UN environment programme

finance initiative

UNEP FI's Comprehensive Good Practice Guide to Climate Stress Testing

Contents

Figures and tables

Acknowledgements

Authors

UN Environment Programme Finance Initiative (UNEP FI)

David Carlin, TCFD Programme Lead
Maheen Arshad, TCFD Programme
Emily Fraser, Copy Editor

External Collaborators

Vincent Noinville, Independent Expert

Project Management

The project was set up, managed and coordinated by UNEP FI, specifically: Remco Fischer and David Carlin.

The pilot project was led by a Working Group of 45 banks and investors convened by UNEP FI:

ABN-AMRO
Access Bank
AIB
Bank of America
Bank of Ireland
Banorte
Barclays
BBVA
Bentall Green Oak
BMO
Bradesco
Caixa Bank
CDL
CIB
CIBC
Citibanamex
Credit Suisse
Danske Bank
Desjardins
DNB
EBRD
FirstRand
FTF
ING
Intesa Sanpaolo
Investa
Itau
KB FG
KBC
Linkreit
Manulife
Mizuho
MUFG
NAB
NatWest
NIB
Rabobank
RBC
Santander
Scotia Bank
Standard Bank
Storebrand
TD Asset Management
TSKB
UBS
Wells Fargo

Acronyms

ACPR	Autorité de contrôle prudentiel et de résolution (France)
AFM	Authority for the Financial Markets (Netherlands)
AI	Artificial Intelligence
AIM	Asia-Pacific Integrated Model
ALM	Asset and Liquidity Management
APRA	Australian Prudential Regulation Authority
AR5	Fifth Assessment Report
AR6	Sixth Assessment Report
BCBS	Basel Committee on Banking Supervision
BdF	Banque de France
BIS	Bank for International Settlements
BOC	Bank of Canada
BoE	Bank of England
BPI	Bank Policy Institute
CAIT	Climate Analysis Indicator Tool
CARMA	Carbon Monitoring for Action
CA100+	Climate Action 100+
CBES	Climate Biennial Exploratory Scenario
CBIRC	China Bank and Insurance Regulatory Commission
CCS	Carbon capture and storage
CDC	Centers for Disease Control and Prevention (USA)
CDP	Carbon Disclosure Project
CDR	Carbon Dioxide Removal
CEO	Chief Executive Officer
CFRF	Climate Financial Risk Forum
CICERO	Centre for International Climate Research (Norway)
CMIP	Coupled Model Intercomparison Projects
CO_2	Carbon Dioxide
COP	Conference of the Parties
COP26	Twenty-sixth session of the Conference of the Parties to the UNFCCC
CVA	Climate Vulnerability Assessment
DNB	De Nederlandsche Bank
EAD	Exposure at Default

EBA	European Banking Authority
ECB	European Central Bank
ESG	Environmental, Social and Governance
EU	European Union
FCA	Financial Conduct Authority (UK)
FSAN	Financial Supervisory Authority of Norway
FSB	Financial Stability Board
GAR	Green Asset Ratio
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GFC	Global Financial Crisis
GFDRR	Global Facility for Disaster Reduction and Recovery
G20	Group of Twenty
HKMA	Hong Kong Monetary Authority
HQLA	High quality liquid assets
ICAAP	Internal Capital Adequacy Assessment Process
IEA	International Energy Agency
IFF	Institute of International Finance
IFRS	International Financial Reporting Standards Foundation
IIASA	International Institute for Applied Systems Analysis
IIF	Institute of International Finance
ILAAP	Internal Liquidity Adequacy Assessment Process
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
ISIMIP	Inter-Sectoral Impact Model Intercomparison Project
IT	Information Technology
ITS	Implementing Technical Standards
I4CE	Institute for Climate Economics
JGCRI	Joint Global Change Research Institute
KNMI	Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorological Institute)
KPIs	Key Performance Indicators
LGD	Loss Given Default
MAS	Monetary Authority of Singapore
NDCs	Nationally Determined Contributions
NGFS	Network for Greening the Financial System
NGO	Non-Governmental Organisation
NIES	National Institute for Environmental Studies
NIESR	National Institute of Economic and Social Research
NZ	Net Zero
NZAOA	Net-Zero Asset Owner Alliance

NZE2050	Net-Zero Emissions 2050
OSFI	Office of the Superintendent of Financial Institutions (Canada)
PBL	Netherlands Environmental Assessment Agency
PBOC	People's Bank of China
PCAF	Partnership for Carbon Accounting Financials
PD	Probability of Default
PFH	Planning for Hazards
PIK	Potsdam Institute for Climate Impact Research
PRA	Prudential Regulation Authority
PREP	Partnership for Resilience and Preparedness
PRI	Principles for Responsible Investment
RBNZ	Reserve Bank of New Zealand
RCP	Representative Concentration Pathway
RST	Reverse Stress Tests
RWA	Risk-Weighted Assets
SCAP	Supervisory Capital Assessment Program (USA)
SCMP	South China Morning Post
SDS	Sustainable Development Scenario
SMF	Senior Management Function
SMU	Singapore Management University
SREP	Supervisory Review and Evaluation Process
SSM	Single Supervisory Mechanism
SSP	Shared socioeconomic pathway
SSRN	Social Science Research Network
STEPS	Stated Policies Scenario
TCFD	Task Force on Climate-Related Financial Disclosures
TVFs	Transition Vulnerability Factors
UK	United Kingdom
UN	United Nations
UNEP	UN Environment Programme
UNEP FI	UN Environment Programme Finance Initiative
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
USD	United States Dollar
WEM	World Energy Model
WEO	World Economic Outlook
WIOD	World Input-Output Database
WRI	World Resources Institute

1. Executive summary

1.1 Overview

Across the world, financial actors have acknowledged the growing risks of climate change to financial stability. Financial regulators, such as central banks, have a clear mandate to ensure financial stability, and as such, must be able to systematically assess climate risks. To understand exposures, risks and resiliency, these supervisors have turned to a common tool: scenario-based stress testing. After the Global Financial Crisis (GFC), traditional stress tests became an integral part of a financial institution's risk management toolkit with regulators conducting large-scale supervisory stress tests.

A climate stress test is a forward-looking exercise designed to measure a financial institution's exposure to climate risks, using scenario analysis including severe climate risks, to assess the potential impact of climate change on the institution's business model. Climate stress tests may leverage significant elements of traditional capital stress testing, but also contain a number of important differences. Institutions can and should leverage the knowledge and skills developed through years of post-GFC stress testing, but will also need to adapt to meet the emerging challenges of conducting a climate stress test.

This report, published as part of United Nations Environment Programme Finance Initiative (UNEP FI) Phase III Task Force on Climate-Related Financial Disclosures (TCFD) programme, aims to provide a detailed user guide for financial institutions looking to understand the nature of new climate stress tests and develop effective plans for executing them. The report was created to assist financial institutions in their climate stress testing journey and should be adapted to meet the needs of a given firm.

Financial practitioners who read this report will benefit from exposure to five major content areas:

- Emerging climate stress testing requirements and the landscape of test structures;
- Best practices for climate stress testing team organisation and the skills required;
- Best practices for climate stress testing data requirements and collection;
- Best practices for selecting the scenarios and models to use in climate stress testing; and
- Best practices for how climate stress testing outputs can and should be applied to meet regulatory requirements and produce useful internal insights.

1.2 Key takeaways

1.2.1 Team organisation and skills

Key messages

- Institution-wide team engagement is required for climate stress testing, with firms assigning responsibilities to a large number of teams from across the organisation.
- Firms should devote appropriate resources (financial and human) to the execution of climate stress testing, with a specific focus on the activities of data collection and analysis, model development and strategic planning.
- A large body of knowledge and skills will need to be developed in-house to reach a satisfactory level of proficiency in running climate stress tests.
- Climate-related training and knowledge development programmes need to be geared towards a diverse set of teams across the firm, rather than just client-facing employees.
- Financial institutions will need to make substantial changes to their organisation including the development of a climate risk team with adequate resources, executive sponsorship and authority to oversee, coordinate and manage the climate stress test.
- Adequate resourcing should be implemented to integrate climate stress testing into the firm's organisational structure and processes with robust governance and oversight.

Climate stress testing is a full institutional endeavor. It demands engagement from business lines, risk teams and support from senior leadership. This report explores the different roles and skills those teams need to play in executing a climate stress test. As shown below, a diversity of teams and skills are involved in both traditional stress testing and climate stress testing. However, climate stress testing also demands new skills and new modes of engagement from traditional stress testing.

