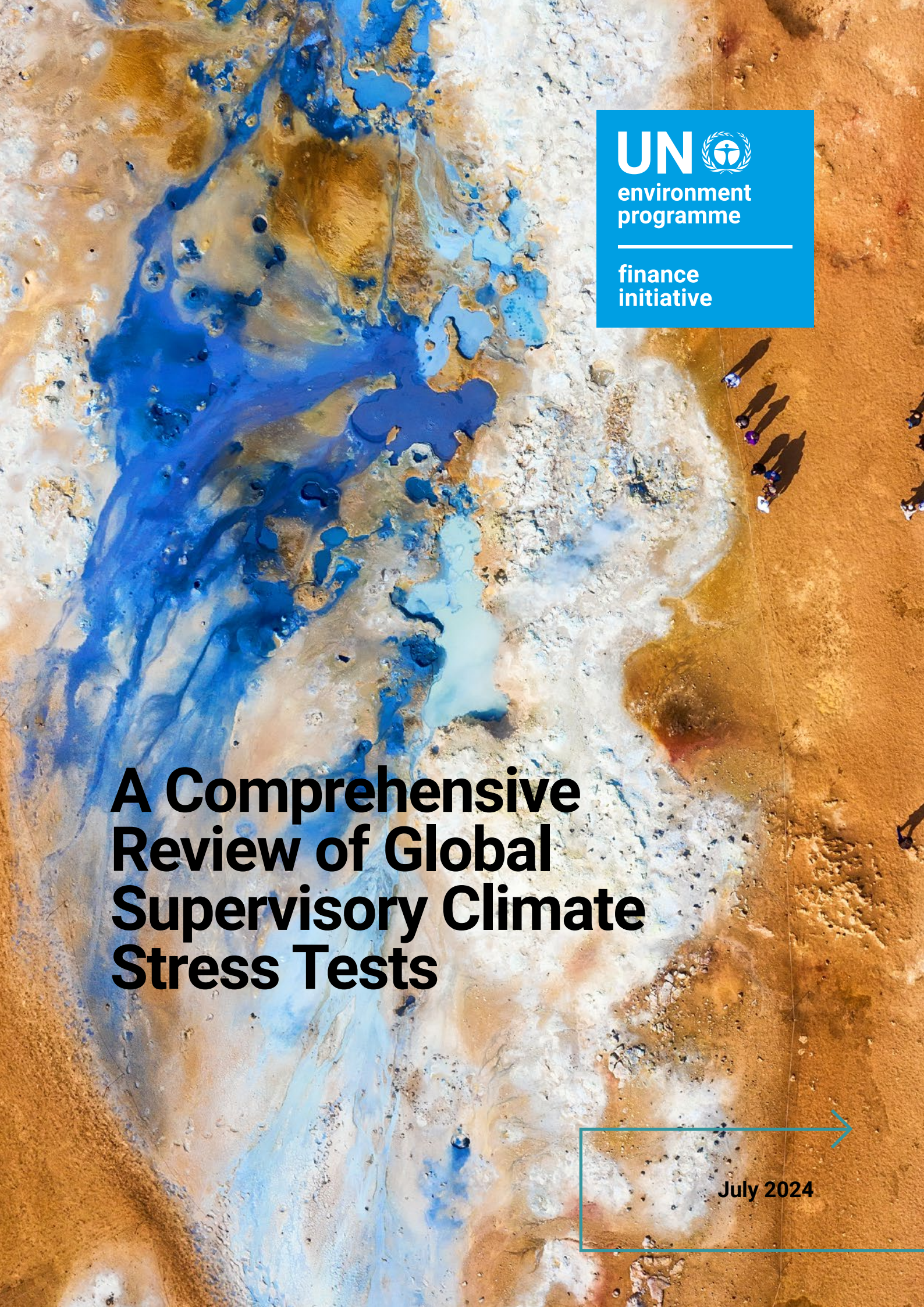

UN environment programme

finance initiative

A Comprehensive Review of Global Supervisory Climate Stress Tests

July 2024

Suggested citation: United Nations Environment Programme (2024). *A Comprehensive Review of Global Supervisory Climate Stress Tests*. Geneva.

Production: United Nations Environment Programme Finance Initiative.

Cover image: elements.envato.com/user/biletskiy/photos

Acknowledgements

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The authors would specifically like to acknowledge the contributions, inputs, and supporting research that have enabled the completion of this report:

Benoit Goye, UNEP FI
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Project management

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The project has been supported throughout the year by the members of the UNEP FI Climate Risk Programme.

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Executive summary

A climate stress test assesses the vulnerability of financial institutions to climate change impacts to understand the financial risks that the global financial system faces from rising global temperature. Supervisory authorities globally are increasingly conducting or planning to conduct such exercises to assess these risks. Dozens of financial supervisors have already conducted climate stress tests or are planning to do so.

This document serves as a resource for both supervisors and financial institutions, offering insights into the latest developments and practices around climate stress testing. It covers the scope, design, modelling approaches, and key findings of supervisory exercises with a view to sharing good practices identified across jurisdictions. Additionally, it provides recommendations and methodological guidance for conducting a climate stress test.

Key elements of supervisory climate stress tests

1. Objectives of climate stress tests

Supervisory exercises can have a diverse set of objectives. However, they have primarily focused on raising awareness of climate risks and fostering climate action within financial institutions. Other objectives identified across supervisory exercises include assessing financial exposure to climate risk under different scenarios, improving climate risk assessment capabilities, and understanding how to adapt business models in response to varying scenarios.

2. Scope of the exercises

Most supervisory exercises target banks, with 61 per cent primarily focusing on this type of financial institution. Around 30 per cent cover both banks and insurers, while a small percentage include investment funds alongside banks and insurers, or just banks and insurers.

These exercises can focus on assessing physical risks or transition risks, or both. Financial risks, such as credit risk and market risk, are commonly evaluated, with credit risk being more frequently examined in supervisory exercises. Some exercises have also assessed other types of risks, such as reputational risk, operational risk, sovereign risk, insurance risk, liquidity risk, and financial stability risk. The assessment of different risk types can either be conducted quantitatively or qualitatively.

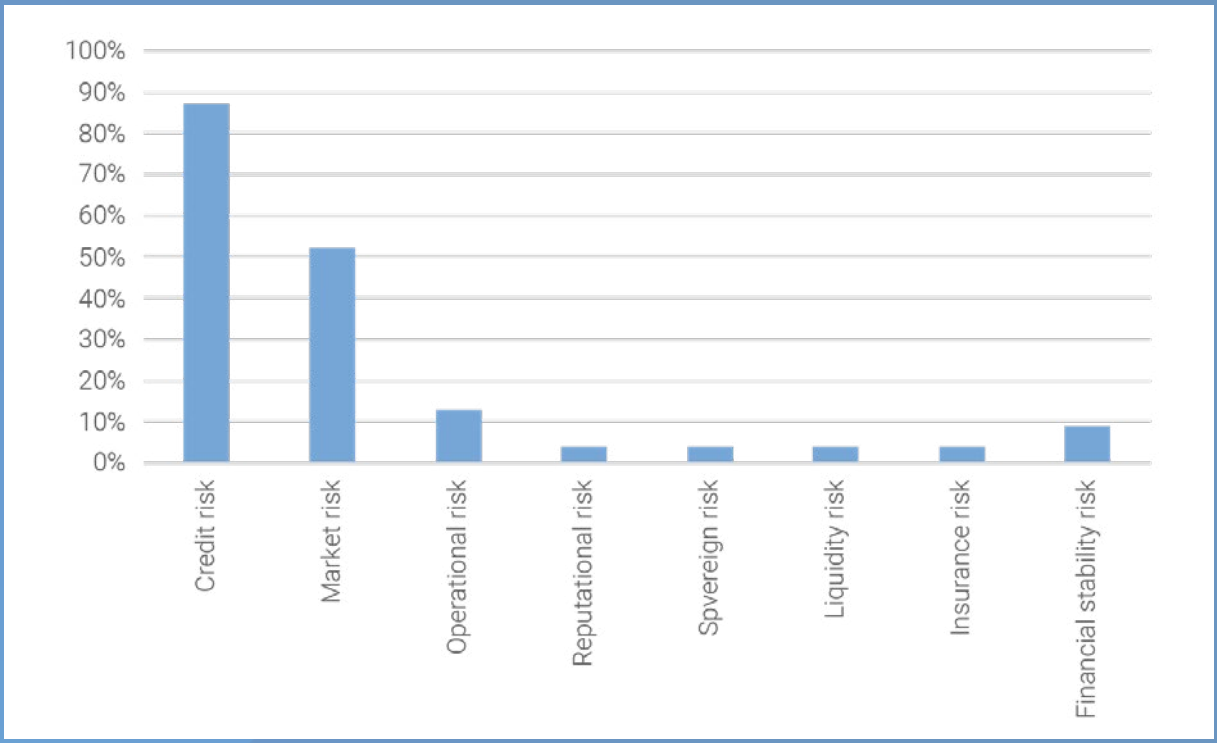


Figure 1: Main financial risks covered in climate stress testing exercises[1]

3. Methodological approaches for climate stress testing

Two main methods are commonly employed when determining the supervisory climate stress testing approach: bottom-up and top-down. These approaches differ significantly in terms of their level of detail, the outputs generated by models, and the resources required. Additionally, climate stress tests can be characterised by the assumptions made about the balance sheet, which can be either static or dynamic. Financial institutions conducting climate stress tests may choose to analyse either individual counterparties or entire portfolios, or a combination of both.

Identifying the key risk metrics and outlining key assumptions are crucial components of the process. Examples of risk metrics used in supervisory exercises include:

- Loan to Value (LTV) ratios
- Probability of occurrence of disasters
- Loss Given Default (LGD)
- Probability of Default (PD)
- Exposure at Default (EAD)
- Non-Performing Loans (NPLs)
- Transition-to-credit-risk intensity (TCI)
- Capital adequacy ratios
- Emissions per Product (EP)
- Gross Emissions (EB)
- Export Participation (PE)

1 These financial risks have been identified from a sample of 23 climate stress testing exercises. More information about these can be found in the appendix.

4. Time-horizon

Many supervisors have typically adopted a 30-year time-horizon for their exercises. However, using such an extended time frame can introduce significant uncertainties. To address this, an increasing number of supervisors are now integrating scenarios with shorter time-horizons (i.e. one to five years) into their assessments. Such time-horizons align better with the time frames traditionally used in financial institutions for capital and strategic planning.

5. Data requirements

Data for climate stress testing typically falls under either traditional financial data or climate data (Table 1). To collect data, institutions need to identify data needs, understand the availability of data sources, implement industry standards, validate data, identify data gaps, and adapt institutional systems.

Table 1: Types of climate-related data required for climate stress testing (adapted from UNEP FI, 2021)

Data type	Data required
Climate hazard data	▪ Historical data on acute and chronic physical risks. ▪ Projections of future acute and chronic physical risks, including their severity and frequency. ▪ Adaptive capacity data to determine client resilience and sensitivity to climate hazards, including current adaptation strategies of clients. ▪ Climate hazard data based on geography, sector, and industry, including economic losses from past climate hazards.
Transition risk drivers data	▪ Data on transition risk drivers, including policy implementation, market shifts, technological changes, and reputation.
Emissions data	▪ Energy and carbon mix of counterparties. ▪ Published or estimated greenhouse gas (GHG) emissions produced by portfolios and assets of clients. ▪ GHG emissions data by region, sector, or industry. ▪ Energy efficiency data; for example, real estate ratings like the Energy Performance Certificate Rating. ▪ Data on carbon pricing by jurisdiction.
Climate-related client data	▪ Identification of the physical assets owned by clients. ▪ Detailed and granular geographical/geolocational data of assets.
Alignment and transition data	▪ Transition pathways set by clients in accordance with the Paris Climate Change Agreements. ▪ Science-based emission reduction targets set by clients. ▪ Climate policies and pledges of countries.

6. Science-based climate scenarios

To ensure risks are fully identified, worst-case (also known as 'tail risk') scenarios need to be incorporated into climate stress testing exercises. However, the climate scenarios that are currently used do not reflect extreme, tail-risk events. A large majority of supervisory climate stress testing exercises have used, or plan to use, the scenarios

by the Network for Greening the Financial System (NGFS). The most common scenario used in these exercises is the current policies scenario, followed by a delayed transition and a Net Zero 2050 scenario. While NGFS scenarios remain a common choice, some supervisors have decided to use alternative or internally developed scenarios.

7. Modelling approaches

The modelling approach for climate stress testing involves combining different models that were not designed to be used together. These models include:

- Climate scenario models to project pathways for selected physical and transition risk variables. Integrated Assessment Models (IAMs) are commonly used due to their ability to describe the interactions between economic activity, emissions, and the climate system. Although IAMs share similarities, each has its own set of assumptions and coverage that can influence the outputs of an exercise.
- Macroeconomic models to translate climate variables from the climate model to selected macroeconomic variables. The National Institute Global Econometric Model (NiGEM) and the G-Cubed model are two macroeconomic models that are being widely used.
- Sectoral and portfolio models to break down the macroeconomic impacts down to the sector-level.
- Financial models to calculate a bank's exposures to climate risks. Internal models can be used to assess changes in metrics.

8. Inclusion of a user-friendly assessment questionnaire

Supervisors are introducing a qualitative narrative portion to their exercises in the form of a qualitative questionnaire. This is motivated by a variety of reasons: to understand challenges to participants' business models from climate-related risks; to gain information on operational and reputational risks; to judge the size of participants' management actions; and to obtain a clearer view of how participants will improve their risk management of climate-related risks.

Current and future potential uses of outputs

Illustrated below are the current and future potential uses of climate stress testing results for supervisors and financial institutions. When using the outputs, it is important to acknowledge the limitations of the exercise.

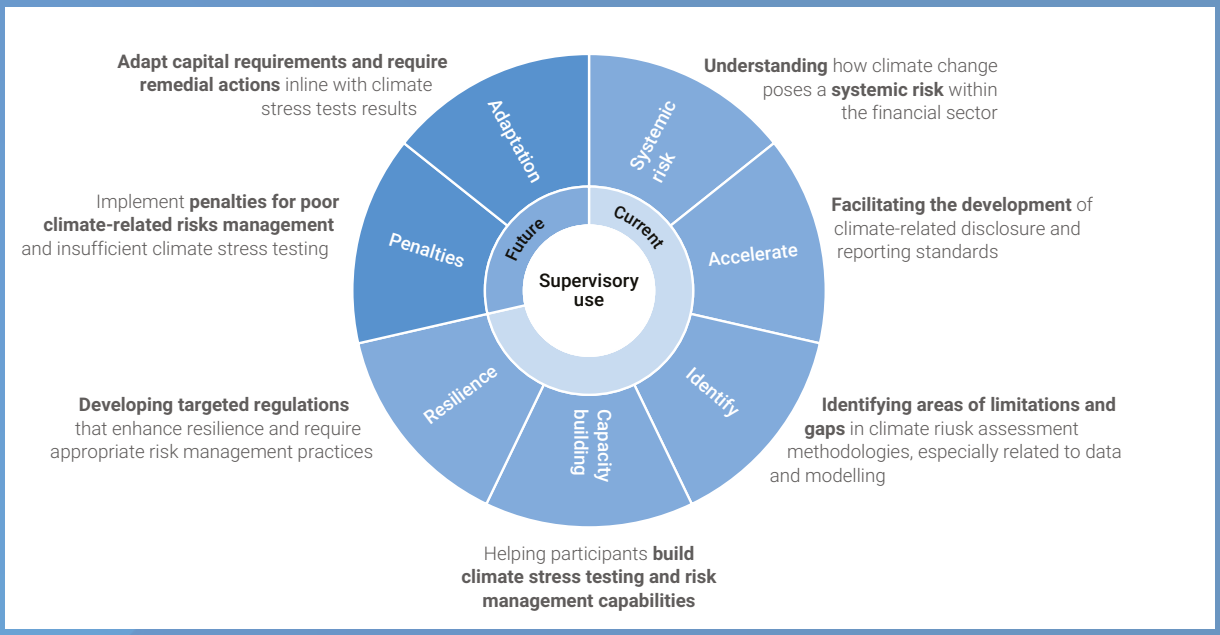


Figure 2: Supervisory use of climate stress testing (own depiction)

Figure 3: Institutional use of climate stress testing (own depiction)

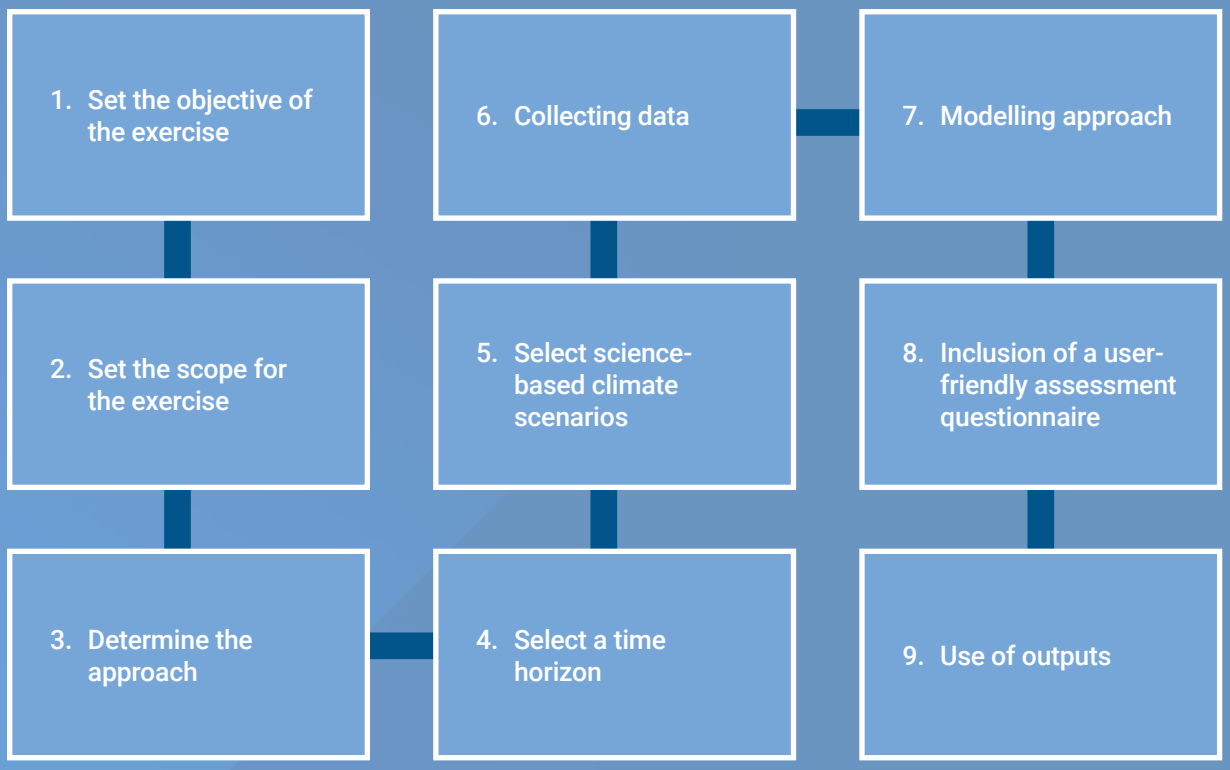


Figure 4: Key steps for conducting a climate stress test (own depiction)

1. Introduction

1.1 Context

Climate change poses a global threat to financial stability, with climate-related risks viewed as systemic risks. As a result, it has become increasingly important to employ forward-looking assessment methods to effectively measure these climate risks and address the challenges posed by climate change for financial institutions. In this context, climate scenario analysis has emerged as a crucial instrument for quantifying and assessing the potential impacts of climate change on economies and financial systems.

A climate stress test assesses the vulnerability of financial institutions to the effects of climate change in order to understand the financial risks that the global financial system faces from rising global temperature and how business models could potentially be affected. This is done by running adverse scenarios or by comparing a range of different scenarios. Running climate stress tests is of great value for financial institutions with a wide range of applications. These include, among others: raising institutions' awareness of climate-related risks; encouraging boards to understand the challenges of climate risks and take strategic and action to manage these risks; identifying gaps in climate expertise and the resources needed to better assess and manage climate risks; and improving climate-related disclosures of institutions (UNEP FI, 2021).

Globally, a growing number of supervisory authorities have conducted a climate stress test. Many others are in the process of conducting such tests or have announced plans to do so in the near future. As a non-exhaustive demonstration, Appendix 1 showcases some of the climate stress tests already carried out or currently in progress by financial jurisdictions globally.

1.2 Purpose of this report

This document is a resource for both financial supervisors and financial institutions to understand the latest developments and practices around climate stress tests. It provides an overall but non-exhaustive picture of the climate stress testing exercises that supervisors and participating financial institutions are currently undertaking or have undertaken. It provides insights into the scope of these exercises, their design details, their modelling approaches, and the main results across exercises. As such, this report

also contributes to the goal of sharing best practices identified across jurisdictions. Further, it provides recommendations and methodological guidance on how to conduct a climate stress test step by step. This report can be considered as a follow-up to the Good Practice Guide to Climate Stress Testing published by UNEP FI in 2021, with the latest guidance based on the learnings from supervisory climate stress testing exercises conducted and with the integration of best practice examples from supervisors. Additionally, this report incorporates perspectives from the members of UNEP FI's Climate Stress Testing Working Group, which were gleaned through surveys and interviews. Finally, the report is accompanied by a supplementary document providing further guidance on data needs, collection and use for climate stress testing.

2. Elements of climate stress tests

2.1 Objectives of climate stress tests

Financial jurisdictions have outlined various objectives for conducting climate stress test exercises (Figure 5). As this area remains relatively new for financial authorities, most of the exercises are aimed at raising awareness about climate risks and mobilising climate action among financial institutions. Some of the key objectives identified across exercises include:

i. Assessing potential financial exposure to climate risk under various scenarios
ii. Enhancing climate risk assessment capabilities across financial institutions
iii. Understanding how to adjust business models in response to different scenarios

A few supervisors have indicated that their exercises could also support the formulation of climate-related government policies, such as national emissions reduction strategies and regional adaptation measures (FSB, 2022).

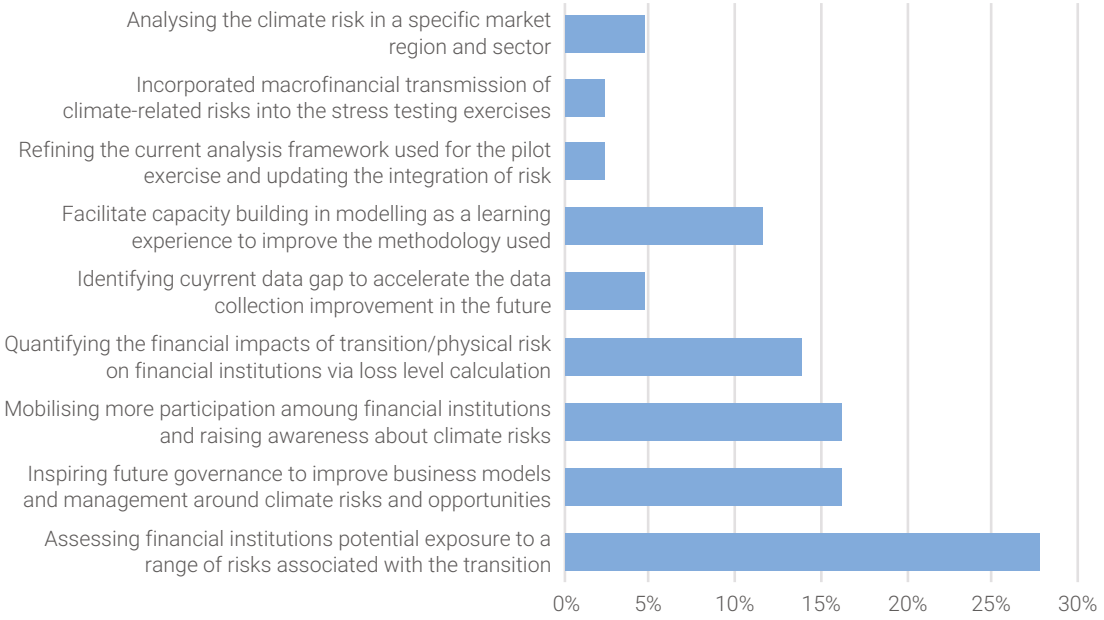


Figure 5: Main purposes of supervisory climate stress testing exercises

2.2 Climate scenarios

Use of the scenarios by the Network for Greening the Financial System (NGFS)

The majority of climate stress testing exercises featured in this report have used the scenarios by the Network for Greening the Financial System (NGFS) or plan to do so (see Table 3).

Created in 2017 by a group of central banks and supervisors, the NGFS aims to support stakeholders in strengthening the global response required to meet the goals of the Paris Agreement. In addition, it seeks to enhance the role of the financial system in managing risks and mobilising capital for green and low-carbon investments (NGFS, 2024). In this context, the NGFS defines and promotes best practices within and beyond its membership (NGFS, 2024).

Designed in partnership with an expert group of climate scientists and economists, the NGFS climate scenarios provide a common reference point for understanding how climate change, climate policy, and technological trends could evolve in the future.

Table 3: Overview of climate stress testing exercises and the NGFS scenarios used

Exercise	NGFS Scenario used for reference
Bank of England	Three scenarios built on the NHGS scenarios (Phase II): ▪ Net Zero 2050—Early action scenario ▪ Delayed transition—Late action scenario ▪ Current policies—No additional action scenario (BoE, 2022)
Australian Prudential Regulatory Authority	Two NGFS Scenarios (Phase II): ▪ Disorderly transition scenario—Delayed transition scenario ▪ Hot house world—Current policies scenario (APRA, 2021)
European Central Bank	Three NGFS scenarios (Phase II): ▪ Hot house world—Current policies scenario ▪ Orderly transition scenario—Net Zero 2050 ▪ Disorderly transition scenario—Delayed transition scenario (ECB, 2022a)
Banque de France	Three transition scenarios aligned to the NGFS scenarios (Phase I): ▪ Orderly transition scenario ▪ Disorderly transition pathway—Late transition scenario ▪ Disorderly transition pathway—Sudden transition (BdF, 2020a)
Hong Kong Monetary Authority	Two NGFS scenarios (Phase II): ▪ Orderly transition scenario—Net Zero 2050 ▪ Disorderly transition pathway—delayed transition scenario (HKMA, 2021)

Box 1: Overview of the NGFS scenarios

The NGFS released its first set of climate scenarios in 2020. Since then, the NGFS has updated its scenarios annually. They are now in their fourth vintage.

