., Erkens, G., Middelkoop, H., and Stouthamer, E. (2019). Mekong delta much lower than previously assumed in sea-level rise impact assessments. Nature Communications, 10, 3847.
- Monetary Authority of Singapore (2020). Response to Feedback Received on Proposed Guidelines on Environmental Risk Management (Banks), 8 December 2020.
- Monetary Authority of Singapore (2022). Financial Stability Review, November 2022. Special Feature 1.
- Munich Re (2024). Natural disaster figures 2023. Media information, 9 January 2024.
- NGFS (2023). NGFS Scenarios for central banks and supervisors, Phase IV, November 2023.
- NGFS (2024). NGFS Climate Scenarios Technical Documentation, version 5.0, November 2024, page 11.
- NGFS (2024). NGFS Climate Scenarios Technical Documentation, version 5.0, November 2024, page 16.
- NGFS (2024). NGFS Climate Scenarios Technical Documentation, version 5.0, November 2024, page 17.
- NGFS (2024). NGFS Climate Scenarios Technical Documentation, version 5.0, November 2024, page 22.
- NGFS (2024). NGFS long-term scenarios for central banks and supervisors, November 2024 (Phase V), Main results, Gross Domestic Product.
- NGFS (2024). NGFS long-term scenarios for central banks and supervisors, November 2024 (Phase V), Scenarios at a glance (1/2), page 10.
- NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V).
- NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V). Annex A.
- NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V). Box 1, NGFS Scenario framework, page 9.
- NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V). Net Zero 2050 scenario narrative.
- NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024 (Phase V). Section 4, Fragmented World, GDP impact across jurisdictions.
- NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024, page 35.
- NGFS (2025). NGFS Scenarios: narratives and key findings, November 2025, on results version 5.0 of November 2024, page 49.
- NGFS. Membership, list of members, Asia-Oceania. ngfs.net.
- NGFS. Origin and Purpose. Network of Central Banks and Supervisors for Greening the Financial System.

- Nie, O., Regelink, M. and Wang, D. (2023). Banking Sector Risk in the Aftermath of Climate Change and Environmental-Related Natural Disasters. Policy Research Working Paper 10326, World Bank, February 2023.
- Nordhaus, W. D. (1992). The 'DICE' Model: Background and Structure of a Dynamic Integrated Climate-Economy Model of the Economics of Global Warming. Cowles Foundation Discussion Paper No. 1009, Yale University, February 1992.
- Office of Insurance Commission (2018). Registrar's Order No. 48/2561 Re: Required Disclosure of Financial Standing and Operating Results of Non-life Insurance Companies. English translation.
- Office of Insurance Commission (2019). Notification of the Insurance Commission re: Criteria, Methods, and Conditions for Governing Enterprise Risk Management and Own Risk and Solvency Assessment of Non-life Insurance Companies B.E. 2562. Unofficial translation.
- Otoritas Jasa Keuangan (OJK). Task and Functions. Indonesia Financial Services Authority, ojk.go.id.
- PAGASA. Tropical Cyclone Information. Philippine Atmospheric, Geophysical and Astronomical Services Administration, DOST.
- PCAF (2022). The Global GHG Accounting and Reporting Standard, Part A: Financed Emissions. Second Edition, December 2022. Pages 19, 52 and 53; Table 5-3, page 57.
- PCAF (2022). The Global GHG Accounting and Reporting Standard, Part A: Financed Emissions. Second Edition, December 2022. Section 5.2, Business loans and unlisted equity, page 70.
- PCAF (2022). The Global GHG Accounting and Reporting Standard, Part A: Financed Emissions. Second Edition, December 2022. Table 5-3, options 3b and 3c, page 57.
- RMI. PACTA: Measure the alignment of financial portfolios with climate scenarios. Paris Agreement Capital Transition Assessment, RMI.
- Riahi, K. et al. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change 42, 153-168.
- SBTi. About us. Science Based Targets initiative.
- Science Based Targets initiative. How it works: setting science-based targets.
- Setzer, J. and Higham, C. (2023). Global trends in climate change litigation: 2023 snapshot. Grantham Research Institute, LSE.
- State Bank of Vietnam (2022). Circular No. 17/2022/TT-NHNN of 23 December 2022 guiding environmental risk management in credit extension by credit institutions and foreign bank branches. English translation: LuatVietnam.
- Swiss Re Institute (2021). The economics of climate change: no action not an option. April 2021, Key takeaways.
- TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, Final Report, Figure 1.

- TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, Final Report, June 2017, section B.1.a, Transition Risks: Policy and Legal Risks.
- TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, Final Report, Table 1.
- TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures, the recommendations and recommended disclosures of Figure 4 of the Final Report, as set out on the TCFD recommendations page, fsb-tcfd.org.
- TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. Final Report, June 2017. Financial Stability Board.
- TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. Final Report, June 2017. Financial Stability Board. Letter from Michael R. Bloomberg, 15 June 2017.
- TCFD (2017). Recommendations of the Task Force on Climate-related Financial Disclosures. Final Report, June 2017. Financial Stability Board. Section A, Introduction.
- TCFD (2021). Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures, October 2021. Supplemental Guidance for Asset Owners, page 42.
- TCFD (2021). Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures, October 2021. Table 3, Common Carbon Footprinting and Exposure Metrics, page 52.
- TCFD. Task Force on Climate-related Financial Disclosures website, notice of October 2023. fsb-tcfd.org.
- TNFD (2023). Guidance on the identification and assessment of nature-related issues: the LEAP approach, version 1.1, October 2023.
- TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023.
- TNFD (2023). Recommendations of the Taskforce on Nature-related Financial Disclosures. September 2023. Section 1.2.
- TPI. History and investor network. Transition Pathway Initiative.
- Transition Pathway Initiative Centre, London School of Economics. Corporate assessments, TPI online tool.
- UNDP Climate Promise. Philippines: key highlights from the NDC (first NDC, April 2021).
- UNDP Climate Promise. Viet Nam: key highlights from the NDC (updated NDC, November 2022).
- UNEP FI (2019). Changing Course: A comprehensive investor guide to scenario-based methods for climate risk assessment, in response to the TCFD, page 38.
- University of Notre Dame Global Adaptation Initiative. ND-GAIN Country Index: Methodology.

- World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Overview, page 2.
- World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Overview, page 4.
- World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Vol. 1, Overview.
- World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning, Vol. 2, Final report. Royal Thai Government and World Bank.
- World Bank (2012). Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning.
- World Bank (2021). Agricultural Land Use and Sustainable Livelihoods in the Mekong Delta: Alternative Scenarios and Policy Implications. Australia-World Bank Group Strategic Partnership in Vietnam, page 2.
- World Bank (2021). Philippines Financial Sector Assessment Program: Climate Change and Environmental Risks and Opportunities, Technical Note, Box 1.
- World Bank (2021). World Bank Support for the Impacts of Typhoon Rai in the Philippines (Odette). Brief, 28 December 2021.
- World Bank (2022). New World Bank Group Report Proposes Path for Vietnam to Address Climate Risks While Sustaining Robust Economic Growth. Press release, 1 July 2022.
- World Bank (2022). New World Bank Group Report Proposes Path for Vietnam to Address Climate Risks. Press release, 1 July 2022.
- World Bank (2023). Reforming Agricultural Insurance in the Philippines. Policy note.
- World Bank (2026). Southeast Asia Disaster Risk Insurance Facility (SEADRIF): Strengthening Financial Resilience in Southeast Asia (P170913). Implementation Completion and Results Report ICR00681, corrigendum of 30 January 2026.
- World Bank Group (2022). Vietnam Country Climate and Development Report, July 2022.
- World Bank Treasury (2022). Case study: The Philippines: Transferring the Cost of Severe Natural Disasters to Capital Markets.
- World Bank, GFDRR, ASEAN Secretariat and UNISDR (2012). Advancing Disaster Risk Financing and Insurance in ASEAN Member States: Framework and Options for Implementation, Appendices, June 2012. Thailand PCRI market profile.
- World Economic Forum (2020). Nature Risk Rising: Why the Crisis Engulfing Nature Matters for Business and the Economy. New Nature Economy Report, January 2020.
- van Vuuren, D.P., Edmonds, J., Kainuma, M. et al. (2011). The representative concentration pathways: an overview. Climatic Change 109, 5-31.

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Use of generative AI

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Its use was confined to the following purposes:

- idea generation and brainstorming on module structure and worked examples;
- language editing of author-specified content;
- literature classification and organisation of the reading list;
- coding assistance for the chart, data-processing, and document-build scripts;
- checking recorded numbers and quotations against their published sources;
- interactive literature searching using AI-enhanced search tools.

The authors specified and reviewed the content of this module. Every cited source was checked against the original publication, and every figure states its provenance on its own face, distinguishing sourced from derived values and from illustrative teaching assumptions; figures whose data could not be sourced were withdrawn. The authors remain fully responsible for the originality, accuracy, integrity, references, and conclusions of the material.

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