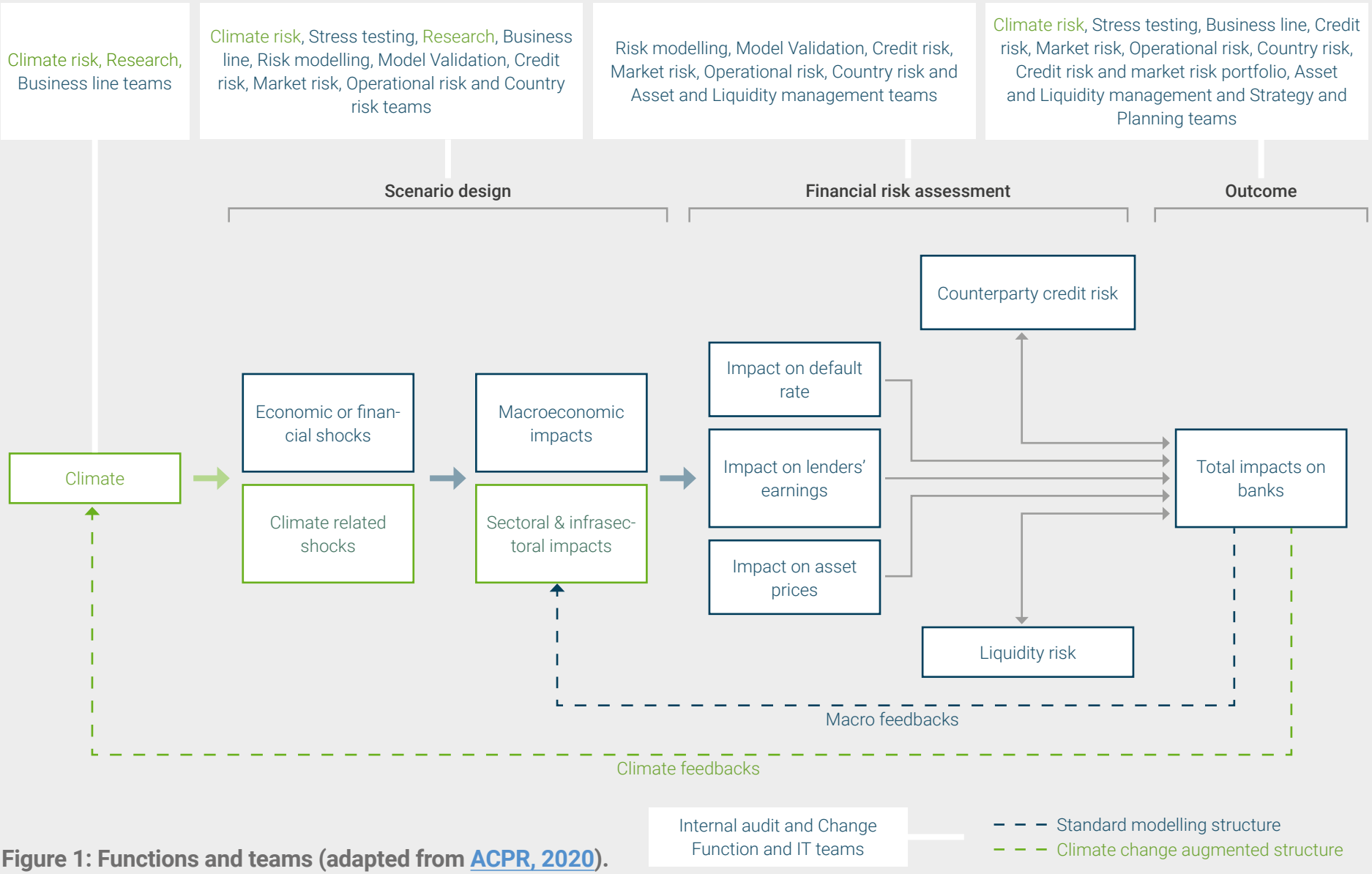

Figure 1: Functions and teams (adapted from ACPR, 2020).

Climate stress testing will require these teams and functions to have varying levels of proficiency in key climate-specific skills and knowledge to ensure the effective design and execution of the exercise. Adequate resources must be devoted to the development of institutional knowledge around climate risks and climate data.

In order to do so, firms should establish staff roles and responsibilities related to climate stress testing, develop policies and procedures inclusive of these roles, appoint climate risk specialists/ambassadors in each team and provide adequate training by experts. It is also recommended that firms establish a firm-wide programme for climate knowledge development to further build organisational expertise. Firms may also rely on external support for skills or knowledge they lack in-house, in the form of external consultants and contractors, national and industry associations and international initiatives.

It is important that climate stress tests are embedded into a firm's current risk processes, with senior management and the board actively engaged in the governance, implementation and management of the programme. It is also recommended that a firm-wide risk committee be established for climate risk.

Financial institutions will have to make substantial changes to integrate climate risk assessment into existing risk and stress testing frameworks. Recommended good practices for embedding climate stress testing into current institutional frameworks include:

- Developing a climate risk team with adequate resources, executive sponsorship and authority to oversee, coordinate and manage the climate stress test;
- Establishing a climate risk research and intelligence function;
- Managing climate-related data centrally;
- Fostering collaboration among a range of senior experts; and
- Establishing a cross-functional project team to design and execute the climate stress test.

1.2.2 Data requirements and collection

Key messages

- Data needed for a climate stress test can be divided into two main categories—traditional macro-financial (macroeconomic as well as financial) data and climate-related (industry-specific, weather-related) data. However, collecting climate data can be a challenge for many financial institutions.
- For effective climate stress testing, firms should develop policies and procedures to support the collection, processing and use of climate data.
- Good practices for collecting data involve identifying data needs, understanding the availability of data sources, implementing industry standards, validating data, identifying data gaps and adapting institutional systems.
- Best practices for securing climate data on and from clients can be divided into three categories: (i) steps firms can take in-house and through collaborations, (ii) steps requiring client engagement, and (iii) steps to build robust data collection processes in the future.
- When collecting emissions data, firms should identify internal sources through which emissions data for clients can be accessed and develop internal tools to calculate emissions data.
- When collecting climate data from external data providers, it is recommended that firms develop an internal policy, identify easily accessible open-source platforms, develop a questionnaire based on the institution's data needs and actively communicate with data providers.
- Adapt existing downstream models, for example loss forecasting models, to incorporate climate-related variables

Collecting climate-related data is a new demand for many institutions that brings with it new challenges. Issues may be encountered due to limited data availability, lack of data quality, limited granularity and coverage, limited comparability and standardisation and difficulty integrating the data into financial processes. In order to overcome these obstacles, firms should develop policies and procedures to support the collection, processing and use of climate data.

Good practice steps for collecting internal and external data include:

- Identifying the firm's data needs for the exercise;
- Exploring a wide range of sources and selecting the most suitable;
- Implementing industry standards;
- Establishing and documenting a clear data validation process;
- Identifying data gaps; and
- Adapting institutional systems and developing methodologies to implement policies and procedures for data collection.

Counterparty-level modelling demanded by some climate stress tests poses its own unique set of challenges. Below we provide recommended guidance for collecting client data for counterparty analysis.

Steps firms can take in-house and through collaborations	▪ Attempt to collect as much climate data on the client using in-house capabilities. ▪ Increase stakeholder collaboration by collaborating with regulators, municipalities and governments. ▪ Develop industry partnerships to provide tools and support to clients to produce data.
Steps requiring client engagement	▪ Take part in open and effective communication with the client on the required data. ▪ Update current client engagement processes by integrating data requirements for climate stress testing.
Steps to build robust data collection processes in the future	▪ Develop questionnaires based on data needs to act as a guide for both the bank and the client for collecting necessary information. ▪ Integrate the use of Geographic Information Systems (GIS) to gather geospatial data.

Financial institutions may also need to collaborate with external data providers to access required data. External providers include open data sources, commercial data sources, scenarios and models. When gathering climate risk data from external data providers, it is recommended that firms:

- Develop internal policies for gathering climate data from external data providers;
- Identify potential data providers and open-source platforms to access required data;
- Develop a questionnaire based on the institution's data needs to determine coverage and methodologies; and
- Actively communicate with data providers, including taking part in initiatives designed to assist data collection.

1.2.3 Scenarios and models

Key messages

The modelling process in a climate stress test consists of modelling climate variables, measuring the impact of climate risks on macroeconomic variables, breaking down the macroeconomic impacts per sector or per portfolio and quantifying the impact on the financial institution. Firms should:

- Adapt reference scenarios geographically and sector-wise and derive the impact on key drivers to develop a relevant scenario narrative;
- Implement a process to integrate the latest scenario developments and emerging methodology standards into the scenario design for climate stress testing;
- Undertake scenario expansion to extrapolate the additional scenario variables required for the climate stress test; and
- Improve modelling capabilities, through identifying gaps in current in-house models and enhancing communication with external modelers and academics on scenario expansion and understanding of different models.

Climate scenario analysis is at the core of climate stress testing. Scenario analysis for a climate stress test includes four main steps—scenario selection, variable selection, modelling for risk quantification, and using the outputs for risk assessment. Scenario and variable expansion are often required to produce credible outputs for diverse geographies, sectors and asset types.

Climate scenarios include physical and transition risk variables which are then combined with macroeconomic and financial variables to quantify the impact of climate risks in a specific scenario. Climate risk variables commonly include physical hazards, carbon price, energy price, energy consumption and greenhouse gas (GHG) emissions. Macroeconomic variables commonly include gross domestic product (GDP), unemployment and inflation. Financial institutions may be required to undertake expansion to extrapolate additional variables for the scenarios. It should be noted that some current internal and regulatory climate stress tests may look at a single aspect of climate risk (transition or physical risk). While this may not give a comprehensive picture of all climate risks faced, these exercises still yield a large amount of valuable information for a firm.