The NGFS scenarios framework characterises scenarios according to their respective implication on physical and transition risk pathways, as illustrated in Figure 6 below.

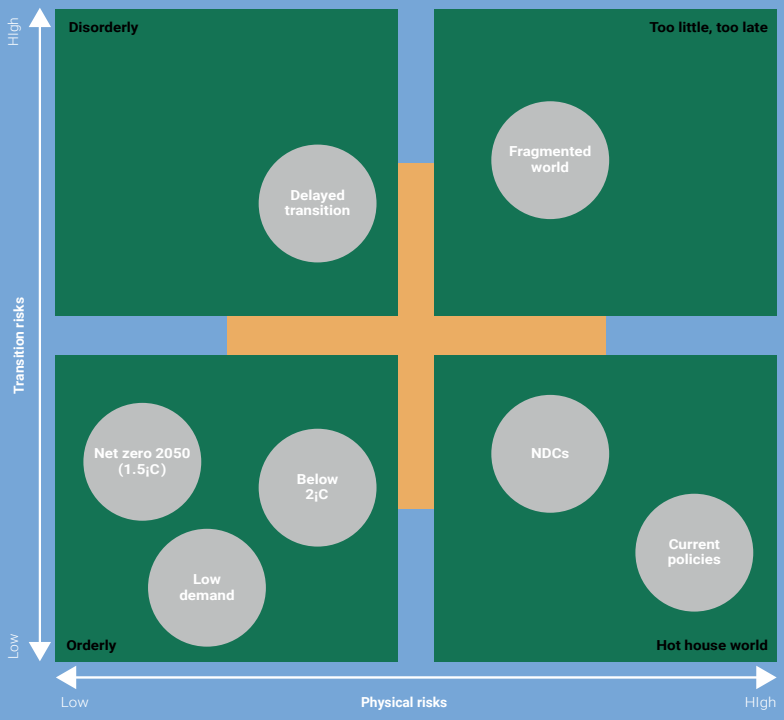


Figure 6: Overview of the NGFS scenarios framework in Phase IV (NGFS 2023a)

Each scenario is characterised by a specific level of physical and transition risks driven by policy ambition, timing, coordination, and technology levers (NGFS, 2023a). The NGFS Phase 4 scenarios can be summarised as follows (NGFS, 2023a):

- **Low demand** explores the global efforts needed to be able to limit global warming to below 1.5°C by 2050 in an orderly fashion, aligned with the Paris Agreement, driven by lower energy demand.
- **Net Zero 2050** limits global warming to 1.5°C through stringent climate policies and innovation, reaching global net zero CO_2 emissions around 2050.
- **Below 2°C** gradually increases the stringency of climate policies, giving a 67-per-cent chance of limiting global warming to below 2°C. Additionally, countries with net zero targets reach them partially (80 per cent of the target).
- **Delayed Transition** assumes annual emissions do not decrease until 2030. Strong policies are needed to limit warming to below 2°C.
- **Nationally Determined Contributions (NDCs)** includes all pledged targets even if not yet backed up by implemented effective policies.
- **Current Policies** assumes that only currently implemented policies are preserved, leading to high physical risks.
- **Fragmented World** assumes a delayed and divergent climate policy response among countries globally, leading to high physical and transition risks. Countries without zero targets follow current policies, while other countries achieve them only partially (80 per cent of the target).

Each scenario can be distinguished through a set of driving forces, as shown in Figure 7 below. These factors include policy ambition, policy timing, coordination, and technology levers (NGFS, 2022b).

Category	Scenario	End of century (peak) warning—model average	Policy reaction	Technology change	Carbon dioxide removal	Regional policy variation
Orderly	Low demand (NEW)	1.4°C (1.6°C)	Intermediate and smooth	Fast change	Medium use	Medium variation
	Net Zero 2050	1.4°C (1.6°C)	Intermediate and smooth	Fast change	Medi-um-high use	Medium variation
	Below 2°C	1.7°C (1.8°C)	Intermediate and smooth	Moderate change	Medium use	Low vari-ation
Disorderly	Delayed transition	1.7°C (1.8°C)	Delayed	Slow/fast change	Low-me-dium use	High vari-ation
Hot house world	Nationally Determined Contri-butions (NDCs)	2.4°C (2.4°C)	NDCs	Slow change	Low-me-dium use	Medium variation
	Current policies	2.9°C (2.9°C)	None current policies	Slow change	Low use	Low vari-ation
Too little, too late	Fragmented world (NEW)	2.3°C (2.3°C)	Delayed and fragmented	Slow/frag-mented change	Low-me-dium use	High vari-ation

Figure 7: Key drivers of NGFS Phase IV Scenarios (NGFS, 2023a)

According to an analysis of a set of supervisory exercises, the climate scenarios used fit within the hot house world, orderly transition, and disorderly transition categories. The most common scenario is the current policies scenario, followed by a delayed transition and a Net Zero 2050 scenario (Figure 8). The Current Policies scenario is the most adverse in terms of physical risks, while the Net Zero 2050 scenario reflects a relatively smooth transition to net zero emissions by 2050. In the Delayed Transition scenario, emissions are only reduced after 2030; as a result, they require more rapid adjustments, which results in higher costs than an orderly transition.

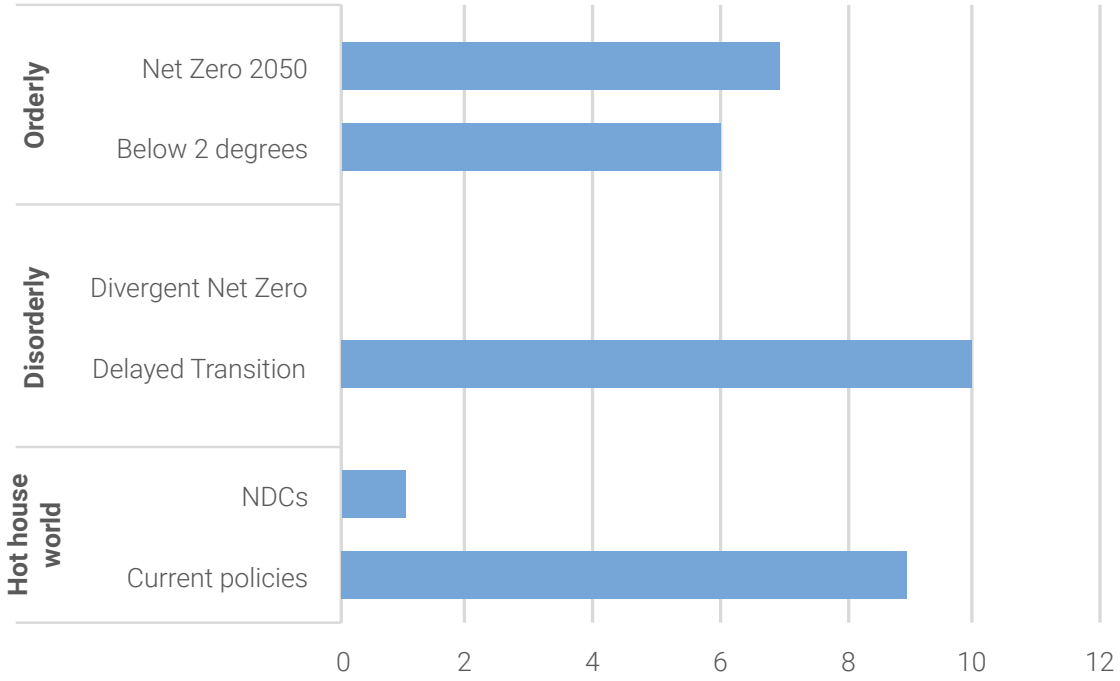


Figure 8: Use of NGFS scenarios reported in supervisory exercises[2]

Benefits and limitations of the NGFS scenarios

The NGFS climate scenarios offer several advantages, primarily in terms of consistency, comprehensiveness, and alignment with international climate goals. These advantages include, but are not limited to, the following:

1. Can be used globally, helping drive a more standardised approach to climate stress testing across institutions and jurisdictions and providing a common starting point.
2. Science-based scenarios aligned with international climate goals, enhancing their relevance and reliability for global financial stability.
3. Designed to be comprehensive, considering a wide range of both physical and transition risks.
4. Covers both acute and chronic physical risks with continuing enhancements in physical risk modelling.
5. Can model the behaviour of the energy, industrial, transportation, agriculture, and real estate sectors.
6. Updated on a regular basis to include the latest available data.

2 These scenarios have been identified from a sample of 23 climate stress testing exercises, which can be found in the appendix

However, the use of NGFS scenarios is not without limitations. Notable examples include:

1. The cost optimisation framework of the IAMs may not be appropriate for adequately assessing the stressfulness of a transition pathway.
2. Interplay between physical and transition risks and their feedback loops are not fully captured.
3. May not capture region-specific risks or unique characteristics of individual financial institutions, including particular regulatory requirements or priorities of a specific jurisdiction.
4. Not providing data in time steps of less than five years.
5. Sectoral coverage of certain sectors remains limited.
6. Do not model the economic consequences of climate tipping points.

Use of other types of scenarios

While NGFS scenarios remain a common choice for supervisors for their exercises, some jurisdictions have decided to use alternative scenarios. Their main reasons were to enhance the assessment of localised risks or to focus on specific risk factors (see Table 4). A large number of these supervisors have collaborated with the domestic meteorological office in their country to develop internal scenarios.

Table 4: Examples of internally developed scenarios by supervisors for their climate stress testing exercises

Exercise	Non-NGFS scenarios used
South African Reserve Bank	Used data from the South African Weather Service to internally build a drought scenario that banks were requested to use to estimate the impact of drought on their credit exposures per sector (SARB, 2021)
Banco de la República Colombia	Used a scenario developed by the Colombian Institute of Hydrology, Meteorology and Environment Studies (IDEAM) that projects change in precipitation until 2100 to assess the impact of physical risk (World Bank, 2021).
Hong Kong Monetary Authority	Developed a physical risk scenario based on climate projections of the Hong Kong Observatory in a scenario of high GHG concentration (HKMA, 2021)
De Netherlands Banke	Used four global scenarios in which the energy transition is disruptive: technology shock, double shock, confidence shock and policy shock (DNB, 2018)

Benefits and limitations of using internal scenarios

Opting not to use the NGFS scenarios and developing internal scenarios could provide benefits. Notable examples include:

- Flexibility to the design and scope of the exercise based on specific needs.
- Enhanced capacity to address local trends and vulnerabilities.
- Greater granularity of scenario analysis outputs

However, using internal scenarios can have limitations, such as:

- Reduced comparability and standardisation among jurisdictions.
- Restricted ability to perform cross-border assessments.
- Possible limitations to the financial industry's ability to address climate risks on a global scale.

The scenarios discussed in climate stress tests can be divided into physical risks and transition risks scenarios.

2.2.1 Physical risk scenarios

As part of a climate stress test, physical risk scenarios can model acute or chronic physical hazards across a time-horizon. Scenarios should include future physical risk settings that are challenging enough to explore potential futures that could result in outcomes significantly different from the current state.

Since Phase 3, climate scenarios by the NGFS have assessed acute risks and now cover four hazards—heatwaves, droughts, river floods, and cyclones—at the country level. Chronic physical risks are assessed using an aggregated damage function. One of the most common scenarios used to assess the impact of high physical risks is the Current Policy scenario by the NGFS. Physical risks in the scenario are estimated using the 95th percentile of the temperature distribution (NGFS, 2023b).

In a climate stress test, climate scenarios need to be translated into peril-specific scenarios for the country and/or region in focus in order to explore the potential impact of location-specific physical risks (NGFS, 2022a). For instance, in the guidelines published by the Hong Kong Monetary Authority (HKMA) for its 2023 climate stress test exercise, the supervisor incorporates a tailored scenario narrative of physical risks. This includes a region-based focus on frequent and prolonged precipitation and heatwaves in Hong Kong and mainland China (HKMA, 2023). Box 2 illustrates an example from the Bank of England (BoE) and its 2021 Climate Biennial Exploratory Scenario (CBES), showcasing the tailoring of the reference scenarios used to regional perils and increased severity to assess exposure to potential risks.

Box 2: Scenario generation for climate stress testing—the case of Climate Biennial Exploratory Scenario (CBES) (BoE, 2022)

To assess physical climate risk in its exercise, the BoE developed the scenario "No Additional Action Scenario" (warming limited to 3.3°C), based on the NGFS's Current Policies scenario. The BoE front-loaded the physical risks impact of the scenario from 2050–2080 to 2020–2050 in order to assess the impact of physical risks within the time-horizon of the exercise. The BoE included a table of physical hazards for a selected set of countries (Table 5). To enhance the specificity of the scenarios, the BoE incorporated data from various entities, such as the UK Met Office, NGFS and Oasis Hub, as well as from the academic literature. Participating institutions were also able to incorporate their own climate data, given it was consistent with the warming levels and the benchmarked data by the BoE.

Table 5: Physical risks by country in CBES (BoE, 2022)

Country	Inland flooding	Drought/ heatwave	Severe weather	Seal-level rise	Storm	Wildfire
UK	Yes	Yes		Yes	Yes	
China	Yes	Yes	Yes	Yes	Yes	
Japan	Yes			Yes	Yes	
Canada	Yes			Yes	Yes	Yes
EU	Yes	Yes	Yes	Yes	Yes	Yes
US	Yes	Yes	Yes	Yes	Yes	Yes
Taiwan	Yes			Yes	Yes	
Singapore				Yes	Yes	
Indonesia	Yes			Yes	Yes	
South Korea	Yes	Yes		Yes	Yes	
South Africa	Yes			Yes		
Mexico	Yes	Yes		Yes	Yes	
Russia	Yes					
Brazil	Yes			Yes	Yes	
Australia	Yes	Yes	Yes	Yes	Yes	Yes
Argentina	Yes			Yes	Yes	
India	Yes	Yes		Yes	Yes	

2.2.2 Transition risk scenarios

Transition risk scenarios model changes in regulations, policies, technologies, and consumer behaviour as the economy shifts to a low-carbon economy. While the NGFS scenarios have an implication on the transition risk levels, the disorderly scenarios capture the highest levels of transition risks.

As part of their exercises, supervisors have selected different drivers for their transition risk narratives. A large proportion of narratives focus mainly on carbon policies or technological changes. For example, the Deutsche Bundesbank adopted the average global carbon price as a proxy for the intensity of policymakers' efforts to mitigate climate change under different scenarios (DBB, 2021). Climate-related stress testing in Colombia, carried out by the International Monetary Fund (IMF), investigated the risks to the financial system based on scenarios of an increase in the carbon tax through the use of bank and firm-level data (IMF, 2021). Banco de España used the Sectoral Carbon Tax model (CATS)[3] to capture the impact of transition risks over time for its exercise (BdE,

3 The Sectoral Carbon Tax Model is linked to the Spanish economy and can simulate the effects of price shocks and GHG emission allowances. The model focuses particularly on sectoral asymmetries across the energy intensity of industries, the source of that energy, and the interdependencies between different industries (Aguilar et al., 2022).

2021). De Netherlands Banke included a technology shock scenario in its 2018 climate stress test (DNB, 2018).

2.2.3 The need for sufficiently stressful scenarios

In a traditional supervisory stress test, a severely adverse scenario is selected to assess the resilience of the institution and the finance sector as a whole to extreme, or even worst-case, plausible events that sit at the tail-end of the distribution. A similar approach needs to be adopted for climate stress tests to ensure risks are fully identified. At present, various levels of stress are modelled by integrated assessment models (IAMs). However, as IAMs are cost optimisation pathways, they are unable to fully capture extreme financial and economic impacts, acute physical risks, volatility, or sharp disruption events (CGFI, 2023). As a result, climate scenarios currently used do not reflect extreme, tail-risk events.

Using a spectrum of stress severity levels helps financial institutions better prepare for a range of possible future scenarios, ensuring that they are robust and adaptable in the face of varying climate-related challenges.

2.3 Data

Successful climate stress testing relies on the availability of robust data. Data for climate stress testing typically fall under either traditional financial data or climate data. However, data for climate stress testing, especially climate data, can pose challenges for many financial institutions.

To collect data, institutions need to identify data needs, understand the availability of data sources, implement industry standards, validate data, identify data gaps, and adapt institutional systems.

2.3.1 Financial data

Traditional financial data are well-known to institutions conducting traditional stress testing. These data include a variety of financial information that in turn enables the evaluation of portfolio-level or counterparty-level risk models. Types of financial data that must be collected for climate stress testing are described in Table 6 below.

2.3.2 Climate data

Climate-related data represent additional components that go beyond the traditional financial data but are required to complete the assessment. Table 7 below highlights the types of climate data that need to be collected for climate stress testing.

Table 6: Types of traditional macro-financial data required for climate stress testing (adapted from UNEP FI, 2021)

MACRO-FINANCIAL DATA

Data type	Data required	Data Sources	Examples
Portfolio data	▪ Portfolio composition by sector and geography ▪ Balance sheets composition ▪ Clients and counterparty data	▪ Internal systems ▪ Clients	The data template provided by the BoE as part of CBES included: ▪ Balance sheet actuals data ▪ Collective investments undertakings ▪ Deposits other than cash equivalent
Credit data	▪ Probability of Default (PD) ▪ Loss Given Default (LGD)	▪ Internal system ▪ External providers	The macroeconomic data used by the BdF reflects the paths published by the NGFS in September 2022. The main macroeconomic variables used were GDP, inflation and unemployment rate (BdF, 2023).
Macroeconomic data	▪ GDP, unemployment, population growth, inflation, (long- and short-term) interest rates, and exchange rates	▪ Official statistics ▪ Scenarios	The Bank of Canada (BoC) and the Office of the Superintendent of Financial Institutions (OSFI) used the Merton framework to generate the Probability of Default (PD) data for assessing the impact of climate transition risk drivers as part of their pilot exercise (BoC, 2022).
Forward-looking data	▪ Financial performance analysis, market data ▪ Macroeconomic forecasts and scenarios	▪ Internal systems ▪ Scenarios	Participating firms in the BoC's exercise selected a sample of borrowers from each of sector/segment and geography from their portfolio. Firms selected a minimum of five borrowers and estimated changes in credit ratings for each under transition scenarios (BoC, 2022).

Table 7: Types of climate-related data required for climate stress testing (adapted from UNEP FI, 2021)

CLIMATE-SPECIFIC DATA

Data type	Data required	Data Sources	Examples
Climate hazard data	▪ Historical data on acute and chronic physical risks. ▪ Projections of future acute and chronic physical risks, including their severity and frequency. ▪ Adaptive capacity data to determine client resilience and sensitivity to climate hazards, including current adaptation strategies of clients. ▪ Climate hazard data based on geography, sector and industry, including economic losses from past climate hazards.	▪ Scenarios ▪ Clients ▪ External providers	For CBES, participating insurers submitted asset information on related material physical hazards and the locations they apply to (BoE, 2021a)
Transition risk drivers data	▪ Data on transition risk drivers including policy implementation, market shifts, technological changes and reputation	▪ Scenarios	For its 2024 exercise, the Bank Negara Malaysia (BNM) will use a showdown carbon price which will be a proxy for (BNM, 2022): ▪ Policy intensity ▪ Climate policy ambition, implementation and distribution ▪ Technological changes
Emissions data	▪ Energy and carbon mix of counterparties. ▪ Published or estimated GHG emissions produced by portfolios and assets of clients. ▪ GHG emissions data by region, sector or industry. ▪ Energy efficiency data (e.g., Energy Performance Certificate Rating in real estate) ▪ Data on carbon pricing by jurisdiction.	▪ Clients ▪ External providers ▪ Internal systems	BNM conducted simulations of the following under different scenarios (BNM, 2022): ▪ Global and domestic energy prices ▪ Energy consumption by fuel type in Malaysia
Climate-related client data	▪ Identification of the physical assets owned by clients. ▪ Detailed and granular geographical/geolocational data of assets.	▪ Clients ▪ External providers	As part of ECB's supervisory exercise, firms were required to match the location of collateral (property) to flood risk based on a flood stress map provided by the supervisor (ECB, 2021a).
Alignment and transition data	▪ Transition pathways set by clients in accordance with the Paris Climate Change Agreement. ▪ Science-based emission reduction targets set by clients. ▪ Climate policies and pledges of countries.	▪ Clients ▪ External providers	Firms participating in HKMA's climate stress test were required to collect the following information of their clients: ▪ Carbon emission data ▪ Awareness climate-related issues ▪ Transition plan to a low-emission business model ▪ Track records in implementing the transition plan

2.4 Elements of a climate stress test

2.4.1 Participant type

To date, the majority of supervisory exercises have been targeted towards banks. Based on analysis conducted on a set of supervisory exercises[4], a large proportion of exercises (61 per cent) primarily focused on banks, with 30 per cent of exercises focused on both banks and insurers. Only 4 per cent of exercises focused on investment funds, banks, and insurers together, as well as just insurers. There are also a few exercises focused specifically on the impact on corporations, households, and the public sector. Covering different types of financial institutions in an exercise can help potentially capture spill-over effects and impacts of interactions between them.

Figure 9: Distribution of participant type across supervisory exercises

2.4.2 Risks covered

Climate stress tests are used to quantify potential financial risks driven by transition and physical risks. Based on analysis conducted on a set of supervisory exercises, 87 per cent of climate stress tests have in some way examined climate impacts on credit risk. Some exercises also examine the impact of climate change on other financial risks such as market risk (52 per cent), reputational risk (4 per cent), operational risk (13 per cent), sovereign risk (4 per cent), insurance risk (4 per cent), liquidity risk (4 per cent), and financial stability risk (9 per cent) (Figure 10).

4 These financial risks have been identified from a sample of 23 climate stress testing exercises, which can be found in the appendix.

Potential exposures to credit risk are determined by exploring the impacts of climate risks on its loan book. Market risks are explored to the potential impact of climate risks on a firm's trading portfolio. The assessment of reputation and operational risks in a climate stress test is often conducted through a qualitative questionnaire. Please refer to Section 2.5 for more information relevant to the qualitative portion of climate stress tests.

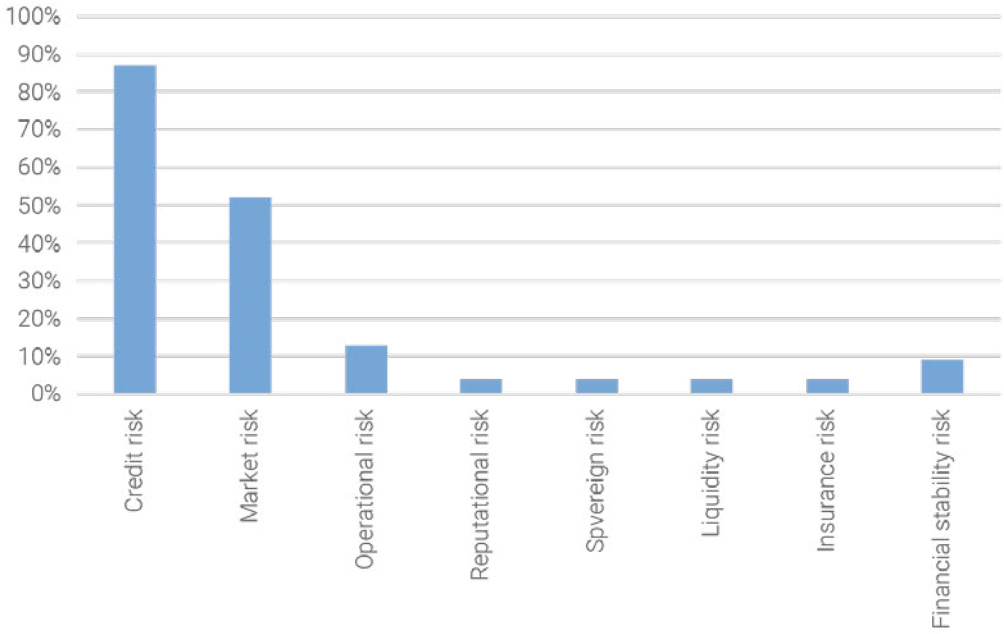


Figure 10: Main financial risks covered in climate stress testing exercises[5]

2.4.3 Risks metrics

The most commonly employed risk metrics for evaluating credit risk and assessing changes in market valuations include the Probability of Default (PD), Loss Given Default (LGD), and Exposure at Default (EAD). These metrics are often used to analyse credit exposures to specific geographical regions or sectors, as well as losses on investment portfolios. Based on analysis conducted on a set of supervisory exercises[6], PD was the most common metric used, with 83 per cent of exercises employing this as the main metric to analyse credit risk. Box 3 illustrates the use of PD by the Banco de España in 2021 (BdE, 2021).

Table 8: Examples of credit and market risk metrics used in supervisory exercises

Risk type	Metrics used
Credit	▪ Probability of Default (PD) ▪ Loss Given Default (LGD) ▪ Exposure at Default (EAD) ▪ NPLs (non-performing loans) ▪ Total increase in expected credit losses ▪ Transition-to-credit-risk intensity (TCI)

5 Ibid.
6 Ibid.

Market	▪ Change in net corporate bonds/equity positions ▪ Risk weighted asset ▪ Value of asset

Table 9: Examples of climate risk metrics used in supervisory exercises

Metrics used
▪ Loan to Value (LTV) ratios ▪ Probability of occurrence of disasters ▪ Loss Given Default (LGD) ▪ Probability of Default (PD) ▪ Exposure at Default (EAD) ▪ Non-Performing Loans (NPLs) ▪ Transition-to-credit-risk intensity (TCI) ▪ Capital adequacy ratios ▪ Emissions per Product (EP) ▪ Gross Emissions (EB) ▪ Export Participation (PE)

Box 3: Banco de España's approach to calculating credit risk (BdE, 2021)

Banco de España calculated the probabilities of default by economic sector. It did so by establishing a top-down framework to analyse the materialisation of risks stemming from the transition to a more sustainable economy over a three-year horizon.

The PD is calculated at the bank level for different economic sectors and business sizes. It takes into account associated businesses, the economic sector, and the group size across period of time. For simplicity, the economic sectors are grouped into industries. Banco de España calculated the average of the PDs of these sectors and used a logit link function[7] for the modelling.

The variables—growth of Gross Value Added (GVA), a vector of macro variables, and a vector of financial ratios—were used to model the PD for different banks, sectors, and sizes. GVA growth and macro variables were part of the scenarios, while financial ratios were generated internally.