When using climate scenarios, good practices for selection, expansion and assessment include the following:

1. Conduct portfolio analysis to understand which portfolios need to be stressed for climate risks;
2. Select a relevant scenario horizon;
3. Identify key climate and economic drivers;
4. Develop criteria for selecting reference climate scenarios;
5. Determine relevant regions and sectors for the scenario;
6. Consider assumptions in relation to the scenario pathways;

7. Adapt/expand the reference scenarios geographically and sector-wise if granularity is insufficient;
8. Derive the impact on the identified key drivers to develop a relevant narrative;
9. Assign responsibility to a team to keep up-to-date with the latest developments in scenario development; and
10. Implement a process to integrate these developments into the scenario design.

The modelling process in a climate stress test requires the use of a combination of various models. Figure 2 below provides a break-down of the modelling approach for a climate stress test.

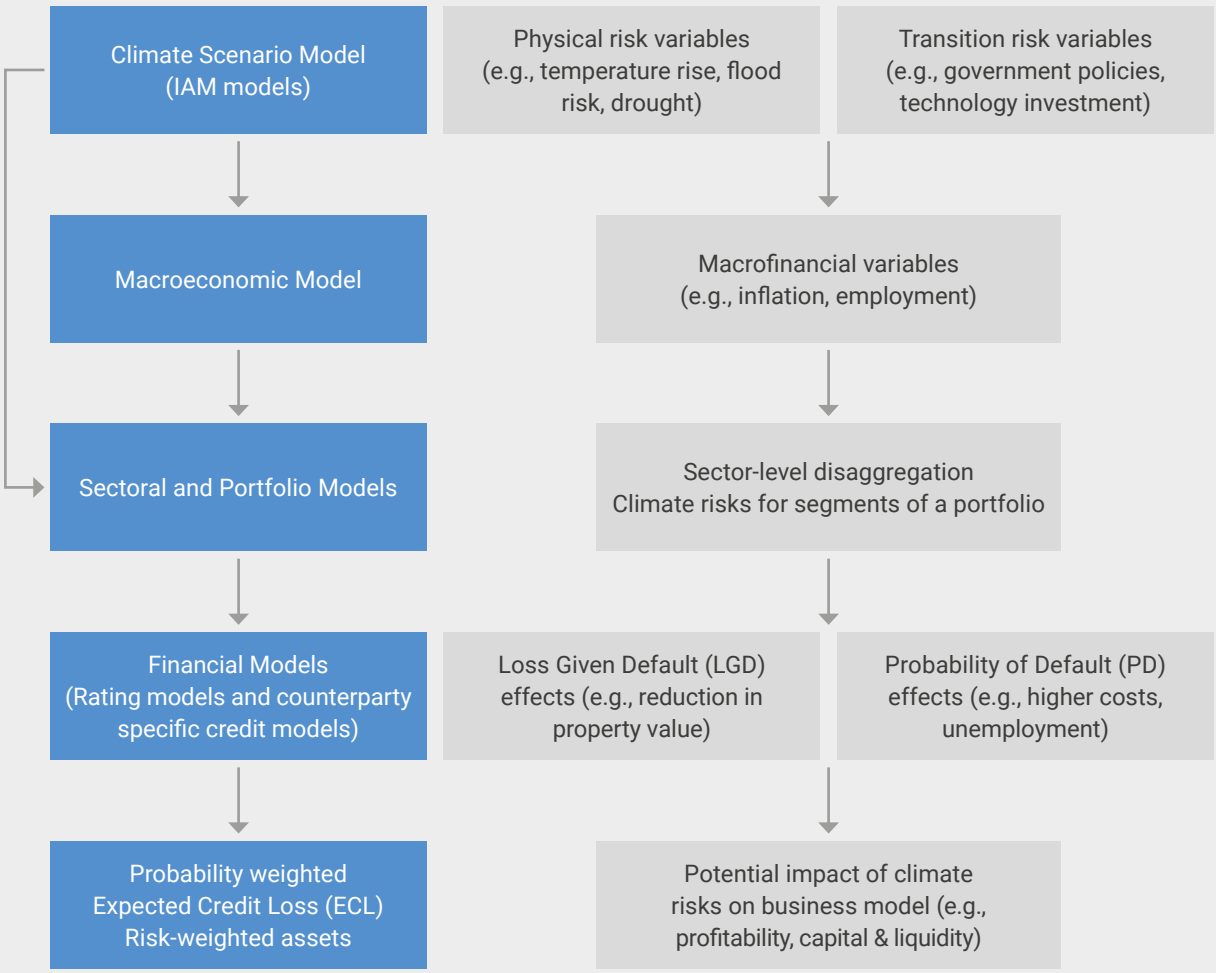

Figure 2: Modelling Approach for Climate Stress Testing.

When conducting modelling for a climate stress test, it is recommended that firms:

- Determine the parameters required for the modelling;
- Define the objective, inputs and outputs and the required components for each model in the approach;
- Develop a range of criteria to determine the types of models to be used for the analysis;
- Survey existing models and providers to onboard;
- Identify gaps in the current in-house models;
- Increase coordination with external modelers and academics for scenario expan-

sion and to improve understanding of different models;
- Improve collaboration with local modelers and institutions; and
- Further develop in-house modelling capabilities aligned with the guidance and specifications provided by supervisory authorities.

1.2.4 Outputs and applications

Key messages

- Supervisory climate stress tests have a wide range of applications, including being a learning exercise to mobilise and raise the firm's awareness of climate risks, encouraging boards to understand the challenges and take a strategic approach to managing risks, improving a firm's climate risk management, modelling and data, and improving a firm's climate-related disclosures.
- Firms need to ensure clear, consistent and wide-ranging coordination and ensure climate stress tests are a key opportunity to learn and trigger action.
- A climate stress test approach should initially be kept simple and focused on material exposures.
- Results can be further leveraged to improve a firm's climate risk management and help set the risk appetite, support the firm's strategy, customer engagement and investment, and support the firm's external disclosures and compliance.

Climate stress testing can produce a wealth of qualitative and quantitative outputs of interest to both supervisors and internal stakeholders. There are a number of ways in which climate stress test results can be effectively used to better manage overall financial system risks, as well as individual institutional climate risks. Current applications for climate stress tests include:

- Mobilising and raising an institution's awareness of climate-related risks;
- Encouraging boards to understand the challenges and take a strategic, long-term approach to managing climate risks;
- Identifying gaps in climate expertise and resources required to assess and manage climate risks; and
- Improving the institution's climate-related disclosures.

Beyond the immediate benefits of the exercise, climate stress testing outputs can be leveraged for further key uses, for example to:

- Improve understanding of the business' vulnerabilities, to inform risk appetites and set targets and limits;
- Develop risk management and mitigation strategies;
- Inform proposed shifts in business strategy;
- Inform customer engagement, especially in vulnerable sectors;
- Provide direction for the firm's climate data and infrastructure investments; and
- Provide value-adding management information and enhanced external reporting and disclosures.

In order to best use the outputs of a climate stress test, climate stress testing exercises need to be effectively communicated across the firm and at all levels of management, they should be a learning opportunity and should trigger action. The climate stress testing approach should be simple and focused on material exposures and the climate risk assessment should be fully leveraged to drive change and improve business performance in light of climate change.

As climate stress testing is still in its early stages, many financial institutions find conducting a test to be a challenging endeavor. This report provides detailed guidance on best practices and regulatory expectations for the climate stress testing process.

Going forward, financial institutions, regulators, climate scientists, modelers, research institutions and other relevant stakeholders should work in harmony to maximise the potential for climate stress testing to be a tool that promotes financial stability, reduces climate risks and accelerates the climate transition.

2. Introduction: The increasing prevalence and relevance of climate stress testing

2.1 Importance of addressing climate risks

As GHG emissions from human activities continue, the Intergovernmental Panel on Climate Change (IPCC) has warned that the planet has already warmed by over 1˚C above pre-industrial levels and could warm by nearly 4˚C by the end of century if emissions are not reduced (IPCC, 2021). According to the latest science synthesised in IPCC reports, continued temperature rise could lead to severe economic, social and environmental consequences. Recognising the scale of these risks, in December 2015 nearly 200 governments took the initiative to strengthen the world's response to climate change by signing the Paris Climate Change Agreement. However, to reach the emission reductions goals that science says are necessary to keep planetary temperatures within safe levels, fundamental shifts are required across the global economy. These shifts to a low-carbon future bring with them distinct challenges and risks for economic sectors.

Financial actors are confronting the looming physical risks of climate change and the increasing transition risks inherent to a low-carbon transition (Figure 3). Being able to better price these risks would help promote financial stability, ensure appropriate allocation of capital to support resilience and adaptation, and hasten the transition to a sustainable future. With these objectives in mind, the Financial Stability Board of the G20 launched the Task Force on Climate-Related Financial Disclosures (TCFD) to improve climate-related risk disclosures. The TCFD issued its first recommendations in 2017 and has issued further guidance in the years that have followed.