7 Formula involving logarithms and exponential functions.

A logit link function is used in the PD modelling. Thus, PD is defined as:

$$pd^{*} = \ln(pd) - \ln(1 - pd) \quad [1]$$

With its inverse:

$$pd = \exp(pd^{*}) / (1 + \exp(pd^{*})) \quad [2]$$

Risk metrics can be further customised to capture the impact of physical or transition risks more holistically. For instance, the ECB and the European Systemic Risk Board developed two intensity metrics—namely, transition-to-credit risk intensity (TCI) and physical-to-credit risk intensity (PCI)—to assess the climate-related vulnerabilities of banks' loan exposures (ECB & ESRB, 2022). Both metrics were constructed by combining banks' loan exposures and borrower-level PDs, with borrower-level emissions data for TCI and with borrower-level physical risk scores to calculate PCI. By integrating financial data with climate-specific metrics, the ECB was able to better account for the interaction between climate risks and existing financial conditions (FSB, 2022).

Table 10 below provides examples of metrics that were used by the Deutsche Bundesbank to assess exposures of assets to rising climate risks (DBB, 2021).

Table 10: Metrics used by Deutsche Bundesbank for climate risk assessment (DBB, 2021)

Loan portfolios			
Metric	**Banks**		
Total in EUR billion	4,789		
Loan portfolios included in the scenario analyses (stressed portfolio), in EUR billion	2,452		
of which: percentage share of loans issues to transition-seneitive sectors	18.8		
Ratio of share of loans inssued to transition-seneitive sectors to the share in value added of these sectors	66.6		
Stressed portfolio as a percentage share of total loan portfolios	51		
Remaining term to maturity of loans in the stressed portfolio, in years	5 to 7		
Securities portfolios			
Metric	**Banks**	**Funds**	**Insurers**
Total in EUR billion	1,474	2,206	1,853
Securities portfolios included in the scenario analyses (stressed portfolio), in EUR billion	1,418	2,027	1,800
Stressed portflio as a percentage share of the securities portfolios of the respective financial sector	96	92	97
Remaining term to maturity of non-financial bonds in the stressed portfolio, in years	6.0	10.5	12.7

Stressed portfolio by asset class, percentage shares			
Government bonds	28	19	30
Non-financial bonds	3	12	9
of which: share attributable to transition-sensitive sectors	45	15	8
Ratio of share attritbutable to transition-sensitive sectors to the share in valye added of these sectors	150	53	27
Financial bonds	52	22	31
Stocks and participating interests	3	23	26
of which: share of attributable to transition-sensitive sectors	33	36	9
Ratio of share attributable to transition-sensitive sectors to the share in valye added of these sectors	117	126	32
Investment fund shares	14	25	4

Balance sheet assumptions

Balance sheet assumptions for a stress test can be grouped into two main categories:

- A **static** balance sheet assumption assumes that a firm's balance sheets do not change over time and that any changes in the balance sheet are the direct impact of the risks or opportunities that materialise in the scenario.
- A **dynamic** balance sheet assumption assumes that balance sheets change over time. Changes include alterations in the characteristics of the counterparty, divestments from existing counterparties, or investments in new counterparties.

Among the two types of balance sheet assumptions, the static balance sheet assumption has been more widely adopted by institutions for stress testing exercises. Benefits of using a static balance sheet assumption include:

- The need for fewer assumptions to be made, resulting in ease in implementing the assumptions.
- Greater data reliability and consistency.
- Enhanced alignment between participating institutions on addressing balance sheet assumptions.
- A reduction in the potential for underestimating financial impacts.

Example of a static balance sheet assumption: The US Federal Reserve Bank's 2023 Pilot Climate Scenario Analysis (CSA) Exercise used a static balance sheet assumption approach. Participants are expected to maintain the loan and/or facility characteristics of each exposure and keep the remaining maturity of each exposure constant throughout the projection period (Fed, 2023; Fed, 2024).

A few supervisors have chosen a dynamic balance sheet assumption. Benefits of a dynamic balance sheet include:

- A realistic view of the results, given that institutions' exposures will evolve over time in reality

- The ability to reflect how financing conditions could alter under a given scenario and thus the capacity to capture feedback loops between the financial sector and the real economy

However, drawbacks of a dynamic balance sheet assumption include that it can require more resources as it requires balance sheets to be projected forward. Many financial supervisors indicated that current data limitations represent a further shortcoming of dynamic balance sheet modelling.

Example of a dynamic balance sheet assumption: The ECB supervisory climate stress test in 2022 used the dynamic balance sheet assumption under the long-term transition risk scenarios, which allowed for balance sheet adjustments over the 30-year horizon. Consistent with the optimistic growth in gross domestic product (GDP) anticipated in the long-term projections, banks foresaw an expansion in their exposure to the 22 NACE[8] sectors analysed in the exercise.

2.4.4 Top-down and bottom-up approaches

Broadly speaking, supervisory climate stress testing exercises can be grouped into two approaches: bottom-up and top-down. There is significant variation between both approaches in terms of granularity, model outputs, and resources required.

- Bottom-up approach: The supervisor sets out common scenarios for financial institutions to use and a set of methodological rules. Financial institutions conduct analysis using the scenarios and feeding into it their internal data and models. The supervisor aggregates results from participating institutions.
  - The approach can involve institutions assessing the potential impact of climate risks at the asset or portfolio level to understand operational exposures.
- Top-down approach: The supervisor runs the exercise without financial institutions conducting any aspects of the exercise. The supervisor develops a set of scenarios and assesses the potential impact on financial institutions using its own data and models.
  - The approach assesses risk at a macroeconomic level, providing a holistic view.

Often the reasons cited for using a top-down approach include that it allows for a consistent methodology across financial institutions, with assumptions and parameters that can be easily adjusted. Top-down exercises are less resource-intensive. Bottom-up approaches are commonly chosen to gain insights into financial institutions' internal methods and their ability to assess climate risks and improve their climate scenario analysis capabilities. A bottom-up approach is also valuable for increasing institutions' awareness of the potential impacts of climate change.

8 The Nomenclature of Economic Activities is a four-digit classification of economic activities by the European Union.

Box 4: ECB top-down and bottom-up approaches for climate stress testing

Top-down: ECB's 2021 economy-wide climate stress test (ECB, 2021b)

The ECB's economy-wide climate stress test in 2021 adopted a top-down approach to implement a common scenario framework, relying exclusively on internal datasets and models. The method used in the exercise had been homogenously applied to all Euro area financial institutions that are part of the sample of the exercise. Figure 11 below illustrates the main elements of the ECB economy-wide climate stress test in 2021.

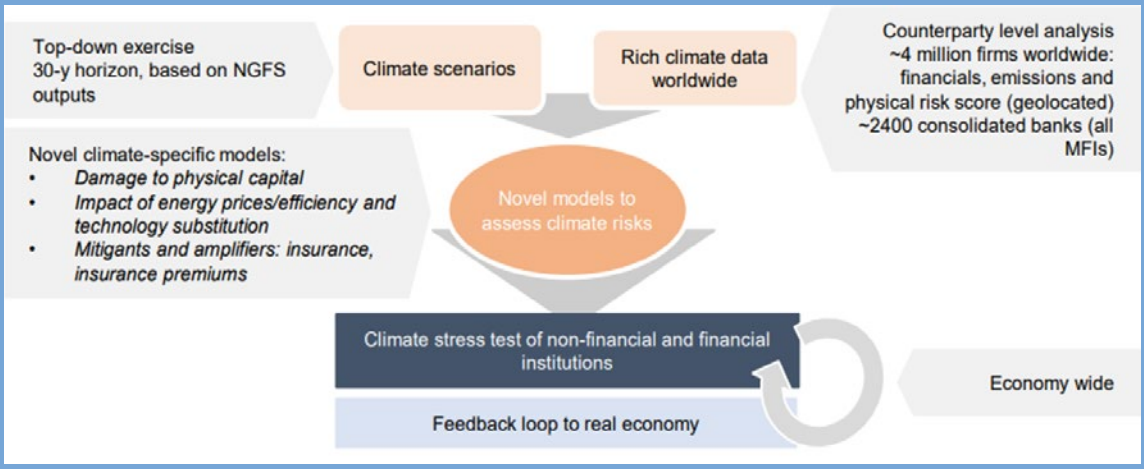


Figure 11: Key elements of the ECB's economy-wide climate stress test (ECB, 2021b)

Bottom-up: ECB's 2022 supervisory climate stress test (ECB, 2022b)

The 2022 supervisory exercise by the ECB followed a bottom-up approach whereby participating banks independently submitted their data and modelling outputs. It comprised three key modules:

Module 1 involved a qualitative questionnaire aimed at assessing banks' climate risk stress-testing capabilities.

Module 2 encompassed two climate risk metrics, examining the sensitivity banks' income to transition risk and their exposure to carbon-intensive industries.

Module 3 constituted the bottom-up stress test component.

2.4.5 Counterparty and portfolio level analysis

As part of a climate stress test, financial institutions can perform either a counterparty-level analysis or a portfolio-level analysis, or a combination of both.

- **Counterparty-level analysis:** Analysis is focused on assessing potential climate risks and opportunities of individual counterparties of the institution. Factors considered in the analysis can be geographical exposure of the counterparty and sectoral exposure, as well as the existence (or not) of any resiliency or transition plans by the counterparty. Results of the assessment can be used to inform decision-making regarding individual clients and exposure.
- **Portfolio-level analysis:** Analysis is focused on the potential impact of climate change on an entire portfolio, which can include a range of assets, investments, and financial products. The assessment provides an aggregated view of a combination of assets and exposures. The results of the assessment can be used to inform firm-wide strategy.

2.4.6 Short-term and long-term horizons

Many supervisors have typically adopted a 30-year time-horizon for their exercises. The long-term horizon allows the examination of the gradual changes in climate behaviour, advancements in technologies, and the decarbonisation of global energy systems. However, an extended time frame can result in significant uncertainties in macroeconomic projections and financial impacts.

A growing number of supervisors have begun incorporating scenarios with shorter time horizons into their exercises. The use of short time horizons can help align climate stress tests to the time horizons (i.e. two to five years) traditionally used at financial institutions for capital and strategic planning. Historically, firms have used time horizons spanning two to five years (or shorter) for traditional stress tests.

Supervisory exercises that encompass both short- and long-term horizons are beneficial for evaluating the long-term effects of climate change, climate goals, and targets. Additionally, they help assess short-term threats to financial stability and the level of institutional preparedness.

Box 5: Short-term and long-term scenarios depicted in the 2023–2024 Climate Risk Stress Test Guidelines of the Hong Kong Monetary Authority (HKMA, 2023)

Short-term scenario

Over a five-year time-horizon, the short-term scenario features a downturn in the global economy, an accelerated transition and an increase in the frequency of extreme climate events. In this scenario, Hong Kong slips into a recession and the economic growth experienced by mainland China in the recent past starts to decrease.

Physical risk: Hong Kong suffers from severe precipitation and cyclones that could cause sufficient damages to properties. These occur more often than they have historically. Between 2023 and 2027, a number of extreme climate events occur.

Transition risk: Considerable investments are made in renewable energy sources and emission-reduction technologies, such as carbon capture and storage. However, there are limited breakthroughs in new technologies. Phasing out coal is more urgent than the phase-out of oil and gas. There is a significant gap between the supply of green energy and power demand, which results in an increase in oil and gas prices over the time-horizon. Mainland China reduces its emissions by 54 per cent.

Long-term

Below 2 degrees scenario: Global collective efforts are promptly implemented to decrease GHG emissions to restrict global warming to less than 2°C. The carbon price gradually rises from 2023 to 2050. Early and ongoing policy measures lead to manageable physical and transition risks. While there is a brief adjustment in the global economy during the transition, long-term benefits include sustainable productivity.

Delayed transition scenario: Climate policies are delayed until 2030, necessitating robust and stringent measures to limit global warming to below 2°C. These policies result in a significant increase in carbon prices, negatively impacting economic growth. Inflation pressures persist in the 2030s due to a shortage of alternatives for traditional energies following the policy implementation.

Current policies scenario: Existing transition policies, enacted before the end of 2022, remain unchanged with no additional new measures introduced. Emissions persistently increase until 2080, resulting in global warming surpassing 3°C by the century's end and a substantial rise in physical risk. Over time, productivity and economic activities are progressively hampered by more severe and frequent climate hazards, accompanied by irreversible changes in climate patterns.

Physical risk: The impact of physical risk under the current policies scenario severely affects Hong Kong, which becomes negatively impacted by an increase in mean air temperature and significant sea level rise. Along with increase in precipitation and cyclones, these impacts pose far greater threats to Hong Kong than all other climate events in the country's history.

2.4.7 Modelling approaches

Different financial institutions have come up with a wide variety of approaches to model climate risks. The Financial Services Agency (FSA) and the Bank of Japan (BOJ), for example, have utilised risk models previously used to assess disasters. By using NGFS scenarios combined with the intensified magnitude of studied disasters, they were able to evaluate the impact of physical risks on insurance claim payments (Financial Services). Some institutions are developing in-house models, while others are acquiring models externally. In some jurisdictions, authorities have joined forces to develop methodologies for climate scenario analysis. A good example is a joint project launched in 2020 by the Bank of Canada (BOC) and the Office of the Superintendent of Financial Institutions (OSFI). Along with six supervised Canadian financial institutions, the two organisations conducted an exercise to improve the understanding of climate risks. However, many gaps remain in the modelling methodologies for a climate stress test.

Overall, the modelling process for a climate stress test consists of the following main steps: modelling climate variables; measuring the impact of climate risks on macroeconomic variables; breaking down the macroeconomic impacts to the sectoral or portfolio-level; and quantifying the impact on the financial institution. The modelling approach involves combining different models that were not designed to be used together. These models include:

- **Climate scenario models** to project pathways for selected physical and transition risk variables.
- **Macroeconomic models** to translate climate variables from the climate model to selected macroeconomic variables.
- **Sectoral and portfolio models** to break down the macroeconomic impacts down to the level of individual sectors.
- **Financial models** to calculate a bank's exposures to climate risks. Internal models can be used to assess changes in metrics.

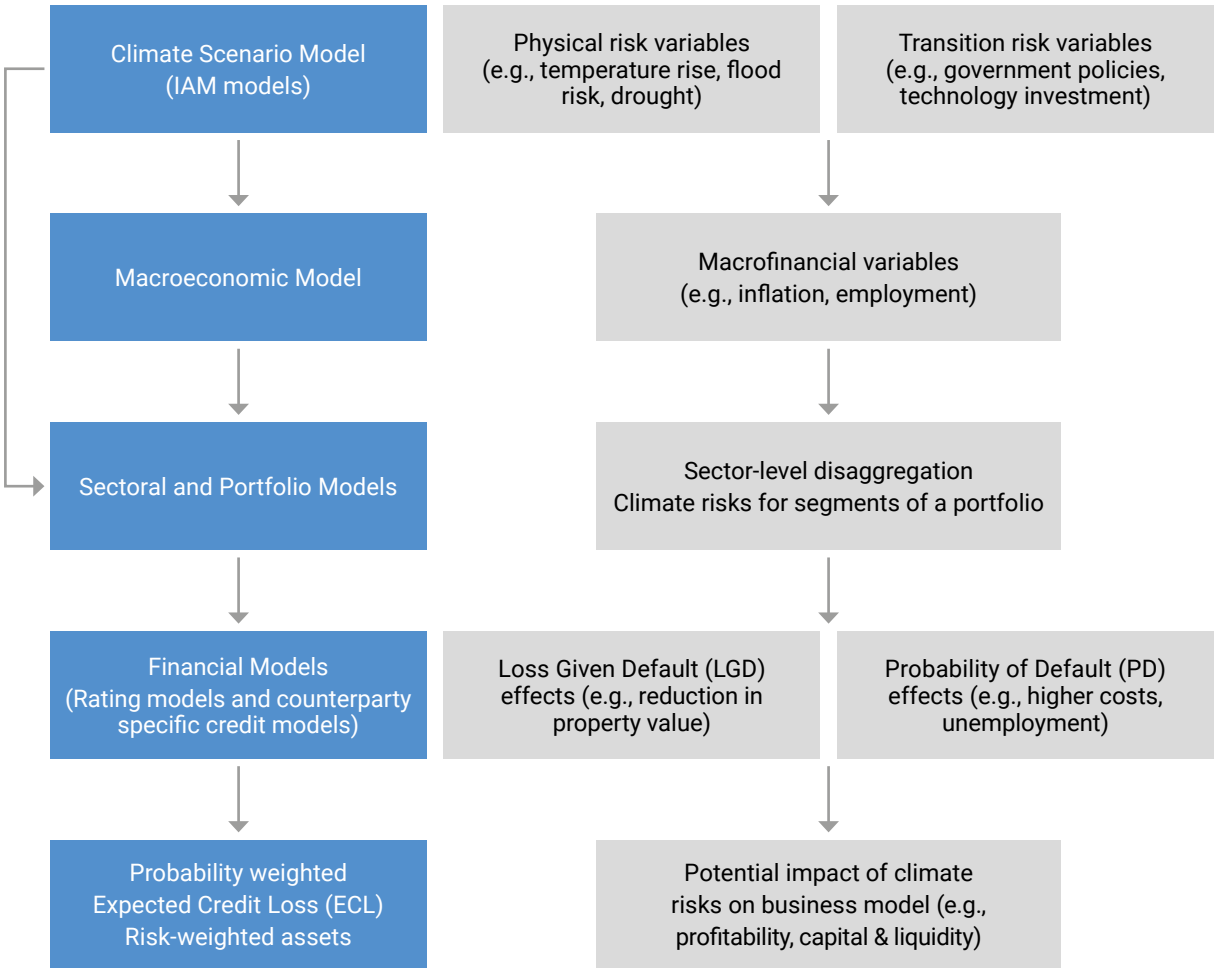


Figure 12: Climate stress testing modelling framework (UNEP FI, 2021)

Climate Scenario Models

IAMs are commonly used by the finance sector in climate stress testing due to their ability to describe the interactions between economic activity, emissions, and the climate system. A 'suite' of IAMs have contributed to the generation of the NGFS scenarios, comprising three well-known IAMs: GCAM, MESSAGEix-GLOBIOM, and REMIND-MAgPIE (Table 9).

REMIND and MESSAGE, two widely used models, are general equilibrium models. REMIND has been designed to identify the optimal mix of investments in the economy and the energy sectors. This model takes into account factors like population size, available technology, policies in place, and climate conditions. REMIND also considers regional trade, energy sources, and emissions allowances. REMIND calculates optimal mitigation strategies with representations of technology scale-up and integration constraints in the power sector. The model uses historical data, such as population size, economic output, energy use, and pollution levels, as well as future projections for advancements in technology and changes in prices (NGFS, 2023a). REMIND has been adopted by many financial institutions, such as the Financial Services Agency (FSA) and the Bank of Japan (BOJ), to study the effects of climate change in the energy sector, especially electricity and fuel prices.

MESSAGE consists of a combination of five different modules: an energy model; a land-use model; an air pollution and GHG model; an aggregated macro-economic model; and a simplified climate model. The MESSAGEix-GLOBIOM model is a detailed technology-oriented optimisation model for energy engineering. Model inputs include GDP and population, energy resources, rate of energy conversion rates, end-use of energy and energy demand, technological advancements, fuel blending, policy modelling, macro-economic factors, land use, and emissions. The model generates key outputs, including regional and country-level data on emissions, land use, prices, and quantities (NGFS, 2023a). Deutsche Bundesbank used MESSAGE for its assessment, citing the model's country-specific energy demand analysis to scale down output variables.

GCAM is a global market equilibrium model that assesses the impacts of different policy scenarios and technology choices on various aspects, such as energy use, land use change, emissions, and climate change. While the model's components aim to capture the behaviour of both human and physical systems, they may not include highly detailed process-scale representations of these components. However, the model components generally offer a reliable representation based on the best current scientific understanding of underlying behaviours. In GCAM, decision-making by actors may not always align with the broader social perspective, as these actors might make choices based on limited information about the future. Key inputs include macroeconomic factors such as population, labour productivity and GDP, CO_2 concentrations, radiative forcing of emissions, global temperature change, historical land use and land cover, vegetation and soil carbon density, electricity, livestock, primary energy, water use, sector-level emissions and activity, energy production and consumption, and the energy supply and demand for all energy commodities. The model produces various outputs related to emissions, land use, prices, and quantities (NGFS, 2023a). OSFI adopted the GCAM model due to Canada's macroeconomic environment and its unique geography within North America. Australian Prudential Regulation Authority (APRA) used GCAM to assess a high number of discrete regions.

Although the three IAMs share similarities, each has its own set of assumptions and coverage that can influence an exercise's outputs.

Table 9: Overview of mitigation options in GCAM, MESSAGE, and REMIND (IAMC, 2023; EPA, 2019; NGFS, 2021b; NGFS, 2023a)

	GCAM	MESSAGEix-GLOBIOM	REMIND-MAgPIE
Institution developed the IAM	Pacific Northwest National Laboratory	International Institute for Applied Systems Analysis (IIASA), Austria	Potsdam Institute for Climate Impact Research (PIK), Germany
Time steps	5-year time steps	10-year time steps	5 (2005–2060) and 10 years (2060–2100)
Time-horizon	2100	2100	2100

	GCAM	MESSAGEix-GLOBIOM	REMIND-MAgPIE
Sectoral breakdowns provided	Buildings, Industry (Cement, Chemicals, Steel, Non-ferrous metals, Other), Transport	Energy, Buildings, Industry, Transport	Buildings, Industry (Cement, Chemicals, Steel, Other), Transport, Energy
Regional coverage	32 modelled regions (highest regional granularity)	12 modelled regions (optimised scenarios under constraints)	12 modelled regions (optimised scenarios under constraints)
Carbon price assumption	Endogenous	Endogenous	Endogenous
Technological assumptions	Exogenous	Exogenous	Endogenous
Behavioural change assumptions	No	Yes	No
Variable coverage	Energy system, Agriculture and land use, Water, Emissions	Energy, Land use, Air pollution and GHGs, Macroeconomic model, Simple climate model	Agriculture, Land-use, Energy, Water and Climate systems

Macroeconomic Models

As stated, NiGEM and G-Cubed models are two macroeconomic models that are being widely used in climate stress testing.

NiGEM is a global econometric model that includes individual country and regional models linked through trade in goods and services and integrated capital markets. Key behavioural equations are econometrically estimated and reflect historical relationships between macro-level variables. The climate module of NiGEM is used to understand the interactions between the macroeconomy, climate shocks, and climate-related policy (UNEP FI, 2021). NiGEM includes endogenous policy responses from both the fiscal and monetary authorities for each region (NGFS, 2021a). One of the main advantages of NiGEM is that it allows the determination of economic and financial impacts on banks' international exposures (which is of crucial importance for banks holding multi-regional assets) as well as exposures at the country level. The French Prudential and Supervision and Resolution Authority (ACPR), BoE, and DNB have used or are currently using the NiGEM multi-country model for their climate stress test exercises (BIS, 2021). In their 2018 energy transition risk stress test, for instance, the DNB emphasised that "using a multi-country model allows us to take account of the fact that energy transition risks can have global impacts. Given the international exposures of financial institutions in the Netherlands, global simulations are more relevant than simulations from a model that considers only the Dutch economy". Figure 13 illustrates the use of the NiGEM model to generate macroeconomic outputs, which can serve as inputs into the supervisor's top-down models. However, a key limitation of such models is that they were not initially designed to simulate the structural economic shifts that could occur from the transition. These models generally make assumptions using estimate coefficients based on historical data that assume that economic relationships are stable over time and use estimate coefficients (DNB, 2018).

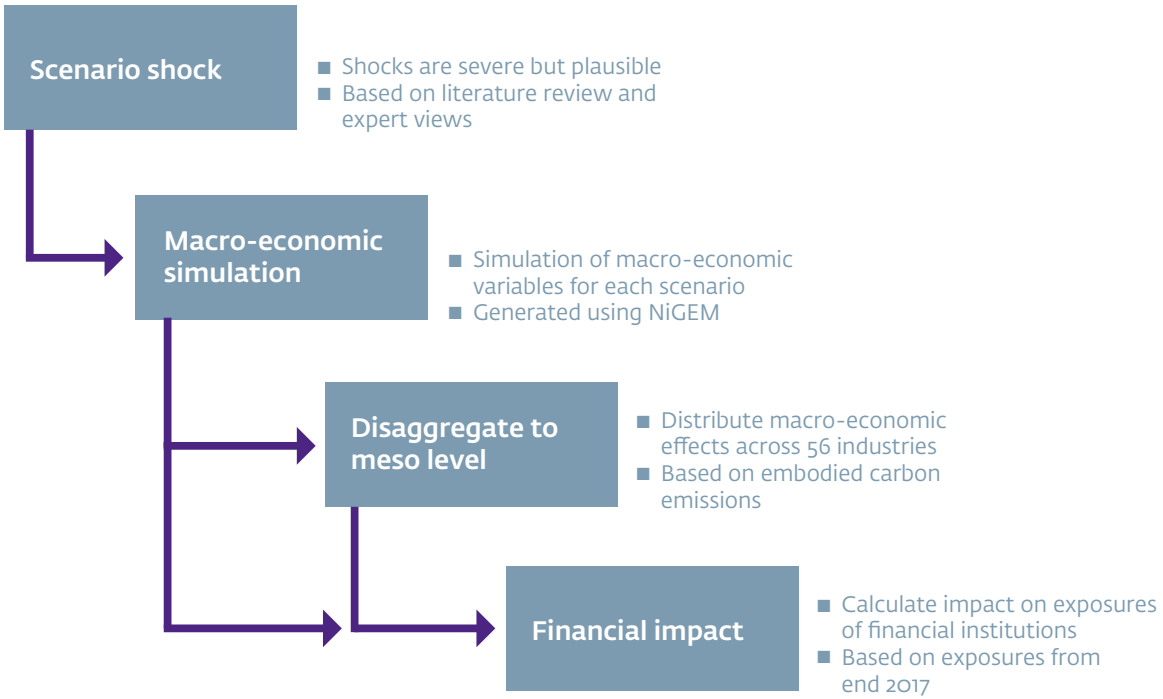


Figure 13: DNB step-based approach to climate stress testing (DNB, 2018)

Another alternative macroeconomic model is G-Cubed, a multi-country, multi-sector, intertemporal general equilibrium model developed by McKibbin and Wilcox (NGFS, 2022c). G-Cubed is designed to bridge the gaps between econometric general-equilibrium modelling, international trade theory, and modern macroeconomics. A set of variables are available for use, including inflation, interest rates, exchange rates, unemployment, and financial valuation, as well as options for monetary and fiscal policy responses. The model also provides a detailed regional and sectoral breakdown, which comprises one of its main advantages. The Climate Vulnerability Assessment (CVA) run by APRA in 2022 adopted the G-Cubed model due to its coverage of Australia and 20 sectors (later extended to 43 sectors). However, participating institutions had to undertake additional considerations for certain sectors, such as the agriculture sector and some sub-sectors of the manufacturing and transport sectors, as the model does not cover non-CO_2 emissions. Specific modelling inputs and decisions of the 2022 CVA have been summarised in the following tables (APRA, 2022a).