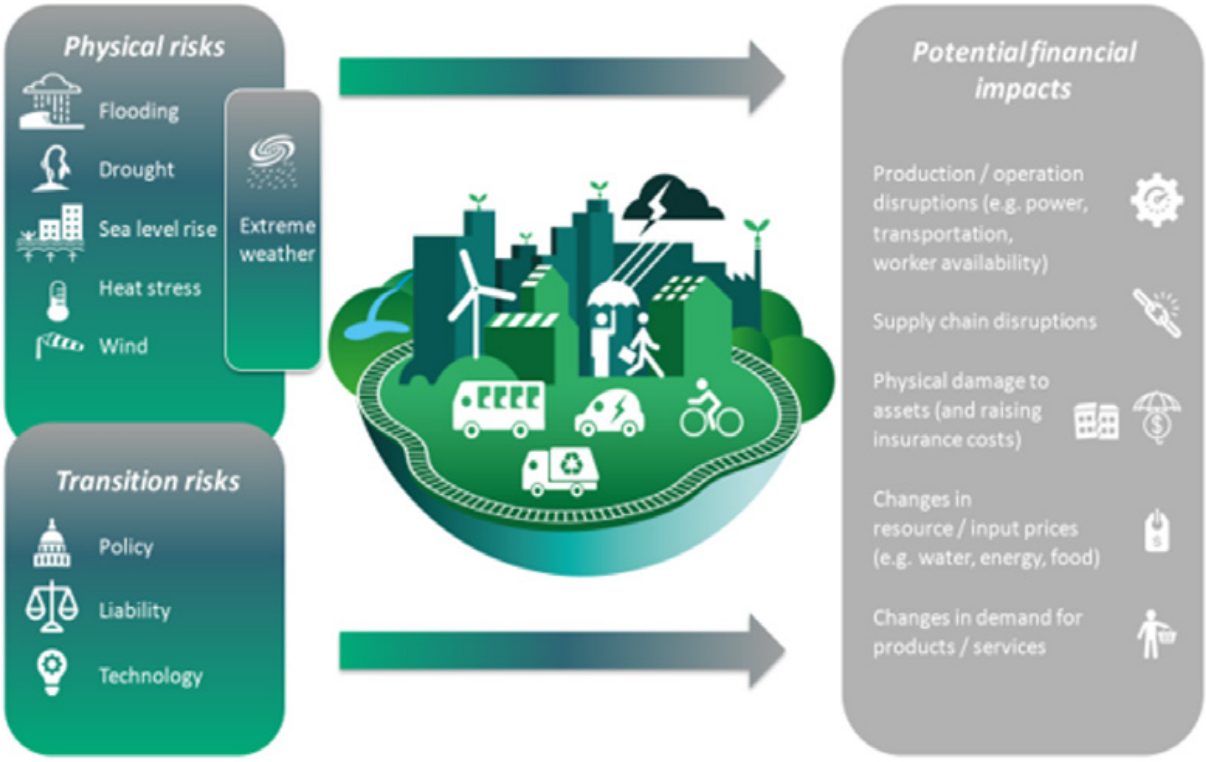

Figure 3: Potential financial impacts of physical and transition risks (CICERO, 2017).

Physical risks are risks associated with the impact of changes in weather and climate, on the economy. Physical risks can be acute in nature, like floods, heatwaves and wildfires, or chronic in nature, such as sea level rise, temperature changes and precipitation changes. The accumulation of acute and chronic physical risks has the potential to cause damage to physical assets, and also negatively affect sectors that are reliant on natural resources and disrupt supply chains. Both acute and chronic physical risks can pose financial risk for firms. For example, physical risk drivers have the potential to negatively impact a borrower's ability to repay a loan due to negative wealth effects. Climate events can cause damage to physical assets of banks' counterparties causing a reduction in the asset value. Damaged assets will lead to a reduction in income which increases the likelihood of a borrower defaulting, posing credit risk for the firm (BIS, 2021). Weather events increasing in frequency, severity and uncertainty also have the potential to create high volatility in financial markets resulting in market risks, and have the potential to disrupt operational ability increasing costs for firms (BIS, 2021).

Transition risks are related to changes in legislation, policies, technology and the market, during the transition towards a low-carbon economy (TCFD, 2017). For example, transition risks can be related to a growing number of jurisdictions that are implementing policies to reduce emissions, technological innovation for less carbon-intensive technology, increasing consideration of climate risks by investors in their decision-making and shifts in consumer sentiments towards lower carbon emissions (BIS, 2021). If a business model of a firm does not adapt to a low-carbon economy, it has the potential to face losses (IMF, 2019). More explicitly, shifts in asset values and higher costs may lead to lower profit margins (IMF, 2019). Transition risks can also give rise to financial risks for financial institutions. For example, implementation of a

carbon tax can increase operating costs for businesses, reducing earnings which can impact their ability to repay loans. Similarly, a low-carbon transition can lead carbon-intensive assets, such as fossil fuel reserves and coal mines, to become stranded assets and devalue, impacting business income. Changes in policies, technological advances and investor behavior can impact borrowing costs and cause a sudden repricing of financial assets. A rapid transition could also lead to sudden shifts in prices, resulting in market risks for firms (BIS, 2021). A transition to a low carbon economy also has the potential to impact countries which receive most of their income from fossil fuels.

Significant losses in GDP, vulnerable infrastructure, lowered productivity and the vulnerability of carbon-reliant sectors, are just a handful of ways in which climate risks will impact the global economy. In addition to economic impacts, it is also important not to underestimate the health and social impacts of climate change. Climate change can limit food and water supply access, causing malnutrition and diarrheal disease. Environmental and living degradation caused by climate change can also lead to internal struggles—such as civil conflicts, forced migrations and an overall perpetuation of social inequality. Further, increased pollution may worsen cardiovascular diseases and respiratory complications, extreme heat may give rise to heat-related illnesses, and severe weather events can lead to injuries, fatalities and negative mental health impacts (CDC, 2021).

Understanding the financial implications of climate change, central banks and policymakers have begun working towards gaining insights into the potential impacts of climate risks on the financial system. One way to do this is by developing stress-testing methodologies that identify climate risks. This report provides best practice guidance for financial institutions on conducting a climate stress test. Section 3 of the report gives an overview of the regulatory climate stress testing landscape and how climate stress tests differ from traditional stress tests. The remaining sections present recommended guidance on four key components for conducting a climate stress test—(1) team organisation and skills, (2) data requirements and collection, (3) scenarios and models and (4) applications of the outputs/results. Together these sections provide clear and concise recommendations on best practices for conducting a climate stress test.

2.2 History of stress testing

Scenario-based stress testing was first adopted by financial institutions in the 1990s but was only used in small-scale isolated exercises with risk managers using historical events as worst-case scenarios. In 2008, the GFC resulted in severe stress causing numerous metrics to reach levels that had not been witnessed since the Great Depression, with regulators realising that the failure of financial institutions could lead to widespread economic harm. The GFC helped identify key gaps in risk management practices across the financial industry at the time, highlighting the need to develop stress testing frameworks with scenarios of severe stress.

Following the recession, stress testing transitioned to a large-scale, comprehensive programme overlooked by regulatory authorities. The first example of a large-scale exercise was the US Supervisory Capital Assessment Program (SCAP) in 2009, which

has been recognised as contributing to the stabilisation of the US financial system. The SCAP was later followed by traditional stress test exercises in other countries, including the European Banking Authority (EBA) and the Bank of England (BoE) (Bank of England, 2016).

Now, traditional stress testing is an integral part of a financial institution's toolkit. A traditional stress test is used to measure the capital resiliency of a financial institution to severe, hypothetical scenarios. The results of a stress test are then used by central banks and regulators to understand risks, adjust capital requirements and develop policy for financial resilience. Over recent years, the stress test has been developed to measure a wide range of resilience metrics (Bank of England, 2016).

Appreciating that stress testing has become a vital tool for risk managers to understand if an institution can withstand severe situations, firms have started using stress testing as a methodology for assessing climate risks. Since assessing climate risks requires forward-looking data and stress tests are forward-looking exercises, they are well designed to measure a firm's exposure to climate risks and their potential impact on business strategies (BIS, 2021), contrary to traditional risk management techniques that rely on historical data and statistical risk modelling.

The use of stress tests to measure the potential impact of climate risks on the financial sector is rapidly evolving (Deloitte, 2020). With the growing uptake of the recommendations by the TCFD, financial institutions have been adapting methodologies to more specifically quantify their exposure to climate risks.' The first climate stress testing exercises by central banks and supervisors took place under the initiative of the Network for Greening the Financial System (NGFS), with the aim of raising awareness of climate risks among firms and to expand methodologies for measuring climate risks. Though climate stress testing is still in its early stages, several jurisdictions have now announced their intention to conduct climate stress tests (see section 3.3.1) (I4CE, 2021).

2.3 Overview of the UNEP FI TCFD programme and climate stress testing

Since the publication of the Financial Stability Board's (FSB) TCFD recommendations in 2017, UNEP FI has convened pilot programmes with a consortium of banks and investors to assist them in implementing the TCFD framework and issuing meaningful climate disclosures. Almost 100 financial institutions (banks, investors and insurers) globally have participated in these pilots and have been supported by nearly a dozen technical partners from climate modelers to climate risk experts. The pilot programmes have created numerous tools, frameworks and guides to empower both participating institutions and those throughout the financial industry to better manage and disclose their climate risks.

The exercise began with a year-long programme known as 'Phase I' of UNEP FI's TCFD Programme, involving 16 international banks. The consortium of global banks collaborated to develop assessment approaches for physical and transition risks and opportunities. The pilot created methodologies that were adaptable and flexible to banks across geographies and that would promote consistency and comparability.

Following Phase I, Phase II expanded to include 39 banks, to enhance their climate risk toolkits and improve their climate-related disclosures. The programme worked to develop a variety of tools, frameworks and thought papers to drive the financial sector forward in identifying, assessing, managing and disclosing climate risks.

Phase III of the TCFD Programme further expanded to include nearly 50 global banks and investors. A larger group of participants has provided a range of perspectives from the financial sector which has led the programme to develop good practices for climate risk assessment and disclosure.

As part of one of the targeted modules, UNEP FI and industry experts delivered a series of seminars and interactive discussions on climate stress testing to participants in the TCFC banking pilot programme. This report aims to synthesise lessons from these sessions into a guide on best practices for climate stress testing for financial sector stakeholders.

3. Current state of climate stress testing

3.1 Comparison of stress tests

3.1.1 Purpose of traditional and climate stress tests

Purposes of a traditional stress test

A traditional stress test helps financial firms forecast their capital positions and infrastructure robustness under different hypothetical, severe economic shocks. It is designed to determine whether a bank would have enough financial resources to withstand extreme economic scenarios in the future and support the economy during economic downturns. As a result, a traditional stress test can serve various purposes. Firstly, a traditional stress test allows firms to identify and assess potential risks which can then be aligned with business strategies and risk management processes at the portfolio-level and institution-level (BIS, 2018). The exercise can help firms identify risks which would have otherwise been overlooked. Traditional stress tests can complement other risk quantification tools, support risk quantification methodologies and provide perspectives on the validity of statistical models (OSFI, 2009). Traditional stress testing also plays an important role in supporting capital management for firms by identifying severe events or changes in market conditions that could impact the institution and assess its solvency (OSFI, 2009). Similarly, the results can also be used in identifying, measuring and controlling funding liquidity risks (OSFI, 2009). Results also help regulators identify which firms do not have adequate capital and help prevent them from defaulting. Authorities also use the results for policy decisions, such as setting minimum capital requirements and bank capital buffer levels (Bank of England, 2016).

Purposes of a climate stress test

A climate stress test assesses banks' vulnerability to the effects of climate change, to better understand the financial risks that the global financial system faces from global warming and how banks' business models could be affected. A climate stress test can be conducted for various purposes. Most importantly, climate stress testing results can be incorporated into an institution's risk management and risk appetite processes. The test identifies new types of risks over a new risk horizon. Exercises are designed to identify and address existing gaps in climate risk assessment, including data quality, and increase awareness among firms of climate risk management (BIS, 2021). Results can also be used to improve the allocation of assets and assess business strategies and planning.

3.1.2 Comparing key features of traditional and climate stress tests

In order to perform forward-looking analysis to assess the vulnerability of financial institutions to climate-related shocks, key features of a traditional stress test have had to be adapted. Differences in features between the two test types include scenario design, time horizon, data and models required, risk types assessed, as well as the outputs and applications of the exercise. Below we provide a detailed comparison between a traditional stress test and a climate stress test (Table 1).

Table 1: Comparison of key features of traditional and climate stress testing.

Characteristic	Traditional Stress Test	Climate Stress Test
Planning horizon	▪ Short time horizon. ▪ Varies between institutions but usually ranges from three to five years. ▪ Examples: ▫ US Federal Reserve: Nine quarters. ▫ Bank of England (BoE): Five years. ▪ Liquidity stress tests are short, ranging from a day to a few months.	▪ Long time horizon. ▪ Varies between institutions but commonly between 30 and 50 years. ▪ Longer time horizons let climate risks materialise but increase uncertainty. ▪ Integration of short and medium-term effects into the exercise is important because: ▫ A low-carbon transition can occur sooner than expected; and ▫ Impacts of physical risks have already begun to materialise.
Balance sheet behaviour over stress horizon	▪ Assume bank balance sheet remains static.	▪ Balance sheets can be static or dynamic. ▪ Some assume that the bank balance sheet remains static, however this assumption is unrealistic due to the nature of the long horizon. ▪ However, strong assumptions are required to model the balance sheet in the dynamic model.

Characteristic	Traditional Stress Test	Climate Stress Test
Number, granularity and types of scenarios used	▪ Typically, three scenarios: ▫ Baseline scenario; ▫ Adverse scenario; and ▫ Can also include a severely adverse scenario. ▪ Adverse scenarios are more negative projections than the expectations of economic activity and financial market developments. ▪ One common scenario is the global market shock for financial institutions and significant trading exposures. ▪ Scenarios can mimic the 2008 GFC. ▪ Includes macroeconomic and market scenarios (both domestic and foreign): ▫ Unemployment rate; ▫ Asset prices; ▫ Gross Domestic Product (GDP); and ▫ Bond yields.	▪ Typically, between three to five scenarios, as several climate-related drivers need to be considered. ▪ Scenarios include climate change variables (physical and transition risks). ▪ Possible shocks include change in policy, energy and food prices, technologies, energy demand, or market confidence. ▪ Some financial shocks and variables used in traditional stress tests remain relevant, for example: ▫ GDP; ▫ Asset prices; and ▫ Default probabilities. ▪ Need to model interactions between climate, macroeconomy and the financial sector. ▪ Climate scenarios need to be more granular to effectively analyse borrower-level risks.

Characteristic	Traditional Stress Test	Climate Stress Test
Data and models	▪ Scenarios are calibrated on past events. ▪ Historical data available on losses and revenues. ▪ Loan portfolios analysis includes modelling of: ▫ Probability of Default (PD); ▫ Loss Given Default (LGD); and ▫ Exposure at Default (EAD). ▪ Trading losses: ▫ Applies risk-factor shocks to exposures. ▪ Operational risk: ▫ Models that relate to losses due to operational risks of economic conditions. ▪ Pre-provision net revenue modelling.	▪ Lack of historical data available on the relationship between climate risk and credit loss. ▪ Scenarios are built on existing research. ▪ Speculative judgement is needed on the impact of climate risks on expected loss. ▪ Lots of information and assumptions needed for counterparty projections across a long time horizon. ▪ Models can assess borrower-level risk: ▫ Reliable approaches focus on loan losses using PD framework. ▪ Models have potential to double count the impact of climate change on asset prices and credit losses. ▪ Results are dependent on emissions, technologies and policy assumptions for a given sector. ▪ Continued climate stress testing can improve data availability and help establish the relationship between climate risk factors & financial information.
Future consequences	▪ A bank must preserve or build up capital reserves. ▪ Banks need to reduce the capital distributed as dividends and share buybacks to shareholders. ▪ Imposition of fines.	▪ Currently, authorities publish results in aggregate, therefore individual institutions are not named. ▪ In the future, institutions may be penalised for not managing climate risks. ▪ Non-compliance may raise legal issues & damage firm credibility.

Characteristic	Traditional Stress Test	Climate Stress Test
Impacts of stress testing, including regulatory effects	▪ Intervention by regulators. ▪ Public information. ▪ Depositors can avoid weak banks. ▪ Use as a tool for measuring and managing future risks. ▪ Banks model capital effects of tail risks in loan books. ▪ Policy development for a resilient banking system.	▪ Climate stress tests are deemed exploratory at this time. ▪ Public information. ▪ Investors can avoid institutions with high implications of climate risks. ▪ To be used to inform the supervisory policy. ▪ Risk management: ▫ Used as a tool for identifying future climate risks; ▫ Banks can manage climate risks in their portfolios and loan books; ▫ Results can be incorporated into business strategy and planning; and ▫ Policy can be developed to address and build resilience to climate risks.
Limitations	▪ Historical data that may originate from aggregate sources with less-detailed data. ▪ Standardised data may skew data results that may be of limited use at the individual firm-level. ▪ Historical data may not fully capture future changes in the economic environment that can induce shocks.	▪ Lack of historical data, resulting in many assumptions based on current research. ▪ Potentially faulty data can give rise to false positives or negatives that can result in under-stressed or over-stressed guidelines.

Characteristic	Traditional Stress Test	Climate Stress Test
Risk types	▪ Gauges investment risk in order to measure: ▫ Asset viability; ▫ Internal processes & controls; ▫ Portfolio risk; and ▫ Overall institutional resilience. ▪ Assesses the following risks: ▫ Credit risk analysis for loan profiles; ▫ Market risk to assess the potential impact of severe market events; and ▫ Liquidity risk, as stress tests may help gauge which assets are more likely to inflict losses & damage business operations. ▪ Risk governance: ▫ Results help assess systemic risk potential for the economy. ▪ Results can be used to complement other risk quantification tools to: ▫ help complement risk quantification methodologies; and ▫ provide perspectives on validity of the statistical models.	▪ Measures potential impacts of: ▫ Physical risk; and ▫ Transition risk. ▪ Assesses physical & transition risks as risk drivers for financial risks. ▪ Currently, most climate stress tests are designed to assess credit risk, however there is potential for the test to look at other financial risks, such as: ▫ Market risk; ▫ Operational risk; and ▫ Liquidity risk. ▪ Additionally, stress tests may also include liability risks, which may arise due to inadequate action towards climate-related risks.