Table 11: G-Cubed parameters for Australia-focused economic modelling

Sector resolution	International
	Australia
Region resolution	International
	Australia
Timesteps	Global
Emissions pathway	Global

Electricity sector	Global
Technology costs	Global
Shared Socioeconomic Pathway (SSP)	Global

Table 12: Comparison of the NiGEM and G-Cubed macroeconomic models

	NiGEM	G-Cubed
Institution developed the macroeconomic model	National Institute of Economic and Social Research	Warwick McKibbin and Peter Wilcoxen
Time-horizon	2050 (UNEP FI, 2021)	2050 (NGFS, 2022c)
Sectoral breakdowns provided	No sectoral breakdowns	Aggregated 20 sectors, including Electricity delivery, Gas extraction and utilities, Petroleum refining, Transportation, Agriculture and forestry, among others.
Regional coverage	38 OECD countries, as well as Argentina, Brazil, Bulgaria, China, Croatia, Hong Kong, India, Malaysia, Romania, Russian Federation, South Africa, Taiwan. Separate regional blocs for the rest of the world.	Covers all countries, 11 regions in the most recent version of the model. (G-Cubed Python, 2023)
Carbon price assumption	Exogenous	Exogenous, Endogenous
Behavioural change assumptions	Incorporated forward-looking Dynamic Stochastic General Equilibrium (DSGE) models.	An increase in carbon prices causes a substitution in the energy sectors away from carbon-intensive energy inputs, shifting the behaviour of all economic actors in all sectors in all countries.
Variable coverage	GDP, inflation, consumption, investment, exports, imports, interest rates, exchange rates, equity prices.	Inflation, interest rates, exchange rates, unemployment, financial valuation, and several options for monetary and fiscal policy responses (NGFS, 2022c).
Examples	De Nederlandsche Bank (DNB, 2018), Banque de France (BdF, 2020b)	Australian Prudential Regulation Authority (APRA, 2021a)

Box 6: BoC and OSFI Modelling Approach

BoC and OSFI employed a different modelling approach compared to other supervisors. They integrated a computable general equilibrium energy-economy model with two macroeconomic models (BoC, 2022b). Collaborating with MIT, the Bank utilised the MIT-EPPA model for sectoral-level analysis, which incorporates global economic dynamics, GHG emissions, and advanced technology assumptions. The model was used in the pilot exercise to assess market and credit risks for sectors in the pilot exercise.

To contextualise sector-level analysis within a larger macroeconomic framework, the Bank employed two of its own models; the Terms-of-Trade Economic Model (ToTEM III) for the Canadian economy, and the Bank of Canada's (BoC) Global Economy Model with Financial Frictions (BoC-GEM-Fin) for the global economy. These models are dynamic, stochastic, general equilibrium frameworks that consider the behaviour of firms and households and incorporate carbon pricing policies (BoC, 2022b).

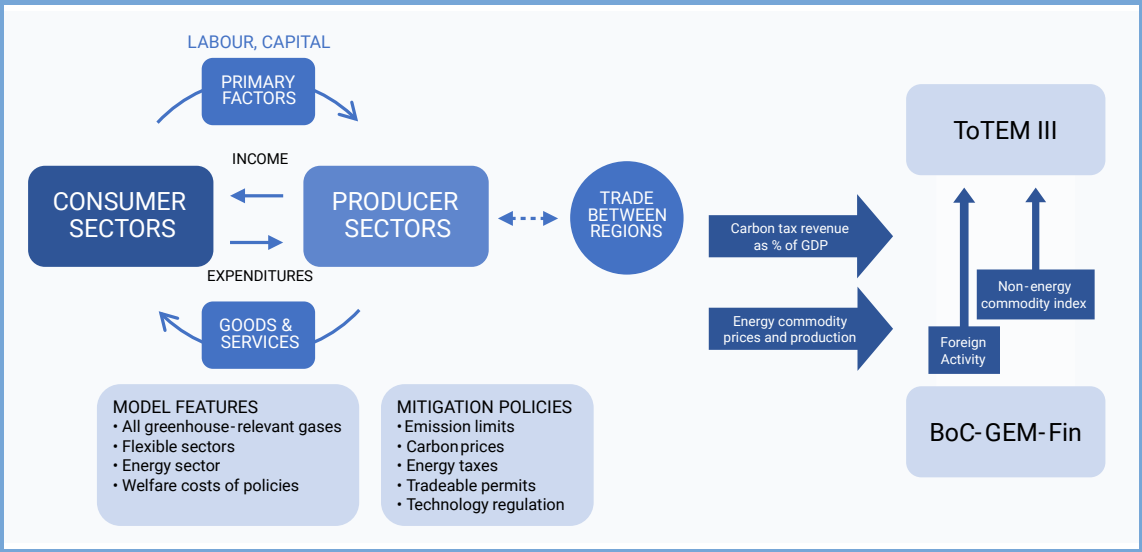


Figure 14: Overview of OSFI and BoC modelling approach (BoC, 2022b)

2.5 Narrative (qualitative) portion

A growing number of supervisors are introducing a narrative portion to their exercises in the form of a qualitative questionnaire to primarily understand challenges to participants' business models from climate-related risks. Other driving motivations include gaining information on operational and reputational risks, the size of participants' management actions, and understanding how participants will improve their risk management of climate-related risks. Some key exercises that included qualitative questionnaires include the ECB's 2022 Supervisory Climate Stress Test, BoE's 2021 Climate Biennial Exploratory Scenario (CBES), Hong Kong Monetary Authority's 2023–2024 Banking Sector Climate Risk Stress Test, and the Monetary Authority of Singapore's 2022 Industry-wide climate stress test (IWST).

The narrative portion can focus on an institution's approach to managing climate risks through its transition plans and commitments, including the strategies and policies that it has in place and the progress towards achieving associated targets. The questionnaire can also explore the integration of climate considerations into investment strategies, the creation of climate-related targets across different business units, the inclusion of climate change in the firm's strategy, the level of reporting to the board, and the incorporation of climate risks into the organisation's risk management framework.

The qualitative questionnaire often covers the following:

- Climate risks identified that the institution is the most exposed to.
- Participants' qualitative views of climate-related risks, such as risks and opportunities from climate change, operational risks, and climate litigation risks.
- Participants' approach to estimating exposure, including questions on the methodology (e.g. concerning data templates, judgements, overlays, and scenario expansion).
- Participants' current risk management practices with respect to climate change.
- Management actions in relation to the results of the exercise and further plans to enhance climate risk management at the firm.

Table 13 below showcases an excerpt of the questions from the BoE's CBES questionnaire to gather information on the narrative aspects of the participants' climate stress test approaches (BoE, 2021c).

Table 13: Excerpt from the BoE's qualitative questionnaire (BoE, 2021b)

Section	Category	Respondents	Question
A. Results and narrative	Results	Banks and insurers	Provide a brief overarching narrative describing the projected results in each scenario. Highlight key vulnerabilities and tipping points over the projection period.
A. Results and narrative	Results	Banks and insurers	Which climate-related risk drivers are your results most sensitive to? Provide a rationale for your answers. In your answers, you might consider both direct impacts from physical damage and regulation on your exposures, as well as indirect impacts (e.g. supply chain disruption or consumer pressures, etc.).
A. Results and narrative	Results	Banks and insurers	Describe your internal governance and processes for responding to this exercise highlighting: ▪ Committees that considered and approved your responses ▪ Key issues that were challenged by committees and changes that were made in response to these ▪ Your quality assurance process Provide documents to evidence what was discussed with senior committees e.g. relevant slide decks, minutes or annotated agendas.
A. Results and narrative	Results	Banks and insurers	Highlight any potentially counter-intuitive projections results, and their explanations.

Table 14 below offers an excerpt of the qualitative assessment questionnaire of the ECB's 2022 climate risk stress test (ECB, 2022c).

Table 14: Excerpt of the ECB's qualitative assessment questionnaire (ECB, 2022c)

#	Question
1	Is climate risk currently included in the institution's stress test framework?
1	Indicate if Yes: Yes, as a portfolio-level stress test
1	Indicate if Yes: Yes, as a sensitivity analysis
1	Indicate if Yes: Yes, as a scenario analysis
#	**If you answered "No" to Question 1:**
2	Is the institution planning to include climate risk scenario analysis in its stress test framework?
2.1	Inclusion of transition risk in the ST framework
2.2	Inclusion of physical risk in the ST framework
3	What is the main reason why the institution does not include climate risk in its stress test framework?
4	If you answered "Data availability" to Question 3, in what part of the functioning of the institution's climate risk stress test framework is data availability a limiting factor?
5	What steps will the institution take to respond to the data availability challenges identified in Question 3?
5	Staff recruitment
5	Internal training and data enhancement activities
5	Improve data collection from counterparties
5	Engage with data providers
5	Other, please specify […]
#	**Questions**
6	Does the institution take into account climate-related factors in other processes? If Yes please indicate below:
6	Yes, for pricing
6	Yes, for credit approval
6	Yes, others, please specify […]
7	Does the institution have a reverse climate risk stress test framework in line with the definition set out in the EBA Guidelines on institutions' stress testing?
7	Indicate if Yes: Including a total GHG emission target
7	Indicate if Yes: Including a CO_2 emission target
7	Indicate if Yes: Including a Paris Agreement target
7	Indicate if Yes: Other, please specify […]
7	Indicate if No:

3. Overview of supervisory practices

3.1 Physical risk climate stress tests

3.1.1 Key characteristics of a physical risk climate stress test

Objective

- Quantify physical event-related financial stability risks.
- Assess the vulnerability of sectors to short-term and long-term physical hazards in a given region.
- Identify exposure to assets and regions and assess potential losses to physical risks.
- Adjust the institution's risk management strategy and business model.
- Quantify the impact of credit risk on financial institutions.

Horizon

- Acute physical risk—short-term horizon, usually between one and three years
- Chronic and acute physical risks; long-term horizon, typically 20–30 years, in some exercises, longer time periods to 2080–2100

Bottom-up/top-down approach:

- Both bottom-up and top-down approaches are frequently used

Risk covered

- Credit risk (qualitative and quantitative)
- Operational risk (qualitative)
- Market risk (qualitative and quantitative)
- Funding risks (quantitative)
- Liquidity risk (qualitative and quantitative)
- Reputational risks (qualitative)
- Environmental risks (qualitative)
- Insurance risks (quantitative)

Physical hazards covered

- Flooding
- Drought
- Sea level rise
- Heatwaves
- Cyclone storms

- Rising average temperatures
- Severe Wind
- Precipitation

Climate scenarios used

- The NGFS scenarios are most commonly used by supervisors to assess physical risk.
- Physical risk scenarios can also be internally developed to assess physical risk.

Selected metrics

- Loan to Value (LTV) ratios
- Probability of occurrence of disasters
- Loss Given Default (LGD)
- Probability of Default (PD)
- Exposure at Default (EAD)
- Carbon Price
- Non-Performing Loans (NPLs)

3.1.2 Case studies

Physical climate stress test by the DNB on flood risk in the Netherlands (DNB, 2021)

In 2021, the DeNederlanscheBank (DNB) published a working paper detailing the methodology and results of their standalone climate stress test exercise, which aimed to analyse the financial impact of climate change-driven flooding on the Dutch banking sector.

Objectives

- Analyse the plausible financial impact of climate change driven flooding on the Dutch banking system.
- Focus on the real-estate sector and the banking sector as a whole.
- Assessment of flood risks under extreme scenarios with low probabilities of occurring using a reverse stress test.

Approach

- A top-down stress-test model and a static balance sheet assumption.
- Adaptation of a standard methodology for stress testing by incorporating flood risk.
- Mapping of the narratives of the six scenarios used to economic conditions, including property damage. Linking accounting data for corporations and industry-level emission data with credit register data for bank lending to calculate corporate default probabilities.
- Configuration of the exercise to a granularity level of a four-digit postcode.

Horizon

- One year

Financial risks covered

- Credit risk
- Market risk

Physical risks covered

- Flooding

Climate scenarios used

- Internally developed six flood risk scenarios

Selected metrics

- PD
- LGD
- NL equities
- CET1-ratio

Results

- The Dutch banking sector has sufficient capital to withstand flood risk but severe flooding in certain parts of the country could lead to capital depletions.
- The risk of flooding is more extreme in densely-populated regions of the country, where the exposure is substantial.
- In some flooding scenarios, the decline in capital is not negligible but is not as large as the results of traditional stress tests.

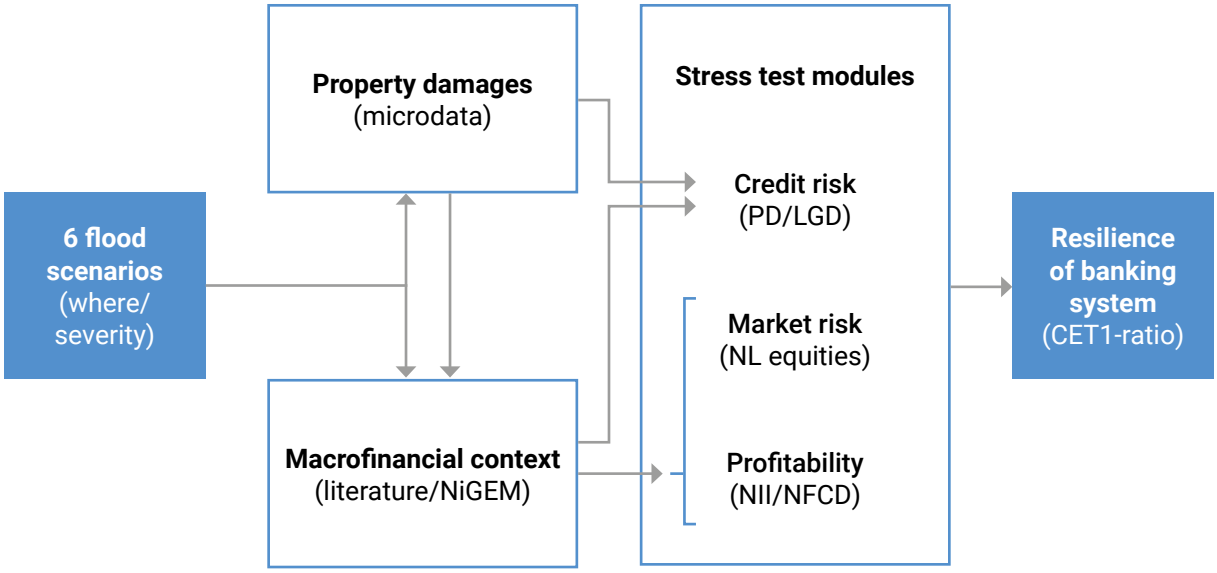


Figure 15: Top-down framework to assess flood risk by the DNB (DNB, 2021)

South African Reserve Bank's stress test on drought (SARB, 2021)

As part of its 2021 Common Scenario Stress Test (CSST), the South African Reserve Bank (SARB) incorporated a climate scenario into its macroprudential stress testing framework. This focused on assessing the potential adverse effect of climate change-driven drought. The results of the exercise were published in the 2021 financial stability review (2nd edition).

Objectives

- Assess the effect of drought on sensitive sectors.
- Determine improvements in climate risk assessment methodologies.

Approach

- A bottom-up approach
- SARB used data from the South African Weather Service to create a drought scenario that was in line with historical patterns. Banks had to estimate how this drought scenario would affect their loans for various sectors. Participants also had to assess the creditworthiness of the government because it might have to help sectors vulnerable to droughts.

Horizon

- Three years

Financial risks covered

- Credit risk

Physical risks covered

- Drought

Climate scenarios used

- Internally developed drought scenario

Selected metrics

- PD
- NPL
- CET1
- CAR

Results

- In comparison to SARB's adverse scenario as part of its CSST, the drought scenario resulted in the CET1 and CAR declining by about 30 basis points relative to the adverse scenario (SARB, 2022).

3.2 Transition risk climate stress tests

3.2.1 Key characteristics of a transition risk climate stress test

Objectives

- Assessing the impact of transition risks on the banking sector.
- Study the possible changes in regulation, technology, or behaviour resulting from transitioning to a low-carbon economy.
- Developing climate stress tests that consider future climate policies.
- Creating awareness of climate risks in financial institutions.

Horizon

- Short-term transition shocks, usually between three to five years.
- Long-term transition risks, usually between typically 20–30 years.

Bottom-up/top-down approach

- Both bottom-up and top-down approaches are frequently used

Financial risks covered

- Credit risk (qualitative and quantitative)
- Market risk (qualitative and quantitative)
- Sovereign risk (qualitative)
- Liquidity risk (qualitative
- Operational risk (qualitative)
- Insurance risk (quantitative)

Transition risks covered

- Policy and regulation
- Technology development
- Consumer preference

Climate scenarios used

- The NGFS scenarios are most commonly used by supervisors to assess transition risk.
- Transition risk scenarios can also be internally developed for short-term horizons and transition risk drivers such as technological shocks.

Selected metrics

- Probability of Default (PD)
- Loss Given Default (LGD)
- Exposure at Default (EAD)
- Exposure to carbon-intensive sectors
- Transition-to-credit-risk intensity (TCI)
- Capital adequacy ratios

3.2.2 Case studies

DNB's short-term exercise (DNB, 2018)

The DeNederlanscheBank (DNB) piloted in 2018 a climate stress test measuring the potential impact of an energy transition on the Netherlands' financial system in the near term.

Objective

- Assess the exposure of the Dutch financial system to a transition to a low-carbon economy.
- Tackle the challenges identified for conducting a climate stress test, such as data and modelling gaps.

Approach

- Top-down approach with a static balance sheet assumption.
- Macroeconomic simulations of the scenarios were combined with transition vulnerability factors to determine the financial impact; losses in relation to bank loans were calculated by adding up extra losses on the loan portfolio compared to the originally expected losses.

Horizon

- Five years

Financial risks covered

- Asset-side losses

Transition risks covered

- Government policy
- Technological developments
- Consumer and investor sentiment

Climate scenarios used

- Developed four internal scenarios: (1) the policy shock scenario; (2) the technology shock scenario; (3) the double shock scenario; and (4) the confidence shock scenario (of consumers and investors)

Selected metrics

- Probability of default
- Transition vulnerability factor (amount of CO_2 emitted)
- CET1-ratio

Results

- Losses from an energy transition could be significant but manageable for financial institutions.
- The exercise calculated stressed assets accounting for 3 per cent for banks, 11 per cent for insurers, and 10 per cent for pension funds.
- Financial institutions need to take into account potential energy transition risks to limit potential exposure.
- To help mitigate a disruptive energy transition and the risk associated with it, timely policy action is necessary.
- The scenarios in the exercise not only impacted carbon-intensive sectors but the economy as a whole as well.

OSFI and BOC's pilot exercise (BoC, 2022b)

The Bank of Canada and the Office of the Superintendent of Financial Institutions (OSFI) conducted a joint pilot climate scenario analysis exercise in 2022. The exercise aimed to enable authorities and participating financial institutions to build capacity for conducting climate scenario analysis and improve the associated disclosures and risk management processes.

Objective

- Enable authorities and participating financial institutions to build capacity for conducting climate scenario analysis.
- Improve assessment and disclosure of climate-related risks.
- Understand potential exposure to transition risks.
- Improve climate-related governance and risk management practices among authorities and financial institutions.

Approach

- Assumed a static balance sheet.
- Combined a top-down and bottom-up approach to assess credit risk.
- Used a top-down approach to assess market risk.
- Mostly focused on exposure within North America and 10 emission-intensive sectors that were broken down to the industry level in order to enhance granularity.

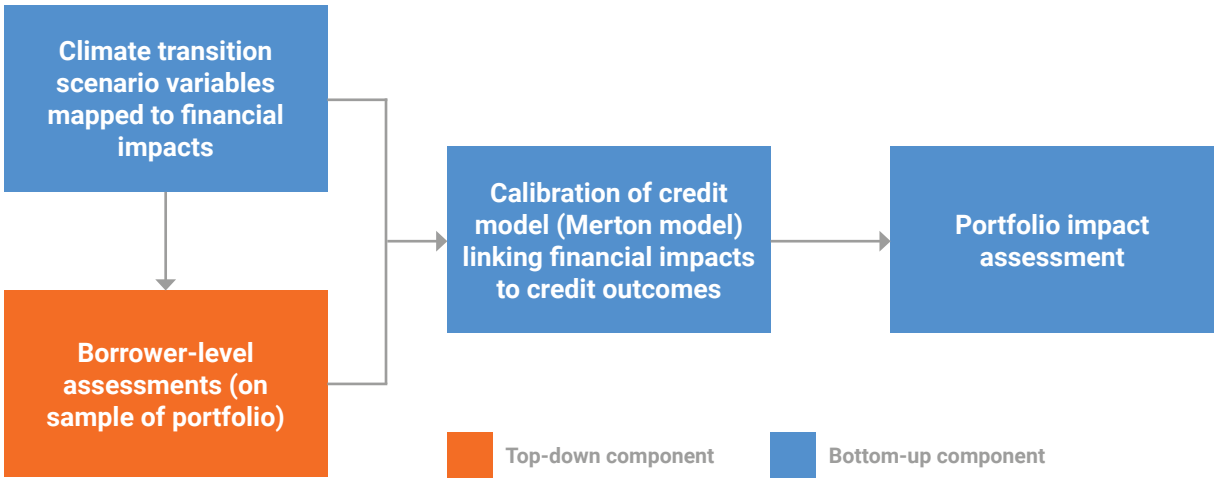


Figure 16: Credit risk methodology by BoC and OSFI (BoC, 2022b)

Horizon

- 30 years

Financial risks covered

- Market risk
- Credit risk

Climate scenarios used

- Four long-term scenarios: Baseline (2019 policies), below 2°C immediate, below 2°C delayed and net zero 2050 (1.5°C)

Selected metrics

- PD
- LGD
- EAD
- Equity value

Results

- The delayed scenario sees a sudden adjustment in asset values in 2030, while the immediate action scenario experiences a smaller adjustment in 2020 followed by a smoother path.
- Analysis indicates decreased equity valuations in fossil-fuel sectors and gains in the electricity sector, suggesting that delayed or sudden climate policy action could pose greater risks of financial market dislocation.
- Overall, there is a negative relationship between the financial impacts on the sector and the change in credit risk, with more negatively affected sectors experiencing larger percentage increases in their probability of default (PD).

- For more costly transition scenarios, especially in the delayed action scenario, credit risk increases are generally larger.

3.3 Examples of combined climate stress tests

Monetary Authority of Singapore's 2022 Industry-Wide Stress Test (MAS, 2022)

In 2022, the Monetary Authority of Singapore (MAS) included a climate scenario analysis exercise as part of its industry-wide stress test. The purpose of the exercise was to raise awareness of potential financial implications of climate risks while enhancing climate stress testing capabilities in Singapore's finance sector. The exercise is part of MAS's multi-year plan to assess the potential risks of climate change.

Objective

- Raise awareness of potential financial implications of climate risks.
- Enhance the learning of both MAS and financial institutions on conducting climate stress tests.
- Build climate scenario analysis approaches.

Approach

- Bottom-up approach with a static balance sheet example.
- Banks and insurers assessed exposure to six sectors determined as climate policy relevant, as well as examining sovereign credit exposure; insurers also examined policy claims for various business lines.

Horizon

- Short-term and long-term horizons covering 2022–2050

Financial risks covered

- Credit risk for banks
- Market/insurance risks for insurers

Physical and transition risk drivers covered

- Carbon tax
- Rising temperatures
- Sea level rise
- Extreme flooding

Climate scenarios used

- Three scenarios; orderly transition, disorderly transition, and no additional policies.

Selected metrics

- Credit loss
- Gross insurance claims
- PD
- Market value of debt holding
- Market value of equities holding

- Projected unexpired risk reserves
- Cumulative credit cost

Results

- A severe flooding shock across the ASEAN-5 economies could give rise to material losses for banks and insurers, with credit losses amounting to 15 per cent of net profits for banks and a substantial increase in gross incurred claims for general insurers and reinsurers.
- Compared to an orderly scenario, a disorderly transition scenario can lead to a higher increase in PDs by 2040, especially for emission-intensive sectors.
- For some banks, total credit losses were similar in both the orderly and disorderly transition scenarios by 2050.
- Banks projected an increase in PDs under the no additional policies scenario due to the rise in physical risks.
- By 2050, annual credit losses amount to 8–9 per cent of banks' net profit.

	Orderly transition	Disorderly transition	No additional policies
Transition risks	**Moderate**	**Moderate to high** (depending on jurisdiction)	**Limited**
Nature of transition	Early and orderly	Delayed and disorderly	Only policies in place by end-2021
Range of shadow carbon prices globally in 2050 (2010 USD t/ CO_2e)	600–900	500–1,100	Below 30
Physicals risks	**Limited**	**Limited**	**High** (both chronic and acute)
Mean global warming relative to pre-industrial times in 2050	1.6	1.8	3.0

Figure 17: Key aspects of MAS's IWST 2022 climate scenarios (MAS, 2022)

HKMA's climate risk stress test (HKMA, 2023)

Following the Hong Kong Monetary Authority's (HKMA) pilot climate risk stress test (CRST) in 2021, the supervisor released the methodology for its 2023–2024 exercise. Based on industry feedback, HKMA has enhanced the design of the exercise to gain an in-depth understanding of the vulnerabilities associated with climate-related risks in Hong Kong's financial industry.

Objectives

- Advance climate stress testing methodologies based on the lessons learnt from its previous supervisory climate stress test.
- Conduct a comprehensive exercise to measure financial institutions' exposure to climate risks.
- Enhance financial institutions' capabilities to manage climate risks.

- Gain an in-depth understanding of potential vulnerabilities and how to address them through strategy and risk management.

Approach

- Bottom-up approach with a static balance sheet assumption.
- Institutions have to assess the impact of climate and macroeconomic risks on their balance sheets and off-balance sheet exposures through in-depth analysis using the tail risk of low-probability events.

Horizon

- A short term horizon (five years) from 2023 to 2027
- A long term horizon (27 years) from 2023 to 2050

Financial risks covered

- Credit risk
- Market risk
- Operational risk

Physical/transition risks

- Increased frequency of extreme climate events, such as heatwaves and heavy precipitation
- Transition policies
- Technological breakthroughs
- Investments

Climate scenarios used

- A short-term scenario with an increase in extreme climate events and an accelerated transition.
- Three long-term scenarios namely: Below 2°C (i.e. orderly transition); Delayed Transition (i.e. disorderly transition); and Current Policies (i.e. transition limited to that brought about by implemented policies).