Characteristic	Traditional Stress Test	Climate Stress Test
Integration of results	▪ Asset Management: Firms are allowed to use results to understand how well assets stand up to market scenarios & external events, such as: ▫ Housing price indexes; ▫ Commercial real estate prices; ▫ Equity prices; and ▫ Stock market volatility. ▪ Risk management: Results can improve business insights by aligning potential risks & losses with proper risk strategies to minimise loss, for example: ▫ Re-evaluation of sectoral lending; ▫ Enhancement of credit rating systems; and ▫ Re-evaluation of risk appetite. ▪ Firms can use results to gauge investment risk, viability of assets & overall investment management. ▪ Results can help establish relationships between different capital holdings & their sensitivity to economic shocks. ▪ Results may help model customer behavior under extreme economic events. ▪ Results can help set in place strategies necessary to mitigate potential losses.	▪ Re-evaluation of business model, internal strategy and planning. ▪ Risk management: ▫ Insight as to which sectors are vulnerable to physical & transition risks; ▫ Re-evaluation of assets held in climate-sensitive sectors & classes; and ▫ Improved portfolio metrics going forward. ▪ Credit & price adjustments: ▫ Improved insight towards credit rating adjustments; and ▫ Enhanced ability to predict & model future price of climate risks. ▪ Sensible lending: ▫ Improved insight towards conditions to include when lending to vulnerable sectors.
Types of results provided	▪ Estimated losses & expenses resulting from various types of risks. ▪ Effect of revenues & expenditures on income. ▪ Potential effect of future operating, investing & cash position on cash-flows. ▪ Overall effect of assets, liabilities & capital level on the balance sheet.	▪ Identification of sectors and regions that are exposed to the potential impacts of climate risks. ▪ Distribution of risks by industries. ▪ Default probabilities to assess credit risk.

3.2 Top-down and bottom-up approaches to stress tests

There are two approaches for performing a stress test—a top-down and a bottom-up approach. A top-down approach is when a supervisory authority performs the test themselves, using their own framework, which includes a homogenised methodology, assumptions, scenarios and models. A bottom-up approach is when a firm uses its own framework as part of a system-wide or supervisory exercise (BIS, 2018). The type of approach used can influence the outputs of the stress test exercise. Both approaches have their benefits and drawbacks. Table 2 below provides an in-depth overview of both approaches for climate stress testing.

Table 2: Overview of top-down and bottom-up stress testing.

Types of Stress Tests	
Top-Down	**Bottom-Up**
▪ Conducted by regulatory authorities or central banks. ▪ The supervisory authority can define the exercise and estimate the magnitude of the impact from a climate shock. ▪ Participating firms may be asked to map the effects of the shock on their assets. (Climate Risk Review, 2020)	▪ Conducted by the firms themselves. ▪ Firms estimate their exposure to potential climate risks. ▪ It is possible for a regulator to provide guidance and direction on the scenarios to use, with the institution then running the scenario analysis and translating them for their counterparties. (Climate Risk Review, 2020; FSB,2020)
▪ Not as resource-intensive as a bottom-up approach for participating financial institutions (Climate Risk Review, 2020).	▪ Highly resource-intensive, requiring firms to use models and collect data at the firm-level (Climate Risk Review, 2020).
▪ Premise and constraints of the test are based on aggregate, macroeconomic assumptions & climate scenarios are adapted to be applicable towards domestic firms (Climate Risk Review, 2020).	▪ Where appropriate, the premise and constraints of the test can be based on a firm's own assumptions about what shocks may affect them & their business model (Climate Risk Review, 2020).
▪ Data is obtained from aggregate sources that are generally less granular to cover a wide range of participants (Climate Risk Review, 2020). ▪ Physical risk data is usually collected by geography by either using country databases to determine their vulnerability to physical risks or using an authority's own estimates for their jurisdiction (FSB, 2020). ▪ Transition risk data is collected using official sector datasets and survey data from financial institutions (FSB, 2020).	▪ Data originates from own firm and possibly third-parties, resulting in the use of more granular data for analysis (Open Risk Manuel, 2016).

Types of Stress Tests	
Top-Down	**Bottom-Up**
▪ Methodologies of a top-down approach can result in difficulties linking sectors and firms, to the degree to which the action of one sector or firm might affect the risks faced by others (FSB, 2020).	▪ Firms may have to use their own models to estimate their exposure to climate risks as a financial variable, which may require institutions to develop internal quantitative models (FSB, 2020). ▪ Disparity in the availability of resources and capital, as well access to modelling systems, between financial institutions can result in a skewed assessment of the financial system as a whole (Climate Risk Review, 2020).
▪ Test results can be compared firm-to-firm due to standardised nature of methodologies (Open Risk Manuel, 2016).	▪ Test results cannot be compared across firms since test methodologies can differ between firms (Open Risk Manuel, 2016).
▪ Individual firms may be less convinced of top-down test results & therefore less likely to implement recommendations based on the outputs of the exercise (Climate Risk Review, 2020). ▪ Generalised results present difficulties in linking relevant climate risks to specific firms, resulting in difficulties in taking appropriate action by institutions (Climate Risk Review, 2020). ▪ Results may give rise to static estimates that may give limited insight into how risks may change in the future and therefore can result in risks being under or over-estimated (FSB, 2020).	▪ Better at capturing firm-specific dynamics due to firms' own estimates of exposure which increases confidence in the usefulness of the results and its implementation in addressing climate risks by firms. ▪ Provides individual firms with the opportunity to underestimate climate risks in order to avoid undesirable outcomes. (Climate Risk Review, 2020)
Examples: DNB's energy transition risk stress test, and ECB's economy wide climate stress test.	Examples: BoE's CBES, and ACPR's climate pilot exercise.

3.3 Climate stress testing regulatory landscape

3.3.1 List of recent announcements and initiatives

Globally, a growing number of supervisory authorities have either conducted, are in the process of conducting or have announced plans to conduct a climate stress test. Table 3 below provides an overview of climate stress testing announcements and initiatives by the country members of the NGFS.

Table 3: List of announcements and exercises by countries for climate scenario and climate stress testing exercises (NGFS, 2021).

Member	Expected end date of the exercise	Balance sheet assumption	Approach	Level of granularity	Risk coverage	Time horizon
Autorité de contrôle prudentiel et de résolution (ACPR)/Banque de France	Concluded (May 2021)	Hybrid	Bottom-up	Sector	Physical, transition	30 years
Australian Prudential Regulation Authority (APRA)	Early 2022	Static, hybrid	Bottom-up, Top-down	Counterparty, macroeconomic, sector	Physical, transition	30 years
Banca d'Italia	Concluded	N/A	Micro-founded approach	Sector	Transition	0 year
Banco Central de Chile	Q2 2022	Static, dynamic	Bottom-up, Top-down	Macroeconomic, sector	Transition	5 years
Banco de España	Dec-21	Static	Top-down	Macroeconomic, sector	Transition	3 years
Banco de la República (Colombia)	Dec-21	Static	Top-down, other	Macroeconomic, sector	Physical, transition	30 years, 80 years for GDP effects
Banco de México	Dec-21	Static, dynamic	Top-down	Counterparty, macroeconomic, sector	Physical, transition	3 years / 20–30 years (tbd)
Bangko Sentral ng Pilipinas (Philippines)	Mid-2022	Static	Bottom-up	TBD	TBD	TBD
Bank Al-Maghrib (Morocco)	Planning phase	Dynamic	Other	Macroeconomic, sector	Physical, transition	30 years
Bank of Canada	Autumn 2021	Static	Bottom-up, Top-down	Counterparty, macroeconomic, sector	Transition	30 years
Bank of England (UK)	May 2022 (sooner if the bank decides not to ask for a second round of submissions)	Static	Bottom-up	Counterparty, macroeconomic, sector	Physical, transition, litigation	"30 years for transition 60 years for physical"
Bank of Korea	Dec-22	Static	Top-down	Sector	Physical, transition	30 years
Bundesbank (Germany)	First part: Nov-21	Hybrid	Top-down	Macroeconomic, sector, entity-level	Physical, transition	5–30 years
De Nederlandsche Bank (Netherlands)	Q4 2021	Static	Top-down	Counterparty	Physical, transition	"1 year for flooding risks 10 years for transition"

European Banking Authority	Concluded (May 2021)	Static	Top-down	Counterparty	Physical, transition	30 years
European Central Bank	Concluded (September 2021)	Static	Top-down	Counterparty	Physical, transition	30 years
Hong Kong Monetary Authority	Dec-21	Static	Bottom-up	Counterparty, sector	Physical, transition	5–30 years
Japan Financial Services Agency/Bank of Japan	June-22	Static	Bottom-up	Counterparty, macroeconomic, sector	Physical, transition	"30 years for transition 80 years for physical"
Malta Financial Services Authority	Q2 2022	Static	Top-down	Sector	Transition	Short-term horizon
Monetary Authority of Singapore	H2 2022	Static	Bottom-up	Counterparty, macroeconomic, sector	Physical, transition	30 years
Oesterreichische Nationalbank (Austria)	Autumn 2021	Static	Top-down	Sector	Transition	5 years
People's Bank of China	H1 2022	Static	Bottom-up, Top-down	Counterparty, sector	Transition	"10 years, 40 years for macro"
Reserve Bank of New Zealand	Late 2023	TBD	Other	Counterparty, macroeconomic, sector	Physical, transition	30 years
"Seðlabanki Íslands (Central Bank of Iceland)"	Dec-21	Static	Top-down	Macroeconomic, sector	Physical, transition	Not yet decided
South African Reserve Bank	November 2021 for the current exercise, 2022-3 for a future excerices	Dynamic	Bottom-up	Sector	Physical	3 years
Suomen Pankki (Bank of Finland)	End-2021	Static	Top-down	Sector	Transition	5 years
Superintendencia Financiera de Colombia	Oct-2021	Static	Top-down	Sector	Physical, transition	"10 years for transition 60 years for physical"
Sveriges Riksbank (Sweden)	The exercise is in planning phase and details are not determined yet					
Swiss National Bank	"First part: end September 2021 Rest: TBD"	Static	Other	Counterparty, macroeconomic, sector	Transition	5–30 years

Blue indicates “concluded”, green indicates “in progress” and grey indicates “in planning”.

3.3.2 Summary of selected international climate stress testing frameworks

PRA/BoE—United Kingdom

The Climate Biennial Exploratory Scenario (CBES) exercise began in 2021 with results expected to be published in May 2022 if a second round of the exercise takes place. 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 of participants and the financial system to climate risks, (2) understand the challenges posed to participating institutions' business models, and (3) assist institutions in enhancing their 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 (Bank of England, 2021).

ACPR/BdF—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. The exercise relied on the scenarios by the NGFS and included a baseline scenario corresponding to an orderly transition and two disorderly transition scenarios. Each of these scenarios combined different assumptions in terms of the trajectory of the carbon tax and total productivity levels of factors. Risks were assessed over a 30-year timeframe, covering the 2020-2050 period. The methodology used static and dynamic balance sheets and covered both physical and transition risks. The climate stress test was designed to be a bottom-up exercise with an international dimension and encompassed 55 sectors. The pilot achieved its objectives of mobilising French banks and insurers, raising awareness about climate risks, quantifying and assessing complex transition or physical risk scenarios, drawing on the work by the NGFS and providing the first measurement of risks and vulnerabilities to which French financial institutions are exposed. Results of the exercise revealed an overall "moderate" exposure of French banks and insurers to climate risk (ACPR, 2021; ACPR, 2020).

AFM/DNB—Netherlands

DNB conducted a climate stress test in 2018, considering the potential impact of energy transition risks to 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 manageable (De Nederlandsche Bank, 2018). DNB is currently conducting a top-down exercise assessing both physical and transition risks with counterparty-level analysis using a static balance sheet. The time horizon for the exercise is one year for flooding risk and 10 years for transition risk. The exercise is expected to be completed in Q4 of 2021 (NGFS, 2021).

FSAN—Norway

In 2019, FSAN conducted a climate stress test on transition risks and published the results in their Risk Outlook Report 2019. Work on possible transition shocks on the Norwegian financial system continued in 2020 by the IMF. The IMF estimated the direct impact of a severe increase in domestic carbon prices on firms under severe assumptions. Secondly, they mapped the impact of an increase in global carbon prices on the Norwegian economy via the oil sector. Thirdly, the IMF modelled the impact of a forced reduction in Norwegian oil firms' output on shareholder portfolios. Results from the exercise showed that such a sharp increase in carbon prices would have a significant but manageable impact on banks (International Monetary Fund, 2020).

Danmarks Nationalbank—Denmark

Danmarks Nationalbank performed a scenario analysis exercise in 2020 to highlight transition risks in the banking sector, based on the scenarios by the NGFS. As a precursor to a fully developed climate stress test, DNB conducted sensitivity analyses to assess whether the banking sector would have a capital shortfall if it faced losses over a given timeframe. The exercise linked corporations' accounting data, industry-level emissions data and credit register data to identify climate risks for corporate lending by banks. Data for energy labels were also included in the assessment of mortgage lending. Results indicated that firms were well equipped to handle transition risks. However, a drastic transition in which the banks need to make large impairment charges over a short timeframe may result in a capital shortfall (Danmarks Nationalbank, 2020).

ECB—European Union

In March 2021, the ECB released preliminary findings from its economy-wide climate stress test, designed to help assess the climate risks faced by the financial sector over the next 30 years. In September, the central bank published an in-depth paper on the results and methodologies of the exercise. The ECB climate stress test combined company-level data with exposure data, with the aggregate trajectories for transition and physical risk embedded into scenarios created by the NGFS. The ECB included three scenarios (1) orderly transition with limited physical risk, (2) disorderly transition with limited physical risk, and (3) hot house world with extreme physical risk. The exercise was conducted entirely by ECB staff and relied upon internal datasets and models. The exercise highlighted sectors and regions in Europe that may be vulnerable to climate risks. For example, preliminary findings suggest that Southern European countries are more susceptible to heat stress and wildfires, while Northern European countries are more vulnerable to flooding. Additionally, mining, energy and manufacturing companies are in carbon-intensive sectors and are therefore the most vulnerable to climate-related policy changes. The ECB has also released its methodology for conducting a bottom-up supervisory climate stress test in 2022 to address institutions' risks towards climate change and their readiness (ECB, 2021). The results from this

exercise will also be used to inform the climate stress test of the Eurosystem balance sheet, which is expected to be completed in early 2022 (ECB, 2021; ECB, 2021).

OSFI/BOC—Canada

In November 2020, the BOC and OSFI launched a joint pilot project on climate risk scenarios to better understand potential transition risks. A report is expected to be published at the end of 2021 to detail specific scenarios, methodologies, assumptions and sensitivities. The project aims further to (1) improve climate scenario analysis capabilities of institutions, (2) increase the understanding of the financial sector's potential exposure to risks associated with transitioning to a low-carbon economy, and (3) improve the understanding of risk-management practices surrounding climate-related risks and opportunities. In 2020, 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) (Bank of Canada, 2020). The NGFS progress report on global supervisory and central bank climate scenario exercises, released in October 2021, provided further updates on the climate scenario exercise being undertaken by the BOC. 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. The central bank developed their own scenarios which align with the NGFS scenarios, including a net zero by 2050 scenario (NGFS, 2021).

CBIRC/PBOC—China

The PBOC has announced that it has been conducting climate-related stress tests with commercial banks, reviewing the implications that climate-related risks may have on their assets (SCMP, 2021). Key features include a bottom-up and top-down approach with counterparty-level analysis. The exercise currently being undertaken by the PBOC includes sector-level granularity, assessing transition risk using a static balance sheet assumption. The selected time horizon spans from 10 to 40 years (NGFS, 2021).

HKMA—Hong Kong

On 4 December 2020, the HKMA shared guidelines for its pilot exercise on climate stress tests with participating financial institutions. The pilot exercise is set to take place in 2021 and aims to assess the banking sector's resilience to climate change and facilitate capacity building of banks vulnerable to climate risks. Through the exercise, the regulator hopes that banks will understand the range of climate-related risks, identify data gaps for risk identification and ultimately establish a robust framework for climate risk management. The exercise will test transition and physical risks separately to focus on exposures directly affected by changes in climate patterns and transition pathways, based on the scenarios by the NGFS. The physical risk scenario will focus on the projected climate situation of Hong Kong in the 21st century, such as increases in temperature, sea levels and more intense cyclones. The transition risk scenarios will capture disorderly and orderly transition pathways. The financial impact on the banking sector will be evaluated both in the short-term and long-term. HKMA will allow participants flexibility on certain aspects of the test, including reporting granularities and exercise coverage (HKMA, 2020).

MAS—Singapore

In October 2020, MAS announced that they will begin to incorporate climate-related scenarios into their annual stress tests for financial institutions over the next two years (by the end of 2022). MAS' upcoming stress test aims to assess the impact of physical and transition risks associated with climate change and references the climate scenarios developed by the NFGS. It is envisioned that the climate stress test will strengthen the resilience of Singapore's financial sector to climate-related risks and develop Singapore as a green finance hub. The climate-related scenarios will include both physical and transition risks, where both qualitative and quantitative information will be incorporated. The scenarios will also include a base and a stress scenario, including a short-term and long-term environmental baseline (MAS, 2020).

APRA—Australia

In September 2021, the APRA published an information paper on its Climate Vulnerability Assessment (CVA), outlining the purpose, design and scope of the exercise. 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 a proportional balance sheet approach. The aggregated results from the CVA analyses are expected to be published by the APRA in 2022 (APRA, 2021).

RBNZ—New Zealand

New Zealand is taking action to become one of the first countries to mandate climate-related disclosure for financial entities, in line with the TCFD framework. The Financial Sector (Climate-Related Disclosures and Other Matters) Amendment Bill has been introduced to Parliament, making climate-related disclosure mandatory for around 200 entities. RBNZ also seeks to incorporate climate risks into its stress testing framework. For its current stress test, it incorporates a disaster shock scenario which assesses the impact of a natural disaster such as a large-scale earthquake on fiscal costs and expenditure (RBNZ, 2020).