Selected metrics

- PD
- Capital adequacy ratios
- Expected credit losses
- Risk weighted assets
- Fair value of assets
- Operational losses

4. Results from climate stress tests

4.1 Physical risk outputs

The round of supervisory climate stress tests that have so far taken place have resulted in some general conclusions related to physical risks. These overall takeaways include:

- Vulnerabilities to physical risks identified in these exercises were determined to be non-negligible in some cases, with such risks having a potential adverse financial impact on participating institutions.
- Financial systems are likely to remain resilient to physical risks; however, the outputs from these exercises are likely to understate the potential impact.
- Without additional climate action to transition to a low-carbon economy, physical risks increase over time.
- Exposures to physical risks are highly dependent on geographical location, with certain parts of a country or certain regions being more vulnerable compared to other areas.
- Less diversified institutions with activities concentrated to specific regions and/or sectors could be at greater risk.
- As physical risks increase, insurance claims also rise by a certain magnitude, with insurers being vulnerable to physical risks in more ways than traditional banks.

Below, we provide examples of results from supervisory exercises showcasing some of the mentioned conclusions.

Box 7: 2021 DNB's flood risk stress test (DNB, 2021)

Key conclusions from the DNB's exercise are in line with the general conclusions observed among supervisory climate stress tests for physical risks. Below we highlight the results from the exercise.

The financial system is likely to remain resilient to physical risks, however, the outputs from these exercises are likely to understate the potential impact.

The exercise determined that the Dutch banking sector has sufficient capital to withstand extreme flooding events in unprotected areas. Capital is expected to deplete between 110 and 132 basis points, which is smaller than the values typically calculated in traditional stress tests. However, the flooding scenarios led to higher capital depletions in protected parts of the country, attributed to greater amounts of real estate and economic activity. In the reporting of its results, however, DNB stated its estimates are subject to some uncertainty.

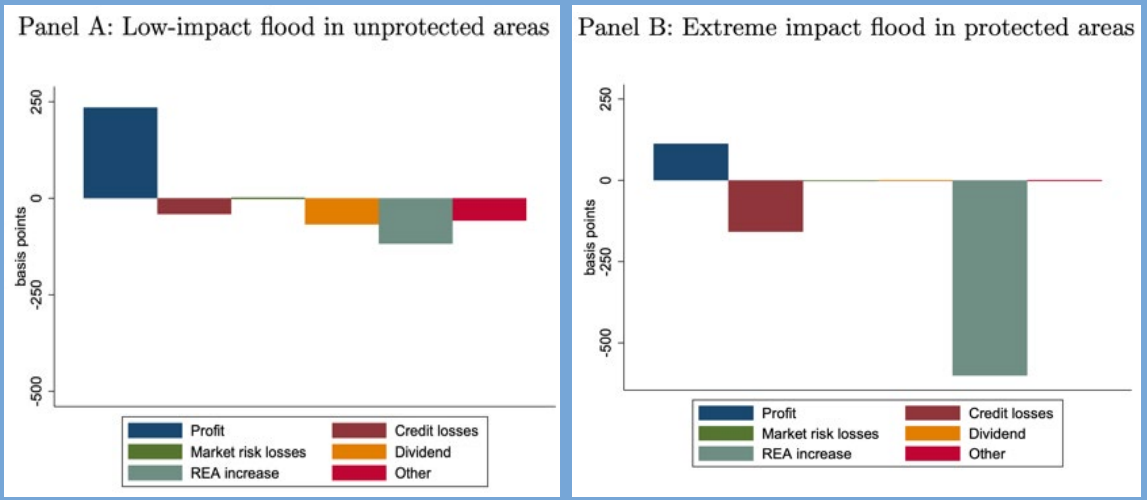


Figure 18: Impact of floods in protected areas (DNB, 2021)

Exposures to physical risks are highly dependent on geographical location with certain parts of a country or certain regions being more vulnerable compared to other areas.

DNB concludes that under a flood scenario with an extreme level of inundation in the populated western half of the Netherlands, there is potential of severe stress for the banking system, with the CET1-ration declining by over 700 basis points with one year of flooding.

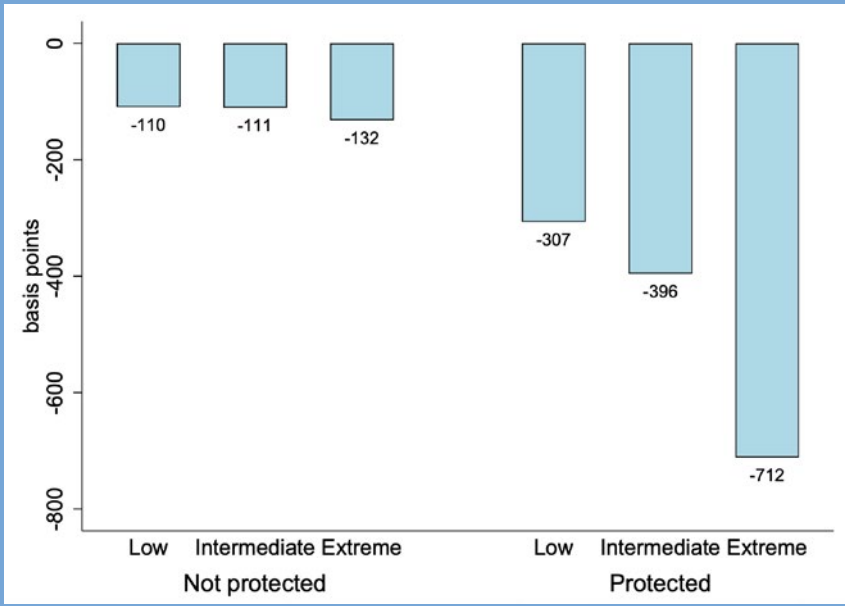


Figure 19: Capital depletion in six flood scenarios over one-year horizon (DNB, 2021)

Box 8: 2022 APRA Climate Vulnerability Assessment (APRA, 2022a)

In the context of its 2022 climate stress testing exercise, the Australian Prudential Regulatory Authority (APRA) highlighted trends similar to those observed in other regulatory climate stress testing exercises. The following elements are particularly noteworthy.

Financial systems are likely to remain resilient to physical risks, however, the outputs from these exercises are likely to understate the potential impact.

As illustrated in Figure 20 below, due to the moderate quality of data available, the exercise may only cover parts of the portfolios stressed and may even be inaccurate in some cases. For instance, the data resolution of chronic variables is graded by the APRA as moderate-to-low.

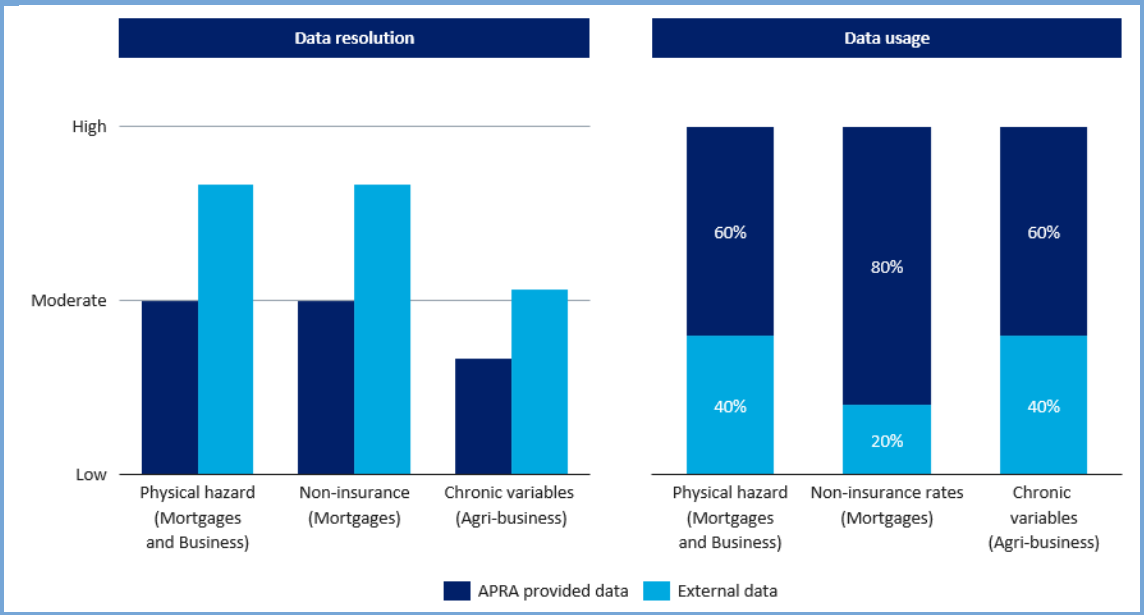


Figure 20: Average physical climate data resolution and usage (APRA, 2022a)

Exposures to physical risks are highly dependent on geographical location, with certain parts of a country or certain regions being more vulnerable compared to other areas.

As illustrated in Figure 21 below, the APRA finds that the portion of exposures with loan-to-value ratio greater than 80 per cent features strong variations across regions. Exposures in New South Wales (NSW) are projected to remain under 14 per cent during the entire time-horizon considered, for instance, while in Western Australia (WA) projections show exposures above 25 per cent throughout the time-horizon considered. Notably, the exposure proportions seem to vary more across regions than across time periods, according to the APRA data shown below.

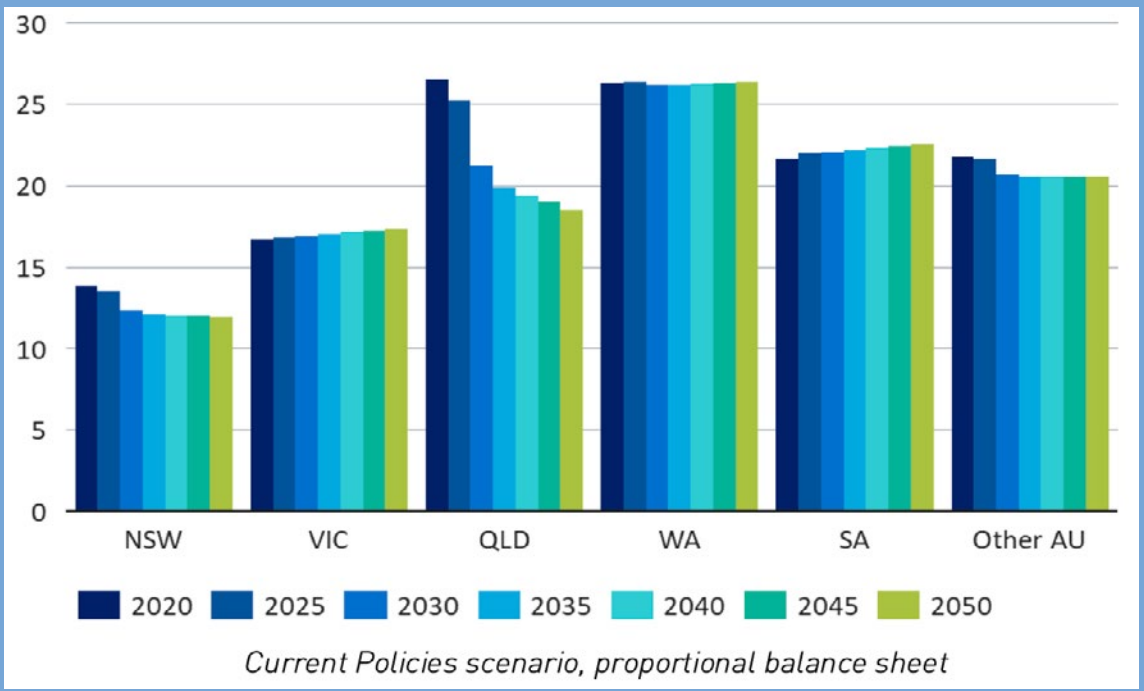


Figure 21: Proportion of exposures with greater than 80% Loan-to-Value ratio by region (APRA, 2022a)

Less diversified institutions with activities concentrated to specific regions and/ or sectors could be at greater risk.

APRA concludes that emission intensive sectors, such as mining, manufacturing, and transport, are likely to face greater vulnerability to transition risks, as shown in Figure 22. The exercise concluded that banks with greater lending exposures to such sectors have a higher possibility of default on loans and losses.

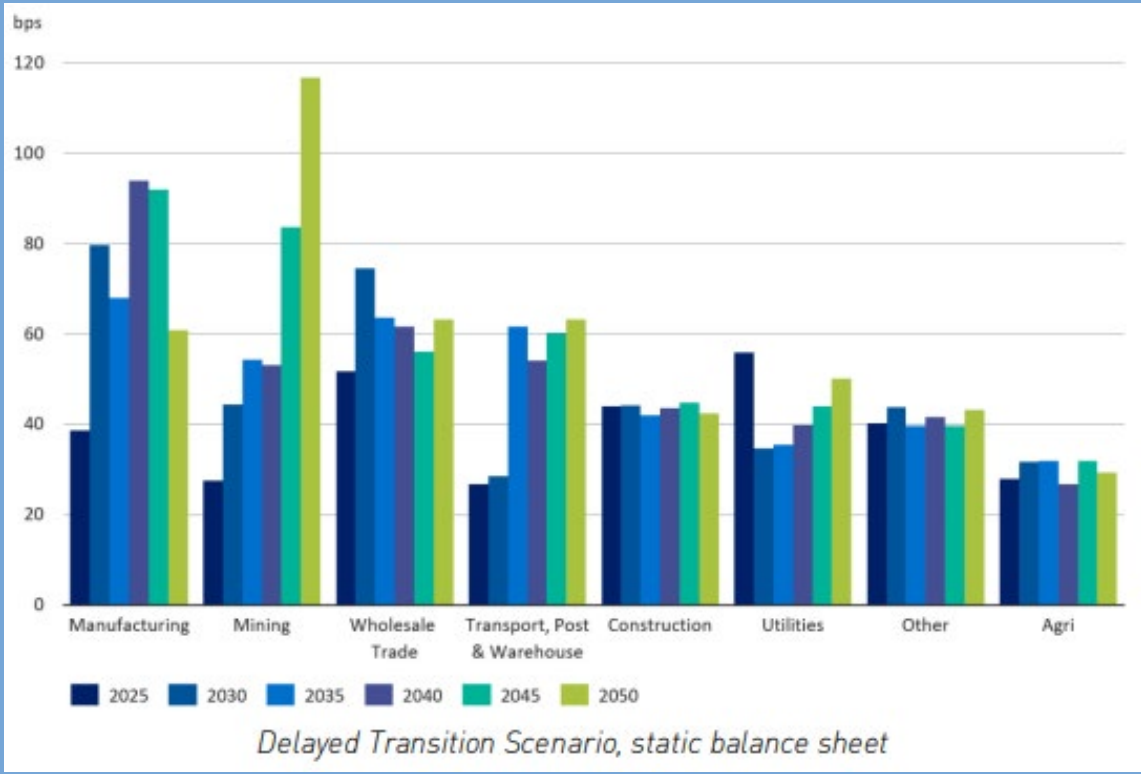


Figure 22: Annual loss rates from business lending from transition risks (APRA, 2022a)

Box 9: 2022 ECB Climate Risk Stress Test (ECB 2022b)

Key results from the ECB's 2022 climate stress testing exercise were in line with the takeaways observed in other regulatory exercises. Crucial takeaways from the ECB's exercise have been highlighted below.

Vulnerabilities to physical risks identified in these exercises were determined to be non-negligible in some cases, with such risks having a potential adverse financial impact on participating institutions.

The ECB concludes in its supervisory exercise that a substantial proportion of financial institutions are exposed to the materialisation of acute physical risks (for example droughts and flooding). This exposure is of varying degrees and, in certain situations, could lead to non-negligible losses. Under the short-term scenarios, the combined credit and market risk losses is estimated to be around EUR 70 billion for 41 banks. This figure accounts for both physical and transition risks.

Without additional climate action to transition to a low-carbon economy, physical risks increase over time.

Results show that under an orderly scenario (warming limited to 1.5°C), loan losses are lower compared to the hot house world scenario (warming at about 3°C). Figure 23 shows that the exposure of banks to physical risks is higher in the hot house world scenario, resulting in higher GVA at the sectoral level. However, the ECB makes note that the trend was not observed in changes to the projected LGD, which can be due to banks not accurately incorporating climate into their credit risk modelling.

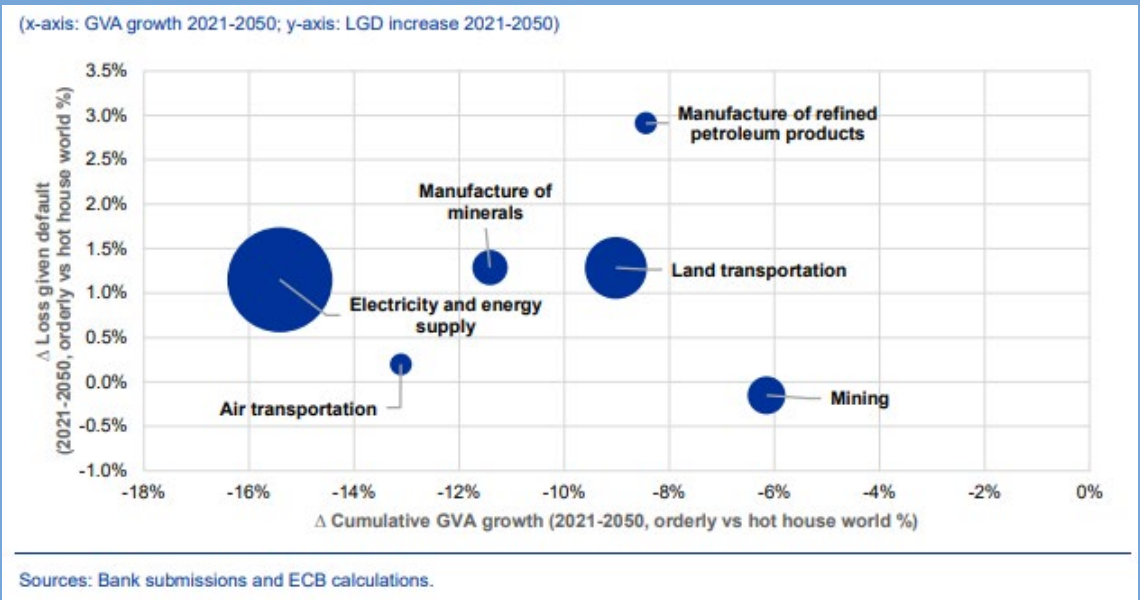


Figure 23: Long-term projections for LGD and GVA growth in the orderly and hot house world scenarios (ECB, 2022b)

Exposures to physical risks are highly dependent on geographical location with certain parts of a country or certain regions being more vulnerable compared to other areas.

The ECB found that drought and heat would decrease productivity in vulnerable sectors while leading to an increase in loan losses in those sectors. Furthermore, projections showed that the geographical location of the exposures is also a driver in increasing loan losses. As shown in Figure 24, the rise in loan losses is estimated to occur in areas with a greater vulnerability to heat and drought.

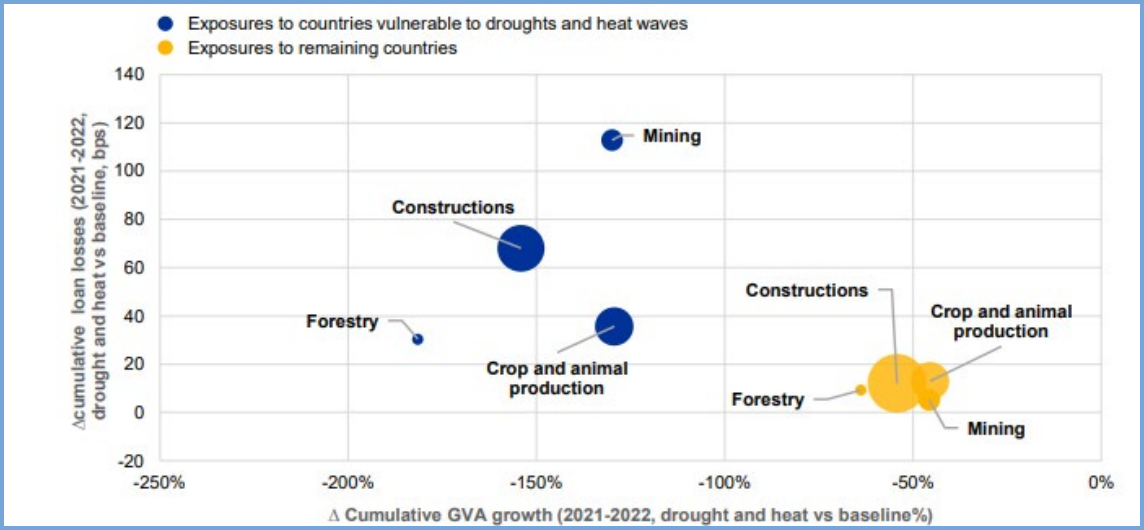


Figure 24: Cumulative loan losses in the drought and heat vs baseline scenario (ECB, 2022b)

Less diversified institutions with activities concentrated to specific regions and/ or sectors could be at greater risk.

As illustrated in 25 below, the mining (97 bps) and constructions (82bps) sectors are estimated to incur relatively larger accumulated loan losses in comparison to other sectors in the drought and heat scenario of the exercise.

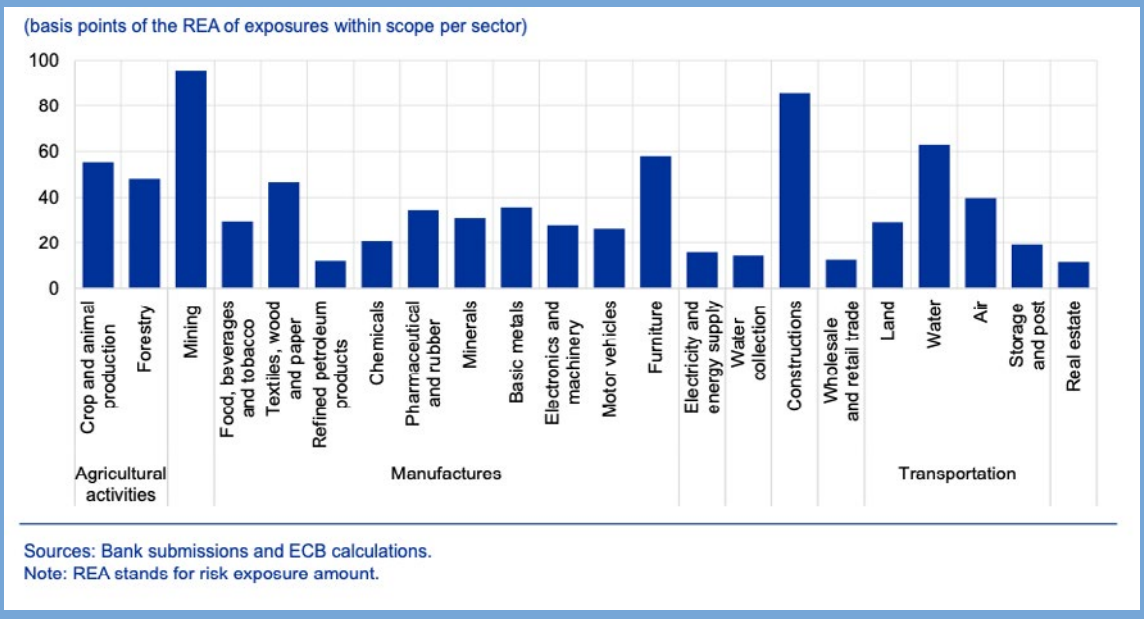


Figure 25: Accumulated loan losses under the drought and heat scenario vs baseline (ECB, 2022b)

Box 10: 2021 BoE CBES (BoE, 2022)

Findings by the Bank of England (BoE) in its 2021 regulatory stress testing exercise are illustrated below.

Without additional climate action to transition to a low-carbon economy, physical risks increase over time.

Overall, the BoE reported that projected climate-related losses were higher for financial institutions as a whole under the severe physical risk scenario (no additional action scenario) compared to the transition scenarios (early action and late action scenarios), as shown in Figure 26.

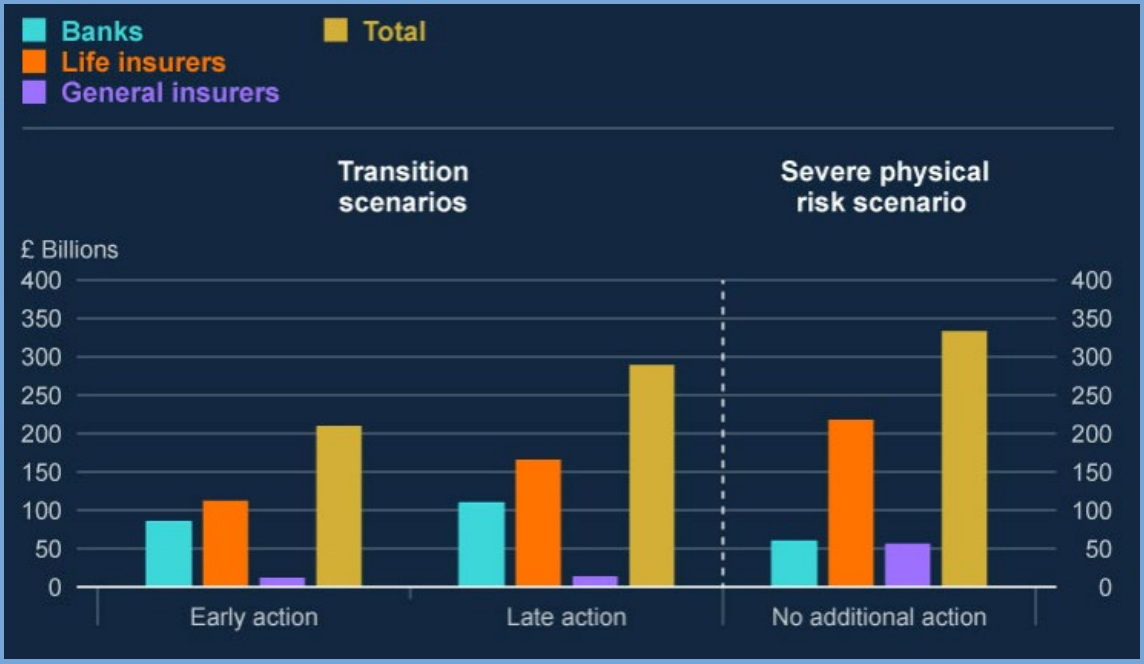


Figure 26: Estimated climate-related losses under three scenarios for financial institutions (BoE, 2022)

Financial systems are likely to remain resilient to physical risks, however, the outputs from these exercises are likely to understate the potential impact.

As part of the CBES results, BoE highlighted results that were understated by participating financial institutions as staff analysis showed higher risk. For example, general insurers projected, on average, annualised losses ranging between 50 to 70 per cent under the no additional action scenario. However, staff analysis suggests that the losses could be four times higher than reported. Similarly, staff analysis showed that corporate impairment rates could be 40 per cent higher than those submitted for the no additional action scenario for banks' wholesale and mortgage exposures. Staff analysis also suggested that projected losses for insurers could be 50 per cent higher for the no additional action scenario.

As physical risks increase, insurance claims also rise by a certain magnitude, with insurers being vulnerable to physical risks in more ways than traditional banks.

Figure 26 shows that losses related to climate change for life and general insurers were much higher than for banks under a no additional action scenario. The overall impact for life insurers was projected to be about 15 per cent of the total market value due to a fall in asset price. For general insurers, annualised losses are reported to range between 50 to 70 per cent, on average, due to an increase in damage caused by extreme physical risks.

The design and scope of the exercises, as well as the underlying assets, can influence the outcomes of an exercise in terms of exposure and vulnerabilities identified (Table 15). Differences in approaches can make it difficult to directly compare the outputs of climate stress tests.

Table 15: Examples of estimates on financial exposure to physical risks (FSB, 2022)

Physical risks	ECB (2021a): ▪ Banks: 30% of corporate exposures
	Bank of Norway: ▪ Real estate: 5.5% of property impacted by 2090
	Reserve Bank of Australia ▪ Real estate: 1.5% of properties prices fall by 10% by 2050
	Bank of Finland: ▪ Real estate: Value-at-Risk amounts to 1.3% of corporate loans
	Bank of England: ▪ Banks: 11% of corporate banking loans to physical risk-vulnerable sectors ▪ Insurers: 17% of assets to physical risk-vulnerable sectors

4.2 Transition risk outputs

Similar to physical risks, the round of supervisory climate stress tests that have so far taken place have resulted in some general conclusions related to transition risks. These overall takeaways include:

- Institutions generate substantial income from activities related to carbon-intensive sectors.
- Exposure to transition risk is bearable but is likely to be understated.
- The rise of long-term transition risks will depend on the transition plans of counterparties in these carbon-intensive sectors.
- Transition risks are projected to be lower in an early-action and orderly scenario than in a delayed and disorderly scenario.
- There are differences in the cost of transition with orderly action resulting in lower costs and providing benefits in terms of opportunities and investments.
- Short-term costs of a transition will be overshadowed by the costs of climate change without stringent action.

- Smaller institutions that specialise in financing a specific industry could be more exposed to transition risks than other institutions.
- Exposures can be concentrated to sectors such as the metals and mining and the transportation sectors.
- Losses across sectors are more concentrated in time in a delayed action pathway, presenting greater risk.

Box 11: 2023 ECB—The Road to Paris: stress testing the transition towards a net-zero economy (ECB, 2023a)

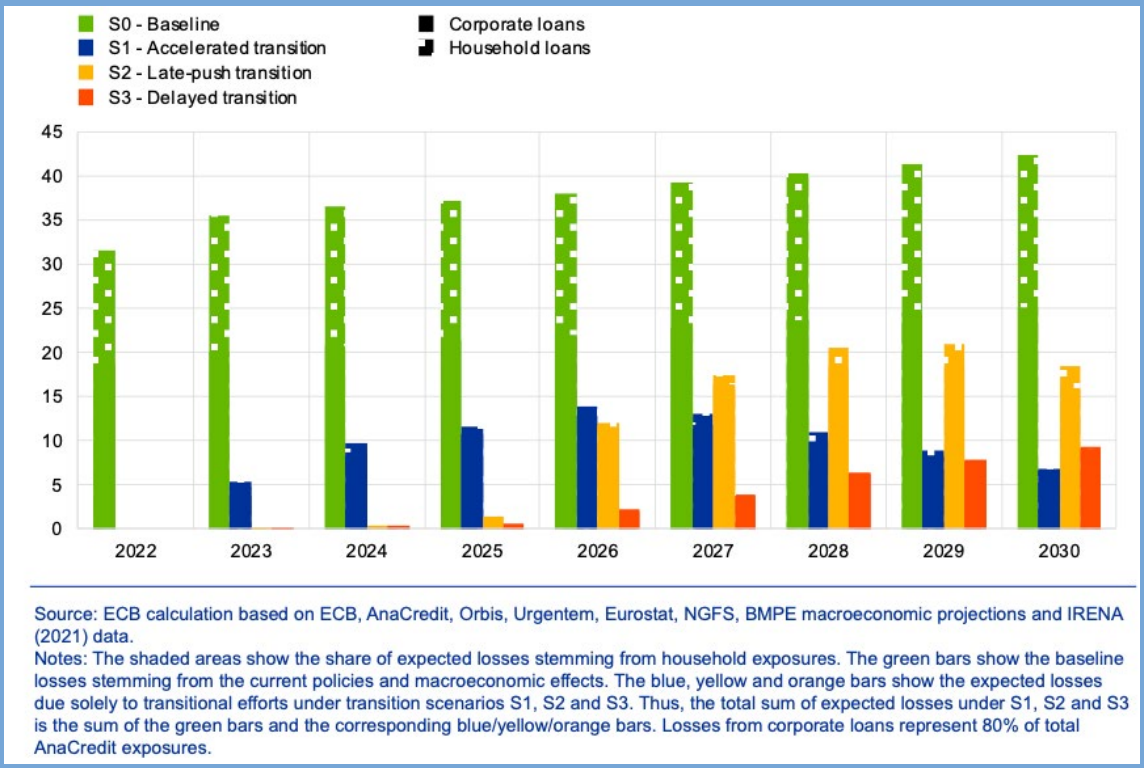
In its top-down exercise, the European Central Bank (ECB) highlights results in line with the key learnings from exercises conducted in other jurisdictions. Below are listed some of the particularly relevant findings.

Short-term costs of a transition will be overshadowed by the costs of climate change without stringent action.

The ECB finds that expected losses would vary substantially across time and scenarios. Specifically, in a late-push transition/disorderly scenario, losses are projected to be higher than in an accelerated/orderly transition scenario, especially towards the four last periods of the time-horizon considered. For example, in 2026, expected losses under the accelerated transition scenario (EUR 13 billion) are estimated to be larger in comparison to the delayed transition scenario (EUR 9 billion). However, in 2030, expected losses under the accelerated transition scenario are estimated to decline. Meanwhile, losses continue to rise under the delayed transition scenario. Expected losses under the baseline current policies scenario remain the highest across the time-horizon, as illustrated in Figure 27.

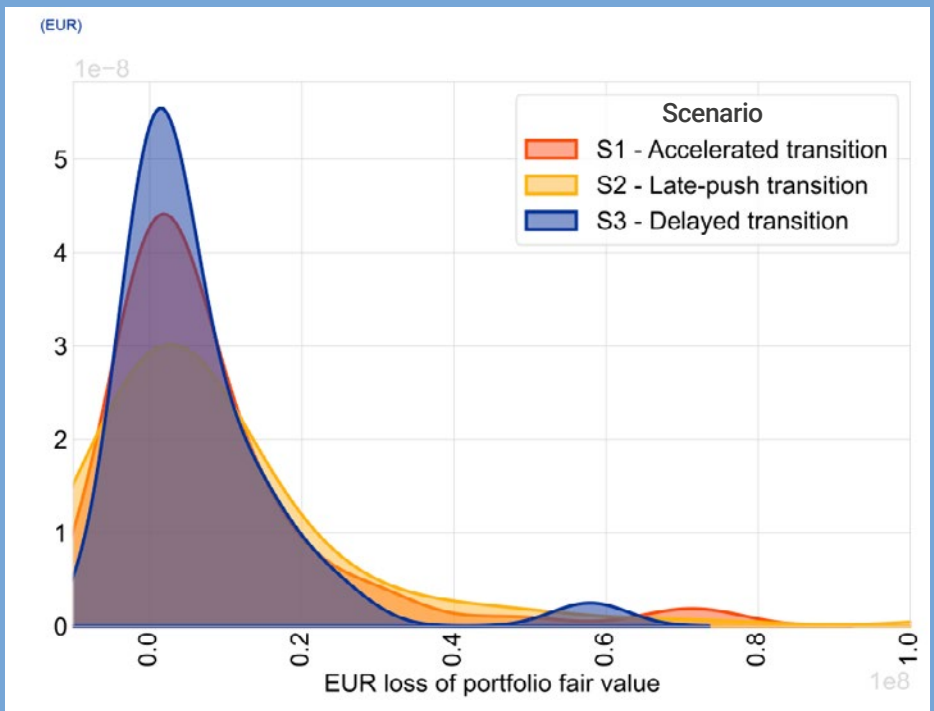
There are differences in the cost of transition with orderly action resulting in lower costs and providing benefits in terms of opportunities and investments.

Figure 28 shows the measured market risk component across three scenarios, plotted as portfolio fair value losses. As illustrated in Figure 27 above, the ECB estimates that average losses till 2030, in absolute terms, would be the highest under the late-push transition scenario (EUR 18 billion), followed by the delayed transition scenario (EUR 8 billion) and then the accelerated transition scenario (EUR 6 billion). Furthermore, the loss distribution also varies depending on the scenario, with the late-push and delayed transition scenarios having fatter tails of distribution in comparison to the accelerated scenario. The ECB also states that market risk losses under the delayed transition scenario are expected to be larger than the other two scenarios. This is because physical risk implications are expected to be greater under the delayed transition scenario after 2030.



Source: ECB calculation based on ECB, AnaCredit, Orbis, Urgentem, Eurostat, NGFS, BMPE macroeconomic projections and IRENA (2021) data.
Notes: The shaded areas show the share of expected losses stemming from household exposures. The green bars show the baseline losses stemming from the current policies and macroeconomic effects. The blue, yellow and orange bars show the expected losses due solely to transitional efforts under transition scenarios S1, S2 and S3. Thus, the total sum of expected losses under S1, S2 and S3 is the sum of the green bars and the corresponding blue/yellow/orange bars. Losses from corporate loans represent 80% of total AnaCredit exposures.

Figure 27: Annual expected losses on corporate and household loans by scenario and year (ECB, 2023a)

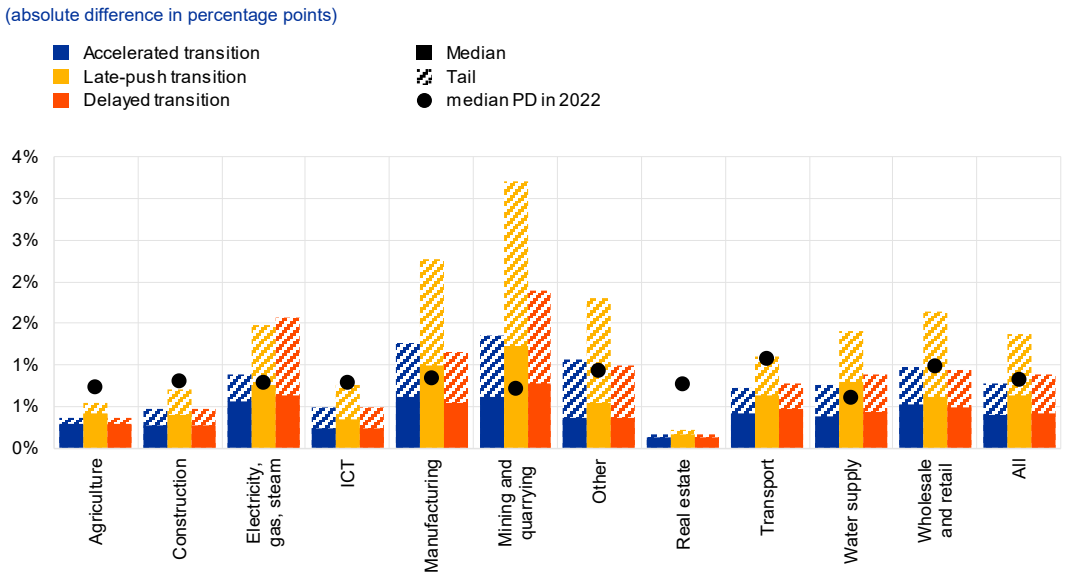


Source: ECB calculations based on Orbis, Urgentem, Eurostat, NGFS, BMPE macroeconomic projections, IRENA (2021) and IPCC (2022) data.

Figure 28: Market risk impact as portfolio fair value losses (ECB, 2023a)

Exposures can be concentrated to sectors such as the metals and mining and the transportation sectors.

The ECB found that the impact of the transition to a low-carbon economy would be heterogeneous across sectors, with the electricity, mining, and manufacturing sectors being the most vulnerable to credit risk (Figure 29). For example, the median corporate PDs across all sectors are projected to increase by 0.5 percentage points, while the mining and manufacturing sectors are expected to increase by 1 percentage points.



Source: ECB calculations based on Orbis, Urgentem, Eurostat, NGFS, BMPE macroeconomic projections, IRENA (2021) and IPCC (2022) data.
Note: Tails were defined as the 75th percentile of firms in terms of PD changes between 2022 and 2030 in each sector and scenario. ICT stands for the Information and Communication Technology sector.

Figure 29: Change in sectoral-level PDs between 2022 and 2030 (ECB, 2023a)

Box 12: 2020 BoC stress testing exercise (BoC, 2022b)

In its 2020 climate stress testing exercise, the Bank of Canada (BoC) highlighted, amongst other
be concentrated to carbon-intensive sectors, as reflected by the sectoral net income yielded from t
with the findings of other exercises in relation to transition risk.

Institutions generate substantial income from activities related to carbon-intensive sectors.

The total credit exposures for all participants were reported to be CAD 239.3 billion. These exposu
banks' and 15 per cent of the insurers' combined total balance sheet assets. Figure 30 shows th
by sector. The sectors that account for the largest exposures are oil and gas, electricity, comm
gy-intensive industries. Together, they collectively account for over 90 per cent of the total credit

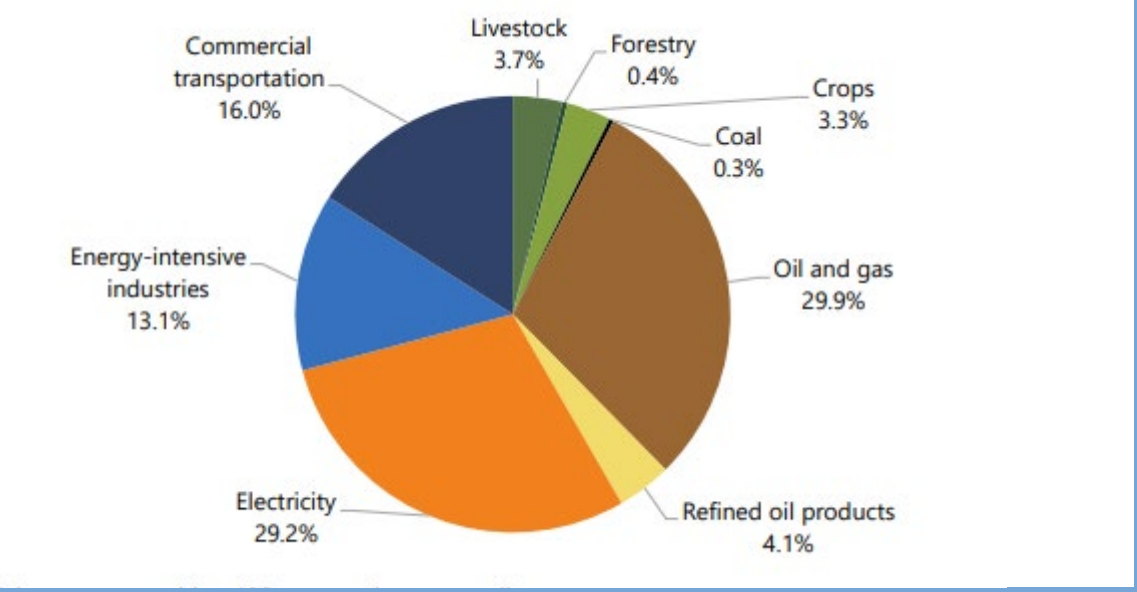


Figure 30: Credit exposure of participants by sector (*BoC, 2022b*)

Exposures can be concentrated to sectors such as the metals and mining and the transportatio

BoC concludes that the sectoral impacts could be grouped into three categories: (1) sectors that e due to the transition; (2) sectors that experience an increase in demand due to the transition; and (culties due to increase in costs as a result of the transition. Figure 31 displays the change in glob three scenarios, relative to the baseline. The below figure illustrates a decline in net income for livestock, crops, and energy-intensive industries under the three transition risk scenarios.

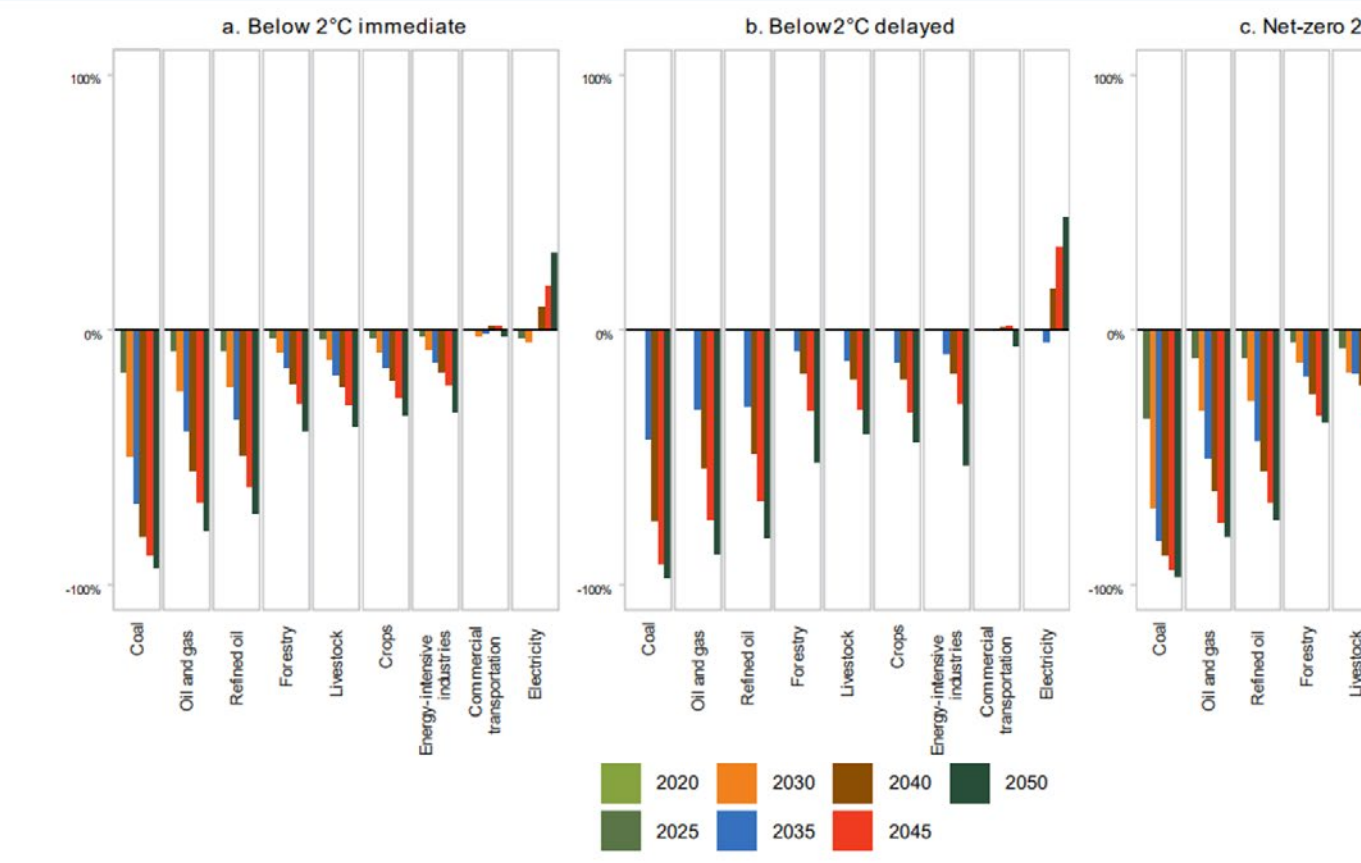


Figure 31: Change in global sectoral net income relative to baseline across scenarios (BoC, 2022b)

Box 13: 2022 ECB supervisory climate stress test (ECB 2022b)

Results from the European Central Bank's (ECB) supervisory exercise highlight elements that were seen in stress testing exercises conducted in other jurisdictions or in exercises conducted in specific countries inside the Euro-area. Below are listed some of the relevant findings.

Institutions generate substantial income from activities related to carbon-intensive sectors.

Figure 32 below shows the interest income and commission income per sector (blue bars) from 22 carbon-intensive industries, as well as the median of the Scope 1, 2, and 3 GHG intensity for those sectors (red dots). Overall, each carbon-intensive sectors taken individually (such as manufacturing of refined petroleum products and mining) account for up to 26 per cent of income for the institutions taking part in the exercise. This makes the impact of a transition non-negligible for financial institutions, especially for firms with large concentrations of exposure to the sectors.

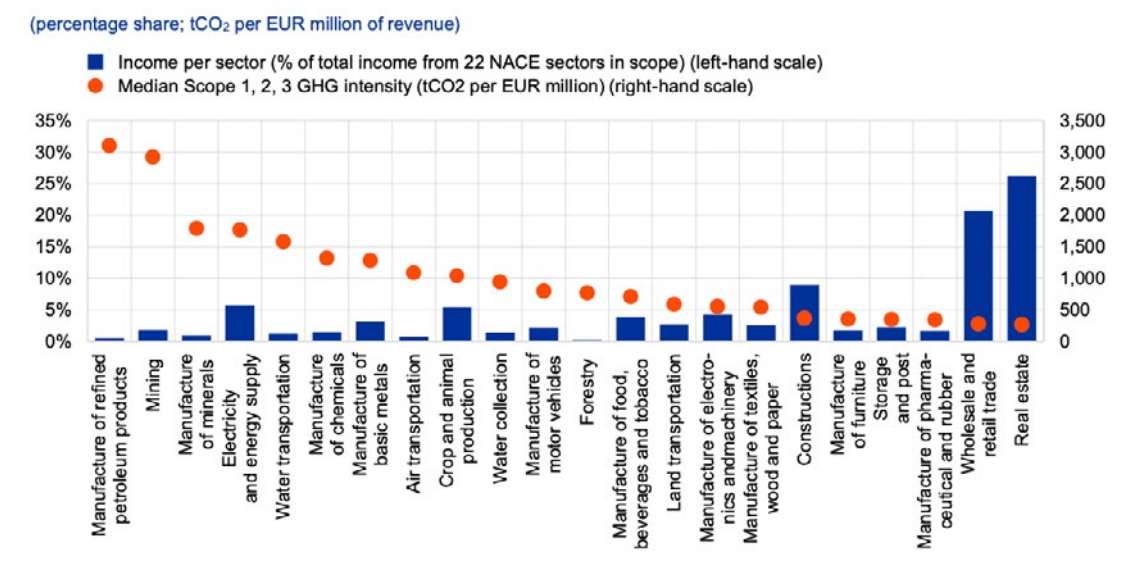


Figure 32: Interest income and fee and commission income per sector from 22 carbon-intensive industries and median of the Scope 1, 2, and 3 GHG intensity (ECB, 2022b)

The rise of long-term transition risks will depend on the transition plans of counterparties in these carbon-intensive sectors.

The ECB found that institutions differ greatly in their long-term climate strategy depending on the sectors and scenarios considered (Figure 33). Between 30 and 40 per cent of institutions in sectors considered less polluting intend to support counterparties in transition by increasing or maintaining exposure to less-polluting sectors. As for carbon-intensive sectors, divestment is the preferred strategy.

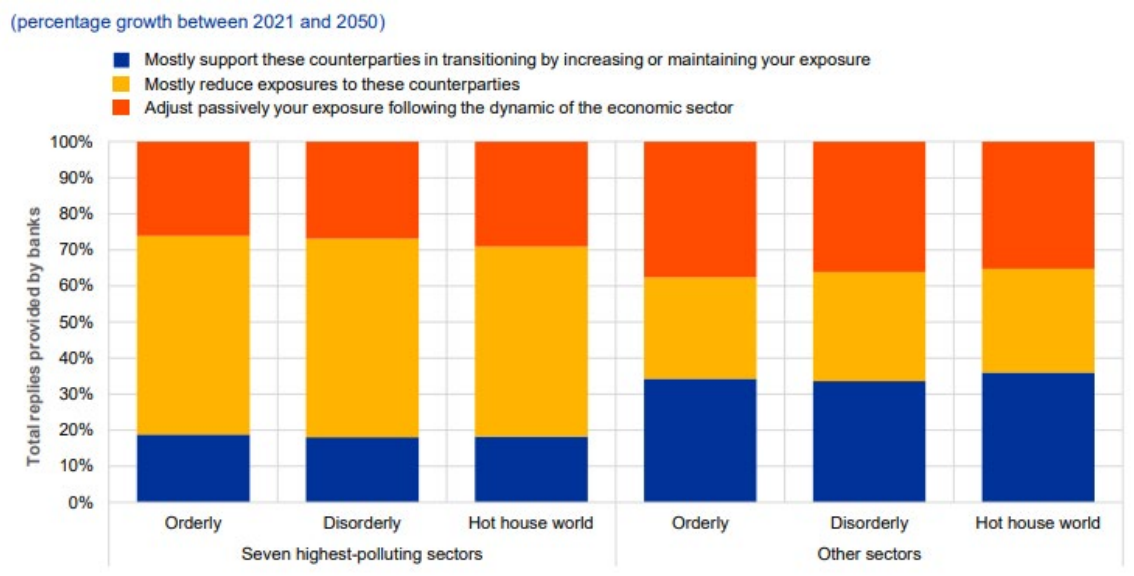


Figure 33: Institutions' long-term strategies (ECB, 2022b)

Smaller institutions which specialise in financing a specific industry could face a higher exposure to transition risks compared to other institutions.

As illustrated in Figure 34 below, small domestic and retail lenders tend to be significantly more exposed to carbon-intensive industries. The ECB calculates that carbon-intensive industries may account for 65 to 85 per cent of total non-financial corporate interest income for this category of lenders. On the other end of the spectrum, Global Systemically Important Banks (G-SIBs) show a significantly smaller exposure to these sectors, with a share of total non-financial corporate interest income issued from carbon-intensive industries ranging from 45 to 72 per cent.

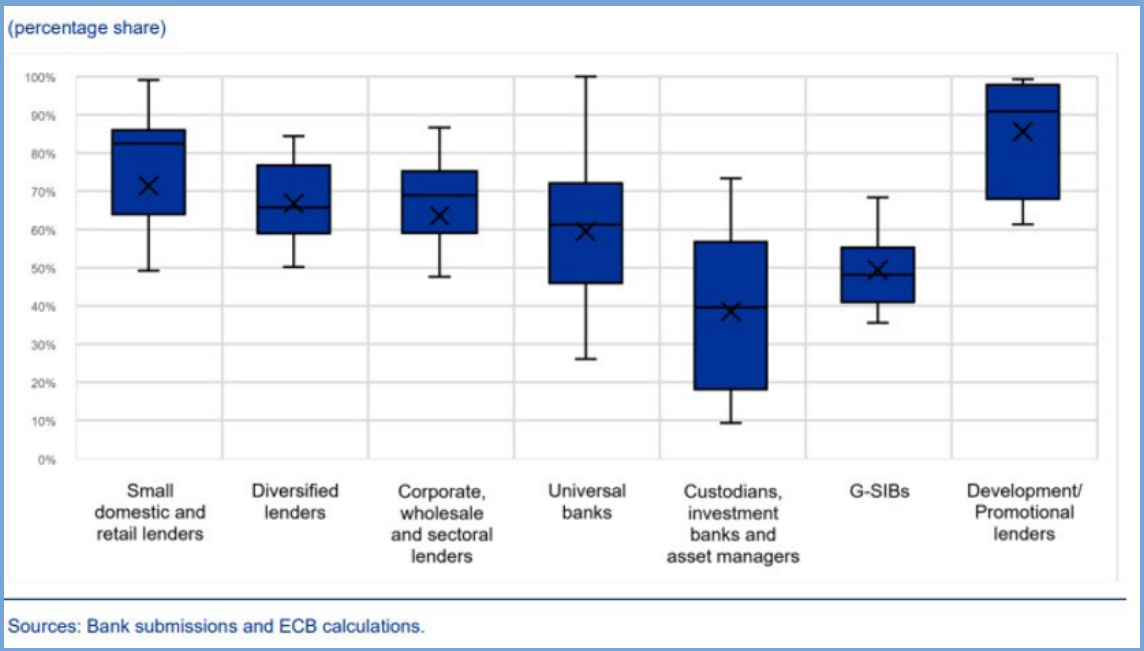


Figure 34: Interest income from 22 carbon-intensive industries as a share of total non-financial corporate interest income (ECB, 2022b)

The design and scope of the exercises, as well as the underlying assets, have been shown to impact the level of exposure measured across exercises (Table 16). Differences in approaches can make it difficult to directly compare the outputs of climate stress tests.

Table 16: Examples of estimates on financial exposure to transition risks (FSB, 2022)

Transition risks	Bank of Norway: ▪ Banks: 20% of loans to transition-sensitive sectors.
	Deutsch Bundesbank: ▪ Real estate: 5.5% of property impacted by 2090.
	Reserve Bank of Australia ▪ Banks: 19% of loans to transition-sensitive sectors; 33% of securities to transition-sensitive sectors; 45% of non-financial bonds to transition-sensitive sectors. ▪ Insurers: 9% of stocks to transition-sensitive sectors; 8% of non-financial bonds to transition-sensitive sectors. ▪ Investment funds: 15% of securities to transition-sensitive sectors; 36% of non-financial bonds to transition-sensitive sectors.
	Banco de España: ▪ Banks: From 1.5% to 3.5% of loans to transition-sensitive sectors.
	ECB (2021a): ▪ Banks: 14% of loans to transition-sensitive sectors.
	Banque de France/ACPR: ▪ Banks: 10% of loans to transition-sensitive sectors.
	Superintendencia Financiera de Colombia: ▪ Banks: From 1% to 26% of loans to transition-sensitive sectors.
	Bank of England: ▪ Banks: 21% of corporate banking loans to transition risk-vulnerable sectors. ▪ Insurers: 21% of assets to transition risk-vulnerable sectors.

4.3 Narrative (qualitative) portion output

Overall responses from supervisory qualitative questionnaires have shown:

- While participants have different levels of maturity and sophistication with respect to governance and risk management practices, all have increasingly recognised climate-related risk as one of their top risks.
- Regarding governance, risk appetite frameworks (RAFs) with incorporated climate-related risks are widely adopted and various board committees have been set up to oversee the management for climate-related risks.
- In terms of the business model and strategy aspect, the results of the questionnaires show that institutions are in the process of identifying risks arising from climate change for key sectors, geographic areas, and related products and services in markets where they are active or considering becoming active.
- Specifically in terms of the risk assessment process, the overall answers to the questionnaires indicate that physical risks are better understood in the risk assessment process, while the impacts of transition risk on institutions' exposure are relatively understated.

Table 17 below demonstrates the insights gained from the BoC-OSFI Climate Scenario Analysis Pilot's qualitative questionnaire on risk management frameworks.

Table 17: Climate-related risks in participants' risk management framework (BoC, 2022b)

Credit risk management	Most of the six pilot participants are still in the early stage of developing capabilities and incorporating climate-related risks as drivers into their risk management framework. The majority have prioritised these efforts given the urgent and transverse nature of these risks. Generally, collateral valuation does not take into account climate-related risks. Loan pricing frameworks do not explicitly reflect either credit risk appetite or business strategy with regard to climate-related risks.
Operational risk management and operational resilience	For most pilot participants, climate-related risks are captured broadly in their operational risk framework. Risk factors are frequently included in the business continuity plans/business resilience programs in response to climate-related risks. Most participants have assessed some aspects of climate-related risks and their impact on operational resilience.
Market risk management	Less than half of the pilot participants consider climate-related risk factors in their market risk frameworks.
Liquidity risk management	Most pilot participants do not consider climate-related risks directly in their liquidity risk management or buffer calibrations.
Insurance risk management	For pilot participants with insurance underwriting activity, some respondents include climate-related risks in their insurance underwriting processes, while others address climate-related risks on a portfolio basis.
Materiality assessment, due diligence and risk quantification	Most pilot participants integrate climate-related risks into their strategic planning. Most conduct climate-related due diligence on institutional clients. Some include climate-related risks in their assessment of materiality. Pilot participants are in different stages of developing their capabilities to quantify climate-related risks.
Capital adequacy	Most pilot participants assess the impact of climate-related risks on capital adequacy through the financial condition testing exercise or through capital planning for traditional risk categories (e.g. credit, market, and operational).
Stress testing / scenario analysis	All pilot participants incorporate climate-related stress testing or scenario analysis either in their enterprise-wide stress-testing programmes or through participating in the current scenario analysis pilot. While all pilot participants conduct climate-related stress tests to some degree, current practices and capabilities for physical risk assessment are more developed than those for assessment of transition risk.

4.4 Limitations in methodologies

Although climate stress testing has been conducted by numerous jurisdictions globally, the incorporation of climate change into the traditional exercise typically carried out by financial institutions remains relatively new with its own set of limitations and challenges.

Summarised below are the key limitations identified in the set of supervisory exercises that have taken place so far.

Lack of granularity

Quantitative outcomes of climate stress tests are less useful for internal use by financial institutions due to their lack of granularity. To improve the granularity of scenario analysis, additional data are required from clients. Furthermore, to enhance sectoral granularity, more risk assumptions and sector-specific risk assumptions are needed to understand the impact.

Data gaps

Climate-related data quality and accessibility remains a significant challenge. Customer-level data are needed to improve the granularity of climate scenario analysis. Locational data of assets of clients remain a challenge. Financial institutions also face difficulties in collecting emissions data (Scope 1, 2 and 3) from their counterparties, especially from smaller sized firms. The ECB has also stated that participants often have difficulty in collecting energy performance certificates (ECB, 2022b). As a first step to overcoming data challenges, many participants are utilising data proxies or making reasonable guesses when counterparty data are not available. However, variation in the methodologies are leading to differences in estimations and proxies among participants. Filling in data gaps can also be costly for institutions, especially if financial institutions need to rely on third-party vendors.

Severity of scenarios

Results of climate stress tests tend to be relatively benign. IAMs are generally structured with a cost optimisation framework, but this can restrict their capacity to evaluate the stressfulness of a transition, as they may not account for suboptimal allocations. Consequently, even scenarios with high transition risk (disorderly scenarios) could represent a "best-case" pathway to a specific temperature outcome, factoring in constraints like the underlying structure for cost optimisation and exogenous estimates of macroeconomic factors. Moreover, at present, there is no benchmark for determining whether the climate scenarios used in an exercise are severe or not.

Uncertainties for long-term horizon stress tests

The long-term horizon of many climate stress testing exercises creates uncertainty in how emissions and climate risks will evolve over the period. It is possible that climate risks evolve in a manner different to those presented under the scenarios used in exercises. Such uncertainties are also evident by climate models having their own set of assumptions and simplifications, which results in different projections for the same temperature output. The ECB (2022b) states that long-term projections (such as 30-year projections) should not be considered as a "robust quantitative measure" and should be used by institutions more as a "direction of travel".

Modelling ability

Financial institutions are still in the early stages of incorporating climate risk into their current credit and market risk models. Participants of climate stress testing exercises find it difficult to translate climate scenarios into macroeconomic variables and determine the quantitative impact using financial models, such as by linking the outputs of climate scenarios to credit risk metrics like PD. Financial models being used at present in climate stress tests have not been designed to assess risks over long-term horizons.

As such, they are better suited to short-term assessments. Consequently, results from many exercises found financial institutions to be somewhat insensitive to climate risks (ECB, 2022b). For example, the Bank of England stated that the projected loss rates provided by participants varied considerably due to institutions being in the process of developing their climate risk methodologies and incorporating a diverse range of approaches (BoE, 2022).

Lack of standardisation

The NGFS has been a key driver in moving towards standardised global data. However, a lack of standardisation still exists between institutions of a given exercise in terms of key assumptions and modelling approaches used. The same is true between supervisory exercises in terms of the design, assumptions, and implementation of exercises. Greater transparency is needed on the methodologies of the supervisory exercises and the expectations from participating financial institutions, such as in relation to data and parameters.

Limited scope

The majority of exercises cover the same sectors and risk types. As a result, it is possible that a substantial proportion of balance sheets remain out of scope of the exercises and are not assessed for exposure to potential impacts of climate change. This can result in potential risks and opportunities being overlooked and certain impacts being either overstated or understated.

5. Use of the climate stress test results

5.1 Supervisory use of the results

On the side of financial supervisors, climate stress tests are used as a learning exercise to identify limitations of methodologies in the current development phase. Results may play a pivotal role as illustrated in Figure 35 below.

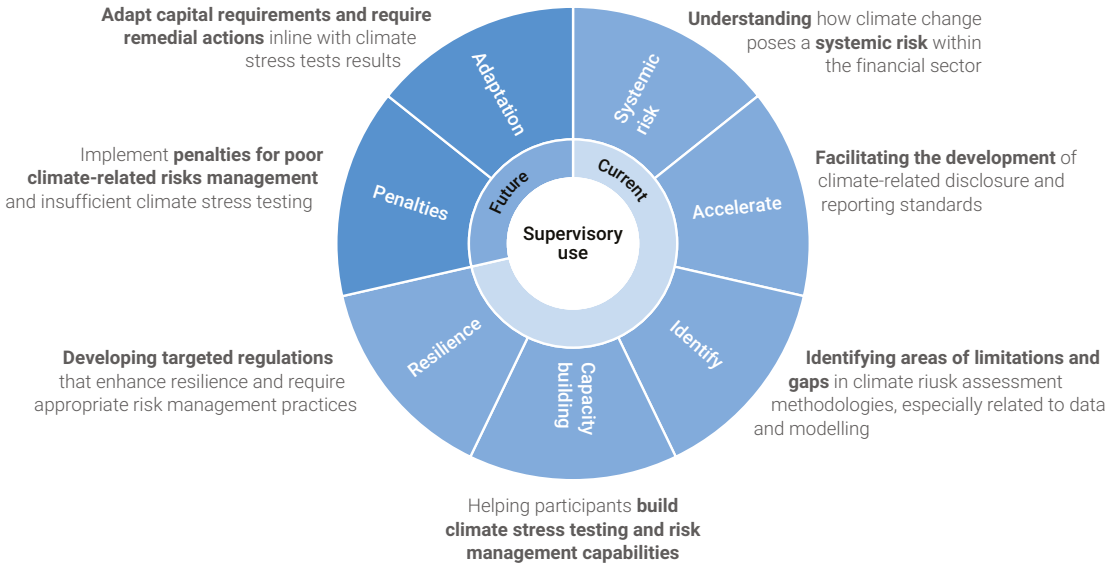


Figure 35: Supervisory use of climate stress testing (Own depiction)

Climate and Environmental Risk Integration in Basel III Pillar II Supervision

Pillar 2 of the Basel Framework, known as the Supervisory Review and Evaluation Process (SREP), aims to ensure that banks have adequate capital to support all risks in their business while also encouraging banks to develop and use better risk management techniques in managing their risks (BIS, 2019). Integrating climate-related and environmental risks into the Supervisory Review and Evaluation Process involves financial institutions recognising the impact of these risks on their performance and financial stability.

The SREP acknowledges the role of bank management in developing an internal capital assessment process and setting capital targets that are on par with the bank's risk (BIS, 2019). Under Pillar 2, supervisors evaluate how banks assess their capital needs relative to risk and how they take measures when appropriate. This process is intended to promote active dialogue between banks and supervisors so that when insufficiencies are identified, prompt action can be taken to reduce risk.

In recent years, financial supervisors have begun integrating climate-related and environmental risks into the SREP under Basel III (Pillar 2). For example, the ECB has integrated climate and environmental risks into its Supervisory Review and Evaluation Process since 2022. In 2023, climate and environmental risks were assessed under element 1 (business model) and element 2 (internal governance) (ECB, 2023b). Improvements were noted for some supervised institutions in terms of their business environment and strategy based on the 2022 review on climate and environmental risks. Even so, a few institutions still highlighted the urgent need to align with supervisory expectations related to defining their business strategy. The results of this showed that climate and environmental risks played a more significant role in determining Pillar 2 Requirements levels for a greater number of banks compared to the 2022 SREP (ECB, 2023b), with 30 per cent of significant institutions receiving SREP measures.

In June 2022, HKMA set out a two-year plan to integrate climate risk into its Supervisory Review and Evaluation Process (Moody's, 2022). Among the notable steps included in this plan are:

- Incorporating of climate risk management as a regular agenda item in prudential meetings, where banks' progress in addressing climate risk and ensuring compliance with new policies can be assessed.
- Integration of climate risk stress tests into its supervisor-driven stress-testing framework, assessing authorised institutions' resilience under various climate and economic scenarios.
- Enhancement of HKMA's "greenness" assessment framework to cover broader environmental risks and transition considerations.
- Retention of the regulatory framework under review so as to consider the inclusion of climate risk in the Supervisory Review Process.

However, at this stage, the results of the SREP on climate and environmental risks has no consequences for capital requirements (BIS, 2019). As we transition to net zero and increasingly face climate-related extreme weather events such as forest fires, flooding and heatwaves, supervisors should consider including climate and environmental risks in minimum capital requirements (KPMG, 2024).

5.2 Institutional use of the results

Conducting a climate stress test can provide financial institutions with various benefits. In addition, with improvements in the sophistication of methodologies, financial institutions should increasingly uptake the potential applications of climate stress tests. Examples of such future developments as shown in Figure 36 below.

Figure 36: Institutional use of climate stress testing (Own depiction)

Monitoring climate risks

Climate stress testing is a valuable exercise for identifying potential climate risks. However, to maximise its benefits, financial institutions should utilise the results to integrate climate risks into their business strategy and its implementation (ECB, 2020).

When integrating climate risks into its strategy and Risk Appetite Framework, financial institutions should consider the types of clients to engage with and the location of assets, as well as the operations of clients and the products and services that an institution could offer (Sarraf, 2022). Doing so will require the following key steps by financial institutions (DNB, 2019; KPMG, 2023):

1. Conduct climate stress testing to identify and assess the materiality of climate risks.
2. Establish a strategy related to climate risk.
3. Monitor material climate risks at the portfolio and client level through a risk appetite statement.
4. Determine relevant Key Risk Indicators (KRIs) and Key Performance Indicators (KPIs).
5. As part of the internal Risk Appetite Framework (RAF), set limits on financial activities (such as lending) for sectors or geographies identified as highly vulnerable to climate risks based on KRIs.
6. Monitor the implementation of the strategy based on limits set.

Financial institutions should set KPIs for identified climate risks, integrating them into their strategic framework (ECB, 2020; ECB. 2023c). Examples of such KPIs include (KPMG, 2023; ECB, 2020; ECB. 2023c):

- Carbon emission footprint and carbon intensity of assets
- Carbon emission footprint of portfolio
- Average energy label of mortgage portfolios
- Number of homes with improved energy labelling due to financing

- Amount of issued sustainable or green products
- Financed emission reduction for portfolio
- Sustainability rating

These KPIs should be measured against a base year, with progress assessed over specific time-horizons, guiding short-, medium-, and long-term strategy development (KPMG, 2023).

In addition to KPIs, financial institutions need to set KRIs to measure risk capacity and exposure. The steps to define climate-related KRIs include determining climate risk categories, defining the scope for lending and investment exposures, listing potential KRIs, and selecting those KRIs that are most relevant. Examples of KRIs include (KPMG, 2023):

- Indicators in RAF showing the volume of financed emissions.
- Absolute limits in credit risk exposures related to sectors or geographies vulnerable to climate risks.
- Relative limits for credit risk exposures related to sectors or geographies vulnerable to climate risks.
- Limits and attention thresholds based on the percentage of low-emitting companies in the portfolio.
- Limits reflecting the physical impact of climate change on operations based on historical losses and scenario analysis.

The monitoring process should include a defined reporting frequency, a level of risk accepted, and escalation procedures for climate risk KPIs and KRIs when risk levels are breached. Roles, responsibilities, action points, and approval processes need to be considered. The risk appetite and set limits should be incorporated into an institution's documentation and underwriting to guide teams involved in related activities. A KRI dashboard can be utilised by a firm to monitor compliance against its stated risk appetite (ECB, 2020; CFRF, 2021).

Key Risk	Key Risk Indicators	Thresholds			How is this risk measured in practice?
		Red	Amber	Green	
Failure to adhere to external climate-related commitments on investment products	Material breaches relating to the climate-related labelling of fund mandates	> X	< = X > = Y	< Y	Breaches could related to, for example: ▪ Marketing materials ▪ Product literature ▪ Client communications ▪ SFDR labelling
	Instances of external challenges on green credentials of funds	> X	< = X > = Y	< Y	There could be several sources for this data: ▪ Complaints from clients ▪ Adverse press comment ▪ Assurance reviews ▪ Regulator feedback

Figure 37: Example of a KRI dashboard (FCA, 2021)

Financial institutions should establish clear and formal escalation procedures for reporting breaches, with defined roles for various teams, senior management, the board, and committees in monitoring and reporting such breaches. For example, the senior management should hold the responsibility for ensuring the integrity of the RAF and promptly identifying, managing, and escalating risk limit breaches. The Chief Risk Officer (CRO) and Chief Financial Officer (CFO) should expeditiously escalate any material breach that could jeopardise the institution's risk appetite to the board and CEO. The business line can be responsible for integrating the risk appetite statement and limits into their activities. This involves actively monitoring compliance, cooperating with senior management, implementing controls for identifying and reporting against risk limits, and promptly escalating breaches. Internal audit teams should evaluate the processes for identification, escalation, and reporting of risk limit breaches.

6. Guidance for supervisors and financial institutions[9]

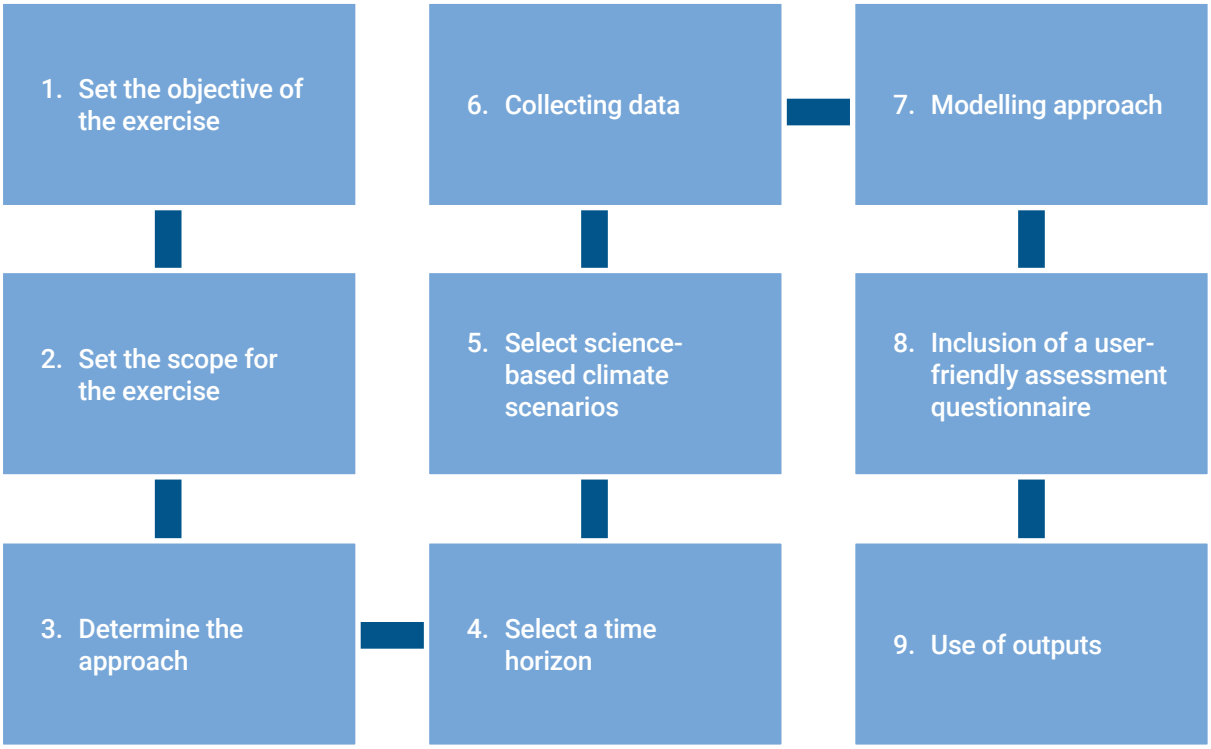


Figure 38: Key steps for conducting a climate stress test (Own depiction)

6.1 Supervisors

Set the objectives for the exercise

- Define the main purpose(s) of the exercise; for example, assessing financial exposure and resilience and enhancing climate risk assessment capabilities.
- Determine whether the exercise is considered a learning exercise or whether the results will have implications.

9 In 2022, the ECB released a document on good practices for climate stress testing based on the learnings from its exercise. The report provides useful guidance for banks in relation to supervisory climate stress testing and can be found at: bankingsupervision.europa.eu/ecb/pub/pdf/ssm.202212_ECBreport_on_good_practices_for_CST~539227e0c1.en.pdf

Set the scope for the exercise

- Determine which types of institutions will be the focus and decide if their participation should be mandatory.
- Identify whether the exercise will assess physical or transition risks, or both.
- Specify which types of financial risks will be assessed in the exercise (such as credit, market, operational, reputational risks) and clarify which of these risks will be assessed quantitatively and qualitatively.
- Define the transmission channels of focus.
- Outline which sectors and parts of a portfolio will be covered.

Determine the approach

- Decide whether it is a bottom-up or top-down approach.
- Specify whether the balance sheet assumption is static or dynamic.
- Identify the key risk metrics that will be used.
- List some of the key assumptions.

Select a time-horizon

- Select time-horizons, i.e. short-term (one to five years) or long-term (20 to 30 years).

Select science-based climate scenarios

- Determine the key temperature outcomes to be assessed.
- Specify the key scenario narratives for the exercise.
- Decide whether external scenarios (e.g. NGFS scenarios) will be used or whether internal scenarios will be developed.
- Define the scenario expansions to be performed and the expected expansions if a bottom-up approach is taken.
- Identify the set of variables that will be used for the exercise.

Collecting data

- Describe the current data collation process in place and how it will be adapted for the exercise.
- Identify the data needs for the exercise and which of these can be collected internally.
- Acknowledge the data sources needed.
- Specify whether collaboration with third party data providers is planned, along with criteria for selection.
- Confirm the presence of a data validation system.
- Clarify which data will be provided and which data are expected to be collected by participating institutions in a bottom-up exercise, outlining the coordination plan and transparency provided to the participants on the data expectations.
- Identify the data gaps for the exercise.

Modelling approach

- Based on the regional and sectoral focus of the exercise, identify the suite of models which will be used for the exercise.
- Specify which internal models will be applied for the exercise, incorporating climate considerations.
- Outline the use of external models and how they will be adapted for the exercise.
- Confirm the granularity of the models being used for the purpose of the exercise.

- Identify limitations of the current modelling approach.
- Confirm the presence of a model validation system.

Inclusion of a user-friendly assessment questionnaire

- Determine whether the exercise includes a narrative portion.
- If yes, clarify the objective of the narrative portion and provide examples of questions, such as those related to climate risks identified, qualitative views on climate risks, participant approach, current and future climate risk management practices, and transition planning.
- Confirm whether participants are expected to share any relevant supporting documents.

Use of outputs

- Acknowledge the limitations of the methodology, data, assumptions, and the overall exercise.
- Outline the plan to use the outputs, whether for developing regulations and standards or prioritising identified gaps.
- Specify expectations from financial institutions regarding the use of the exercise outputs.
- Clarify the next steps after completion of the exercise.

6.2 Financial institutions

Set the scope of the exercise

- Decide if it is an internal or supervisory exercise.
- Define the main purpose(s) of the exercise; for example, assessing financial exposure to climate change, increasing awareness of climate risks, and enhancing climate risk assessment capabilities.
- Determine if the exercise is considered a learning exercise or if the intention is to use the results to inform climate risk management and strategy at the institution.

Set the scope for the exercise

- Establish whether the exercise assesses physical or transition risks, or both.
- Specify the types of financial risks that will be assessed in the exercise (such as credit, market, operational, reputational risks). Indicate which of these risks will be assessed quantitatively and qualitatively.
- Identify the transmission channels of focus.
- Outline the sectors and parts of a portfolio that will be covered.

Determine the approach

- Determine whether it is a counterparty-level analysis or a portfolio level analysis, or a combination of both.
- Clarify whether the balance sheet assumption is static or dynamic.
- Define the key risk metrics that will be used.
- Identify some of the key assumptions.

Select a time-horizon

- Choose the time-horizons that will be selected for the exercise, i.e., short-term (one to five years) or long-term (20 to 30 years).

Select science-based climate scenarios

- Determine the key temperature outcomes to be assessed.
- Specify the key scenario narratives for the exercise.
- Decide which scenarios will be used for the exercise and whether, if it is a supervisory exercise, the supervisor has provided the scenarios; in the case of an internal exercise, are external scenarios (e.g. NGFS scenarios) being used or will internal scenarios be developed?
- Outline the scenario expansions needed to be performed.
- If it is a supervisory exercise, clarify whether the supervisor has provided a set of variables and what other variables may need to be added; if it is an internal exercise, determine the set of variables that will be used for the exercise.

Collecting data

- If it is a supervisory exercise, determine which of the data will be provided by the supervisor and whether a data template has been provided.
- Identify the data needs for the exercise and which of these can be met internally.
- Identify any external data sources that will be needed.
- Identify the data needed to be collected from clients and communicate how these data needs will be addressed.
- Confirm collaboration with third party data providers based on the data needed. Specify the criteria used for selecting a data provider.
- Verify the existence of a system to coordinate and collate the data for the exercise.
- Confirm the presence of a data validation system.
- Identify the data gaps for the exercise and indicate whether missing data will be addressed by using data proxies and estimations.

Modelling approach

- Based on the regional and sectoral focus of the exercise, outline the suite of models that will be used for the exercise.
- If it is a supervisory exercise, clarify whether the supervisor has provided any guidance on the modelling approach.
- Specify which internal models will be applied for the exercise and how climate change will be incorporated into the modelling to measure climate risks.
- Indicate which external models will be applied for the exercise and how they will need to be adapted for the exercise.
- Assess whether the granularity of the models being used are sufficient for the purpose of the exercise.
- Identify the limitations of the current modelling approach.
- Confirm the presence of a model validation system.

Inclusion of a user-friendly assessment questionnaire

- Establish whether the supervisory exercise includes a narrative portion.
- If yes, confirm the ability to disclose information and provide evidence regarding the institution's climate risk identification and methodologies, current and future climate risk management practices, transition planning, and so on.

Use of outputs

- Acknowledge the limitations of the methodology, data, assumptions, and the overall exercise.
- Outline plans for using the outputs, such as enhancing risk management practices, building capabilities and skills, informing changes to the business model, supporting day-to-day risk management, and developing mitigation strategies.
- Identify the next steps after completion of the exercise.

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Appendix

Appendix 1—Resources from peer stress tests

APRA (Australian Prudential Regulation Authority), 2022—Australia

APRA has released an information paper on the aggregated findings of its Climate Vulnerability Assessment (CVA) of Australia's five largest banks. This analysis provides insights into the potential financial exposure of institutions, the financial system and the economy to the physical and transition risks of climate change. The exercise has been adapted from existing stress tests with Australia's five largest banks taking part. The objectives of the CVA are to measure banks', the financial system's and the economy's exposure to potential climate risks, understand how a bank can adjust its business models and undertake management actions in light of the potential risks faced under different scenarios, and help improve firms' capabilities in climate risk management. The CVA is based on two NGFS Phase II scenarios: a delayed but rapid transition to reduce emissions with high transition risks and a scenario with limited further global action with high physical risks associated. The exercise covers a time period from 2020–2050 using a static and proportional balance sheet approach (APRA, 2022b).

OSFI (Office of the Superintendent of Financial Institutions) and Bank of Canada (BoC), 2021—Canada

In November 2020, the BoC and OSFI launched a joint pilot project on climate risk scenarios to better understand potential transition risks. The final report for this project was released in January 2022 to detail specific scenarios, methodologies, assumptions and sensitivities. The project aims further to improve the climate scenario analysis capabilities of institutions, increase the understanding of risk exposure levels, and improve the understanding of risk-management practices. Four transition scenarios were studied: (1) business as usual, (2) nationally determined contributions (NDCs), (3) 2˚C consistent and (4) 2˚C delayed action. The time-horizon selected was 2020 to 2050 (at five-year intervals) (BoC, 2022b). The BoC has assessed market risk using a top-down approach at the sectoral level and used both a top-down and bottom-up approach for assessing credit risk (NGFS, 2021a).

Office of the Superintendent of Financial Institutions (OSFI), 2024—Canada

OSFI has published a draft methodology for its 2024 Standardized Climate Scenario Exercise (SCSE). The SCSE aims to measure climate risks that are arguably not reflected using traditional risk quantification techniques. The SCSE will consider characteristics associated with individual exposures that are not typically used in risk quantification but may provide strong risk discrimination under future climate scenarios. The SCSE is a foundational step; it is the first climate scenario analysis issued to federally regulated financial institutions (FRFIs) by OSFI, and its results will be used to define future exercises. The SCSE combines bottom-up and top-down approaches. Top-down in the sense that OSFI will define and develop the 2024 SCSE methodology, scenarios, adjustment parameters, and calculations. Bottom-up in the sense that FRFIs will identify exposures, classify them into relevant sectoral and geographical segments, and perform calculations. The SCSE includes four separate modules and a questionnaire. Transition market risks in the finance sector, transition credit risks in the finance sector, transition risks in real estate (exposure assessment), and physical risks in real estate (exposure assessment). All participating FRFIs will be required to complete the workbook and questionnaire according to the associated instructions and using the supporting data. OSFI will encourage FRFIs to complete a copy of the workbook, or a subset of it, using their own approaches, models, and data if they believe the SCSE does not adequately capture their specific climate risks (OSFI, 2023).

International Monetary Fund (IMF), 2021—Colombia

This exercise conducted by the IMF aims to quantify the financial stability implications of climate-related transition risks in Colombia. It explores risks imposed on the banking system based on scenarios of an increase in the domestic carbon tax by using bank- and firm-level data. Focusing on the deterioration of firms' balance sheets and the exposure of banks to different sectors, the extent to which such policy shock would transmit from nonfinancial firms to the banking system is assessed. A much more comprehensive version of the carbon tax than is currently in place is considered, and the effects of a carbon tax imposed on the basis of GHG emissions are explored. As such, they include emissions of GHG, such as N_2O and CH_4, as well as CO_2 emissions from changes in land use, residue management, and combustion of fuels other than oil and gas derivatives, like coal. Moreover, it is assumed that the tax burden falls ultimately on the final emitter of the greenhouse gases rather than on the producer of any particular fuel. The IMF observed that the agriculture, manufacturing, electricity, wholesale and retail trade, and transportation sectors appear to have a larger impact on the transmission of the risk to the banking system. Results also suggested that a large increase in the carbon tax can generate significant but likely manageable financial stability risks for the country and that a gradual increase in the carbon tax to meet a higher target over several years could be preferable in terms of financial risks. A gradual increase would also have the benefit of allowing for a smoother adjustment to a higher carbon tax for stakeholders (IMF, 2021).

Danmarks National Bank, 2020—Denmark

In this exercise, Danmarks National Bank examines the impacts of transition risks on the Danish banking sector. The exercise uses a number of sensitivity analyses to determine the potential capital shortfall faced by the banking sector if it incurred a loss of a certain size over a given time frame. It is assumed that these impairment charges are not distributed evenly across the banks. On the banks' corporate loans portfolio, the impairment charges are distributed on the basis of emission intensity in the industries to which the banks make loans. On the mortgage loans portfolio, the impairment charges are distributed on the basis of the energy labelling of the properties mortgaged as collateral for the loans. The stress test is thus based on the assumption that the loans that give rise to the largest impairment charges during a green transition are loans to customers engaged in particularly climate-damaging activities. For the exercise, the supervisor linked accounting data for corporations and industry-level emission data with credit register data for bank lending. On the banks' mortgage loans, it is possible to link lending to data for energy labels (NBD, 2020).

ECB (European Central Bank), 2021 to 2023—European Union

In March 2021, the ECB released preliminary findings from its economy-wide top-down climate stress test, designed to help assess the climate risks faced by the financial sector over the next 30 years. The ECB included three NGFS scenarios: (1) orderly transition with limited physical risk, (2) disorderly transition with limited physical risk, and (3) hot house world with extreme physical risk.

In 2022, the ECB conducted a bottom-up supervisory climate stress test to address institutions' risks towards climate change and their readiness by addressing wider aspects of both qualitative and quantitative evaluation. It covered both transition and physical risks and according to the risks considered, the time-horizon varies from a long-term 30-year horizon to a short-term three-year horizon. Three scenarios largely based on Phase II of NGFS—(i) an orderly transition, (ii) a delayed, disorderly transition, and (iii) a "hot house world"—was adopted to assess the potential climate impact. The results from this exercise, published in February 2022, were used to inform the climate stress test of the Euro system balance sheet (ECB, 2021b; ECB, 2022b).

In 2023, the ECB concluded its second bottom-up economic-wide climate stress test and published its result in September. There are three main updates compared with the previous one: (i) ECB constructed new short-term transition scenarios based on the climate scenarios of the NGFS; (ii) ECB has developed new climate risk models that account for recent developments in the European energy sector, particularly the increase in energy prices triggered by Russia's invasion of Ukraine; (iii) ECB has calculated the investment needed to successfully transition towards net zero emissions in a more granular way (ECB, 2023a).

Prudential and Supervision and Resolution Authority (ACPR) and Banque de France (BdF), 2021—France

The authorities conducted their climate pilot exercise from July 2020 to April 2021. The pilot exercise was voluntary and carried out by banks and insurers with the objective of better mobilising French banks and insurers, raising awareness about climate risks, and quantifying and assessing complex transition or physical risk scenarios. The exercise relied on the scenarios by the NGFS and included a baseline scenario corresponding to an orderly transition and two disorderly transition scenarios. Risks were assessed over a 30-year time frame, covering the 2020–2050 period. The methodology used static and dynamic balance sheets with a bottom-up approach. Moving forward, in June 2023, the ACPR launched its second climate stress testing exercise, this time restricting its scope to the insurance sector. Preparatory work was carried out with insurers throughout 2022 in the context of a market-wide working group that aimed to draw conclusions from the first stress-testing exercise and make certain improvements or supplementing analyses (ACPR, 2021, ACPR, 2023).

Deutsche Bundesbank, 2021—Germany

The Deutsche Bundesbank conducted a sensitivity analysis of climate-related transition risks on the German financial sector. Specifically, the exercise calculated potential losses incurred by banks, funds, and insurers on various financial instruments, including government bonds. The aim of the analysis was to quantify the impact of the transition to a low-carbon economy on the balance sheets of German financial intermediaries. In particular, emissions reduction targets and corresponding carbon price increases acted as risk factors with varied effects across the economy as a whole. These risk factors were assumed to also have an impact on the financial system via the usual risk channels, such as credit risk and market risk. The Bundesbank's analysis is based on the climate scenarios by the NGFS. The climate scenarios are broken down into key macroeconomic and financial variables using NiGEM. For this purpose, the scenarios are first differentiated by sector using a production network model. In the next step, market and credit risk models are used to determine historical elasticities between, on the one hand, the variables depicted in the scenarios and, on the other, sectoral credit default rates as well as corporate bond valuations. Lastly, the losses at the level of securities and borrowers are mapped to the balance sheets of German banks, funds, and insurers (DBB, 2021).

HKMA (Hong Kong Monetary Authority), 2021—Hong Kong

In 2021, the Hong Kong Monetary Authority (HKMA) undertook a pilot exercise on climate risk stress test (CRST) to assess the climate resilience of the Hong Kong banking sector and facilitate the capability building of participating authorised institutions (AIs) in measuring climate risks. The CRST comprises three scenarios, namely a physical risk scenario of a worsening climate situation and two transition risk scenarios representing different pathways (i.e. disorderly and orderly) to a low-emission economy. Physical risk and transition risk are assessed separately under these scenarios. The CRST scenarios cover different time-horizons for capturing both the short-term impact of abrupt changes in climate patterns and transition policies and the long-term impact of early and progressive actions. It is assumed that the banks will not change their business strategies over the horizon of assessment and will maintain a static balance sheet (HKMA, 2021).

In April 2023, HKMA published Guidelines for Banking Sector Climate Risk Stress Test for a new round of exercise, which is scheduled to run from June 2023 to June 2024. As compared to the pilot exercise, a broader set of scenario variables and assumptions, including sectoral impacts and macroeconomic indicators, will be provided (HKMA, 2023).

Financial Service Agency (FSA) and Bank of Japan, 2022—Japan

This pilot scenario analysis exercise was conducted by the Financial Services Agency (FSA) and the Bank of Japan (BOJ) in cooperation with three major banks and three major non-life insurance groups. Scenarios published by the NGFS were used as a basis. The FSA and BOJ adopted a bottom-up approach, whereby a framework with three NGFS scenarios was laid out (namely, Net Zero 2050, Delayed transition, and Current policies), and financial institutions were asked to conduct the analysis with their own models. The impacts of both transition and physical risks (mainly acute risks by floods) were examined to assess the mid- to long-term effects of climate change on banks' business and financial soundness via credit risks based on credit exposures. The results indicated that the banks' estimated increase in annual credit costs due to transition and physical risks was considerably lower than their average annual net income. It was demonstrated that each bank had the capacity to conduct a risk analysis not only for the scenarios set in their own climate risk disclosures but also for the common scenarios of the exercise (FSA & BOJ, 2022).

BNM (Bank Negara Malaysia), 2022—Malaysia

The BNM published a Discussion Paper on its 2024 Climate Risk Stress Testing Exercise in June 2022, setting out its preliminary guidelines for a bottom-up stress test involving both banks and insurers. The objectives of the exercise include quantifying financial institutions' exposures to climate change and potential losses, Identifying current gaps and challenges faced by financial institutions, and accelerating data collection and risk management quality. Three adverse scenarios, Current Policies, Nationally Determined Contributions (NDC) and Delayed Transition scenarios, are used to analyse the climate impact of both transition and physical risks on the institutions' financial performance. To take into consideration the gradual materialisation of the physical risks like sea level rise, the BNM adopts a long-term approach (2023–2050 and 2050–2100) to enable an accurate assessment. The Bank proposes financial institutions to assume a static balance sheet approach for the ease of implementation of this exercise.

De Nederlandsche Bank (DNB), 2021—Netherlands (Flood risks)

Using a stress test framework and geocoded data on real-estate exposures for Dutch banks, the DNB explored the level of flooding which could potentially begin impairing financial stability. To quantify flood-related financial stability risks, the DNB started from a standard approach to financial stress testing, which was modified to incorporate flood-risk considerations. The supervisor followed a reverse stress test approach, focusing on property damages related to flooding risk. In addition, a perspective for the banking system as a whole is provided. For the exercise, DNB used data from ten Dutch banks, capturing 95 per cent of the assets of the Dutch banking sector. Data used included granular data on real-estate exposures data sets on the location of properties, loan contracts for which these objects serve as collateral, coupled with official flood risk maps. The climate-financial-risk implications of flooding were assessed at the 4-digit

postal code level. DNB found that the banking sector is capitalised sufficiently to withstand floods in unprotected areas, where there is relatively little real estate. However, capital depletions would increase quickly in case more severe floods hit the densely populated western part of the Netherlands. These findings have possible implications for various policy areas, including macroprudential policy (DNB, 2021).

AFM (Dutch Authority for the Financial Markets)/ DNB (De Nederlandsche Bank), 2018—Netherlands

DNB conducted a climate stress test in 2018, considering the potential impact of energy transition risks on the Dutch financial sector. DNB analysed four scenarios: (1) the policy shock scenario, (2) the technology shock scenario, (3) the double shock scenario, and (4) the confidence shock scenario (of consumers and investors). The scenarios were defined to materialise within five years, thus ensuring that the stress test results are relevant to financial institutions, decision-makers and other stakeholders in the near term. Furthermore, the stress test only considered transition risks and not physical risks. The impact of each scenario on Dutch financial institutions was calculated using data of slightly more than half of the total aggregate exposures of Dutch banks, insurers and pension funds, from which they concluded that losses were sizable but management (DNB, 2018).

MAS (Monetary Authority of Singapore), 2022—Singapore

The MAS conducted in 2022 an Industry-Wide Stress Test exercise with findings published in MAS' Financial Stability Review 2022 (MAS, 2022). The participants include both banks and insurers with a static balance sheet approach. The exercise was designed to raise awareness of the potential economic and financial implications of climate risks and facilitate learning for both MAS and Financial institutions as capabilities are developed in this area. It has incorporated a range of long-term (2022–2050) climate scenarios that take reference from the Phase II NGFS Scenarios: Orderly Transition, No Additional Policies, Disorderly Transition. Median estimates of banks' cumulative credit costs for their Climate Policy Relevant Sectors (CPRS) exposures by 2050 ranged from 587 to 609 basis points across the three scenarios. Insurers projected a decline in the market value of their CPRS and sovereign debt holdings for all three scenarios due to a persistent rise in interest rates across the scenario horizon.

South African Reserve Bank (SARB), 2021—South Africa

As part of the 2021 Common Scenario Stress Test (CSST), the South African Reserve Bank (SARB) piloted a bottom-up climate change risk exercise. This focused mainly on physical risks with a drought scenario. Banks were requested to quantitatively simulate the solvency impact of the drought scenario over the three-year stress horizon, with the impact incorporated into the already stressed solvency positions from the CSST adverse scenario. This was complemented by qualitative assessments of the impact of transition risks and the materiality of environmental risks to different economic sectors. Banks were requested to estimate the impact of the scenario on their credit exposures per sector and report the impact on selected variables using metrics such as PD and NPLs. The exercise also assessed the impact on the creditworthiness of the sovereign, as the

government may be expected to offer relief measures to sectors affected by droughts (SARB, 2021).

Banco de España (BDE), 2021—Spain

An initial analysis of the energy transition risks' impact on the banking sector was conducted by Banco de España in 2021 using its Forward-Looking Exercise on Spanish Banks (FLESB) in-house stress-testing framework. In this exercise, the probability of default of the business lending portfolios was modelled with a high level of granularity by enterprise size and by sector. Other risk factors and balance sheet and income statement features were also projected consistently with the macroeconomic scenarios in order to obtain estimates for the institutions' profitability and solvency. The macro-financial scenarios used for this exercise were designed in-house and are based on the higher price of emission allowances and on different extensions of the coverage of the Emissions Trading System (ETS). These changes to environmental legislation are reflected in different shocks over a three-year analysis horizon to the real gross value added (GVA) growth paths for that sectoral breakdown. The Banco de España's Central Credit Register (CCR) was used to model different risk parameters relevant to the exercise. The probability of default (PD) of banks' business lending exposures is estimated using the CCR database separately for each sector and enterprise size (large firms, SMEs and sole proprietors). These PDs were stressed by taking into account the sectoral shocks to the transition scenarios' GVA growth, in addition to the attendant deterioration of the financial position (profitability, leverage, etc.) of each sector of activity. The other parameters and sources of income and loss for the banks are also stressed using the FLESB framework on the basis of the impact of the transition scenarios on the aggregate macroeconomic forecast for the overall economy. Overall, the scenarios have a moderate impact on the credit quality of business lending; however, those sectors with greater greenhouse gas emissions are significantly more affected (BdE, 2021).

PRA (Prudential Regulation Authority)/BoE(Bank of England), 2021—United Kingdom

The Climate Biennial Exploratory Scenario (CBES) exercise began in 2021 with results published in May 2022. Participants include large UK banking groups, life insurers and general insurers, which account for 70% of the country's bank lending to households and businesses and approximately 65% of the UK life insurance market by asset size. The desired outcomes for the exercise are to (1) size the financial exposures to climate risks, (2) understand the business models' challenges, and (3) enhance climate risk management. The CBES scenarios build upon the NGFS climate scenarios for early policy action, late policy action and no policy action. All three scenarios will explore both transition and physical risks to a certain degree over the period 2021–2050. Further, they will measure the impact of the scenarios on their static end-2020 balance sheets (BoE, 2022).

Federal Reserve (Fed), 2023—United States

The Fed's 2023 Pilot Climate Scenario Analysis Exercise aimed to learn about large banking organisations' climate risk-management practices and challenges as well as to enhance the ability of large banking organisations and supervisors to identify, measure, monitor, and manage climate-related financial risks. The exercise comprised both a physical risk module and a transition risk module. Participants were required to estimate

the financial impact of climate scenarios on a relevant subset of their credit exposures over a 1-year time horizon and 10-year time horizon for physical and transition risks, respectively. While the physical risk module focused on estimating the effect of shocks on residential and commercial real estate, the transition risk module focused on estimating the effect of different transition pathways on corporate loan portfolios and commercial real estate. Participants were also asked to respond to a qualitative questionnaire in relation to their governance, risk-management practices, measurement methodologies, results for specific portfolios, and lessons learned. Six U.S. bank holding companies participated in this pilot exercise (Fed, 2023; Fed, 2024).

Appendix 2—Resources on climate scenarios

NGFS IIASA Scenario Explorer

This web-based user interface provides intuitive visualisations and displays of the transition risk scenarios' time series data. This database also includes macroeconomic data from the National Institute Global Econometric Model (NiGEM) and data on the impact of physical risks on GDP.

NGFS CA Climate Impact Explorer

The physical risk scenarios' time series data can be found on this interface. Extended sets of physical data can be found in the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) database. As a community-driven climate-impacts modelling initiative, ISIMIP offers a consistent framework for cross-sectoral, cross-scale modelling of the impacts of climate change.

Appendix 3—Resources on climate data

Table 18: Transition risk data (UNEP FI, 2023)

Data source	Transition risks covered	Geographical coverage
CAIT Climate Data Explorer (by WRI)	GHG emissions, emission pathways, pledges, and targets	Global
CDP Open Data Portal	GHG emissions	Global
En-ROADS simulator	Different emissions pathways and drivers of temperature rise	Global
Greenhouse Gas Protocol	Product life cycle and corporate value chain (scope 3) GHG inventories	Global
IIEA Net Zero by 2050 scenario	Policy, technology, and market risks based on the IEA's net zero by 2050 scenario	Global, with breakouts by region at a high level

IIASA scenario explorer	Policy, technology, and market risks based on a wide range of IPCC 1.5°C scenarios	Global, regional, and national at varying degrees of specificity
IMF World Economic Outlook	Macroeconomic forecasts/ scenarios that can be used to understand potential policy, technology, and market shifts	Global, regional, and national
IPCC emissions factor database	Emission factors for various activities	Global with some regional variation
NGFS scenario portal	Policy, technology, and market risks based on the NGFS scenarios	Global, breakout into specific regions and national level downscaling
SENSES project on climate scenarios	Policy, technology, and market risks based on a wide range of IPCC 1.5°C scenarios	Global
The Lowdown v2.0	Coal capacity for countries	Global
UN data	Methane, carbon dioxide (CO_2), HFCs, Nitrous oxide, Nitrogen trifluoride, PFCs, and Sulphur hexafluoride	Data for 43 countries, available for 29 years

Table 19: Physical risk data (UNEP FI, 2023)

Data Source	Physical hazards covered	Geographical Coverage
CDP Open Data Portal	Storms, extreme heat, sea water intrusion, droughts, floods, and forest fires	1,224 cities, states and regions
Climate Central	Extreme sea levels, storm surge data, high tide events, coastal flooding, sea level changes, and severe winds	Global
Climate Impact Explorer by Climate Analytics	Temperature rise, seasonal precipitation, sea level rise, and extreme weather events, such as floods, droughts, and heatwaves	Global
GFDRR ThinkHazard!	Extreme heat, floods, earthquakes, land-slides, sea level rise, water scarcity, and wildfires	Global
Google Dataset Search	Hurricanes, sea level rise, and temperature rise	Global
INFORM index	Variety of quantitative factors and resources to support physical risk assessments	Global
IPCC Assessment Report 6: Impacts, Adaptation, Vulnerability	Latest report on impacts of physical hazards, adaptation, and vulnerabilities to climate change	Global

IPCC Assessment Report 6: The Physical Science Basi	All major physical risk hazards	Global
KNMI—Climate Explorer	Temperature rise, droughts, cyclones, and precipitation	Global
Oasis Hub	Flooding, cyclones, earthquakes, extreme weather, and landslides	Global
PREPdata	Temperature rise, precipitation, coastal risks, water risks, and other extreme events	Global
UNEP Global Risk Data Platform	Tropical cyclones, storm surges, droughts, earthquakes, fires, floods, and landslides	Global
World Bank Climate Change Knowledge Portal	Temperature rise, seasonal precipitation, sea level rise, extreme weather events, such as floods, droughts, and heatwaves	Global
WRI Aqueduct Water Risk Atlas	Water risks, including flooding and droughts	Global

Table 20: Examples of data and sources for climate-related risk management

Data	Source	Link
Carbon emissions	International Energy Agency	Link
	Worldometer	Link
	European Commission (EDGAR)	Link
	Bloomberg	Link
	US Environmental Protection Agency (EPA)	Link
Energy supply	International Energy Agency	Link
ESG scores	Sustainalytics	Link
	MSCI	Link
	LSEG	Link
	S&P	Link
	Bloomberg	Link
Credit ratings	S&P Global	Link
	Fitch	Link
	Moody's	Link
Climate adaptation	European Commission, European Energy Agency (EEA)	Link
	International Monetary Fund (IMF)	Link
	CMRA (US only)	Link

Implied temperature	Climate Action Tracker	Link
	MSCI	Link
	International Monetary Fund (IMF)	Link
	World Bank	Link
	European Commission, Copernicus	Link
Green bonds	Climate Bond Initiative	Link
	LUXSE/LGX	Link
	International Monetary Fund (IMF)	Link
	Bloomberg terminal	Link

UN environment programme

finance initiative

UNEP Finance Initiative brings together a large network of banks, insurers and investors that collectively catalyses action across the financial system to deliver more sustainable global economies. For more than 30 years the initiative has been connecting the UN with financial institutions from around the world to shape the sustainable finance agenda. It has established the world's foremost sustainability frameworks that help the finance industry address global environmental, social and governance (ESG) challenges. Convened by a Geneva, Switzerland-based secretariat, more than 500 banks and insurers with assets exceeding US$100 trillion work together to facilitate the implementation of UNEP FI's Principles for Responsible Banking and Principles for Sustainable Insurance. Financial institutions work with UNEP FI on a voluntary basis and the initiative helps them to apply the industry frameworks and develop practical guidance and tools to position their businesses for the transition to a sustainable and inclusive economy.

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