Below we provide a comparison of eight major climate stress test exercises by supervisory authorities (Table 4).

Table 4: Comparison of key regulatory climate stress tests.

Authority	PRA	ACPR	DNB	APRA	ECB Economy-wide Test	Danmarks National-bank	HKMA	ECB Supervisory SSM Test
Scope	Largest banks and insurers	Banks and insurers	Banks, insurers, pension funds	Banks	Banks and companies	Banks	Banks	Banks
Inclusion	Mandatory	Voluntary	Voluntary	Mandatory	Mandatory	Not applicable	Voluntary	Mandatory
Balance-sheet reference	End-2020	End-2019	End-2017	Not disclosed	End-2020	Not disclosed	Not available	End-2021
Period	30 years (to 2050) for transition risk and 60 years for physical risk	30 years (to 2050)	5 years (to 2023)	30 years (to 2050)	30 years (to 2050)	9 years	5-30 years	Up to 30 years (to 2050), depending on the scenario
Balance-sheet assumption	Static	Static until end-2025; dynamic from 2026	Static	Static and proportional	Static (allows for feedback loop)	Not disclosed	Static	Static and dynamic, depending on the scenario
Focus of exposures	Lending book and large corporate counterparties	Business loans, equity, corporate credit spreads, sovereign credit spreads, commodities and interest rate	Bond and equity holdings and corporate loans	Mortgages and businesses	Corporates from credit and market portfolios	Corporate loans and mortgages	Sectoral exposures	Mortgages and corporate exposure

Authority	PRA	ACPR	DNB	APRA	ECB Economy-wide Test	Danmarks National-bank	HKMA	ECB Supervisory SSM Test
Counterparty-level analysis	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Type of risks	Physical, transition and litigation	Physical and transition	Transition	Physical and transition	Physical and transition	Transition	Physical and transition	Physical and transition
Number of scenarios	Three	Four	Four	Two	Three	One	Not disclosed	Five
NGFS scenarios	Built on NGFS scenarios	NGFS scenarios used as a starting point	Not applicable	Built on NGFS scenarios	Built on NGFS scenarios	Not applicable	Based on NGFS Scenarios	Based on NGFS scenarios
Calculation	Uses internal models (bottom-up approach)	Uses internal models (bottom-up approach)	Top-down stress model approach	Bottom-up, top-down approach	Top-down approach	Top-down approach	Uses internal models (bottom-up approach)	Uses internal models (bottom-up approach)
Results due	May 2022	Published in May 2021	Published in 2018	Early 2022	Assessment to be undertaken in 2022	Published in November 2020	Assessment to be undertaken in 2021	Will be conducted from March to July 2022
Public disclosures	Yes, in aggregate; not at firm-level	Yes, in aggregate; not at firm-level	Yes, in aggregate; not at firm-level	Yes, in aggregate; not at firm-level	Yes, in aggregate; not at firm-level	Yes, in aggregate; not at firm-level	Not stated	Not stated

Authority	PRA	ACPR	DNB	APRA	ECB Econo-my-wide Test	Danmarks National-bank	HKMA	ECB Super-visory SSM Test
Scope	Largest banks and insurers	Banks and insurers	Banks, insurers, pension funds	Banks	Banks and companies	Banks	Banks	Banks
Inclusion	Mandatory	Voluntary	Voluntary	Mandatory	Mandatory	Not applicable	Voluntary	Mandatory
Balance-sheet reference	End-2020	End-2019	End-2017	Not disclosed	End-2020	Not disclosed	Not available	End-2021
Period	30 years (to 2050) for transition risk and 60 years for physical risk	30 years (to 2050)	5 years (to 2023)	30 years (to 2050)	30 years (to 2050)	9 years	5-30 years	Up to 30 years (to 2050), depending on the scenario
Balance-sheet assumption	Static	Static until end-2025; dynamic from 2026	Static	Static and proportional	Static (allows for feedback loop)	Not disclosed	Static	Static and dynamic, depending on the scenario
Focus of exposures	Lending book and large corporate counterparties	Business loans, equity, corporate credit spreads, sovereign credit spreads, commodities and interest rate	Bond and equity holdings and corporate loans	Mortgages and businesses	Corporates from credit and market portfolios	Corporate loans and mortgages	Sectoral exposures	Mortgages and corporate exposure

Authority	PRA	ACPR	DNB	APRA	ECB Econo-my-wide Test	Danmarks National-bank	HKMA	ECB Super-visory SSM Test
Counterparty-level analysis	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Type of risks	Physical, transition and litigation	Physical and transition	Transition	Physical and transition	Physical and transition	Transition	Physical and transition	Physical and transition
Number of scenarios	Three	Four	Three	Two	Three	One	Not disclosed	Five
NGFS scenarios	Built on NGFS scenarios	NGFS scenarios used as a starting point	Not applicable	Built on NGFS scenarios	Built on NGFS scenarios	Not applicable	Based on NGFS Scenarios	Based on NGFS scenarios
Calculation	Uses internal models (bottom-up approach)	Uses internal models (bottom-up approach)	Top-down stress model approach	Bottom-up, top-down approach	Top-down approach	Top-down approach	Uses internal models (bottom-up approach)	Uses internal models (bottom-up approach)
Results due	May 2022	Published in May 2021	Published in 2018	Early 2022	Assessment to be undertaken in 2022	Published in November 2020	Assessment to be undertaken in 2021	Will be conducted from March 2022 to July 2022
Public disclosures	Yes, in aggregate; not at firm-level	Yes, in aggregate; not at firm-level	Yes, in aggregate; not at firm-level	Yes, in aggregate; not at firm-level	Yes, in aggregate; not at firm-level	Yes, in aggregate; not at firm-level	Not stated	Not stated

3.3.3 Importance of internal climate stress tests

As financial institutions mature in their approach to climate stress testing and the requirements around teams and skills, data and infrastructure, models and scenarios are increasingly fit-for-purpose, they may find that their risk management and strategy needs require climate stress tests that differ from regulatory stress testing exercises.

Regulatory stress tests often reflect the concerns and needs of the regulators to deliver on their supervisory and financial stability objectives, which often differ from the objectives of a financial institution. Below we have listed three main reasons why institutions may also choose to run an internal climate stress test.

1. **Desire to use scenarios and assumptions different from those in the regulatory exercise.** Institutions may wish to use scenarios and/or assumptions that are more applicable to their business, for example in relation to plausible transition pathways, certain policies coming into force, carbon pricing at different time points, the speed of electrification in a particular industry, the development (or lack thereof) of carbon capture and storage (CCS). Typically, these would be the scenarios used for TCFD reporting but institutions may choose to have additional scenarios for their internal use in planning and risk management.
2. **Need for a different or more detailed focus.** A regulatory scenario may not account in enough detail for a particular country or geography, a sector or a company that the institution believes might carry a specific risk for the institution. These scenarios might only be used by the institution for internal planning and risk management purposes.
3. **Desire to consider the impacts of specific and sudden events on their portfolios**. For example, extreme weather events or a significant shift in public policy in a particular sector, may have significant and specific impacts on trading book positions. Market risk scenarios would be a common example of this kind of impact analysis.

In response, financial institutions can leverage the work done on regulatory climate stress tests to develop and run a variety of scenarios, at different frequencies, for different audiences, from comprehensive to very narrow analysis, and all shades in between (Bank of England, 2021).

4. Team organisation and skills

Key messages

- Institution-wide team engagement is required for climate stress testing, with firms assigning responsibilities to a large number of teams from across the organisation for this exercise.
- Firms should devote appropriate resources (financial and human) to the execution of climate stress testing, with a specific focus on the activities of data collection and analysis, model development and strategic planning.
- A large body of knowledge and skills will need to be developed in-house to reach a satisfactory level of proficiency in running climate stress tests.
- Climate-related training and knowledge development programmes need to be geared towards a diverse set of teams across the firm, rather than just client-facing employees.
- Institutions will need to make substantial changes to their organisation including the development of a climate risk team with adequate resources, executive sponsorship and authority to oversee, coordinate and manage the climate stress test.
- Adequate resourcing should be implemented to integrate climate stress testing into the firm's organisational structure and processes with robust governance and oversight.

4.1 Team organisation

4.1.1 Institution-wide team engagement for climate stress testing

In order to effectively execute climate stress tests, financial institutions need to engage a large number of teams from across the organisation. Through UNEP FI's TCFD programme, participants suggested the teams that they believe should play a role in stress testing. Their answers included risk modelling, traditional stress testing, economics, research and relevant business lines. This section will provide greater detail on the roles and responsibilities required to effectively execute a stress test. In addition, it will explore the skills needed for both climate stress testing and improved climate risk management.

This section will also provide specific recommendations for different teams, along with guidance on how to develop the necessary skills and knowledge. It will also discuss institutional mobilisation and governance for conducting a climate stress test.

4.1.2 Teams and their respective roles

Figure 4 below illustrates the general functions and the teams that should be involved in climate stress testing.

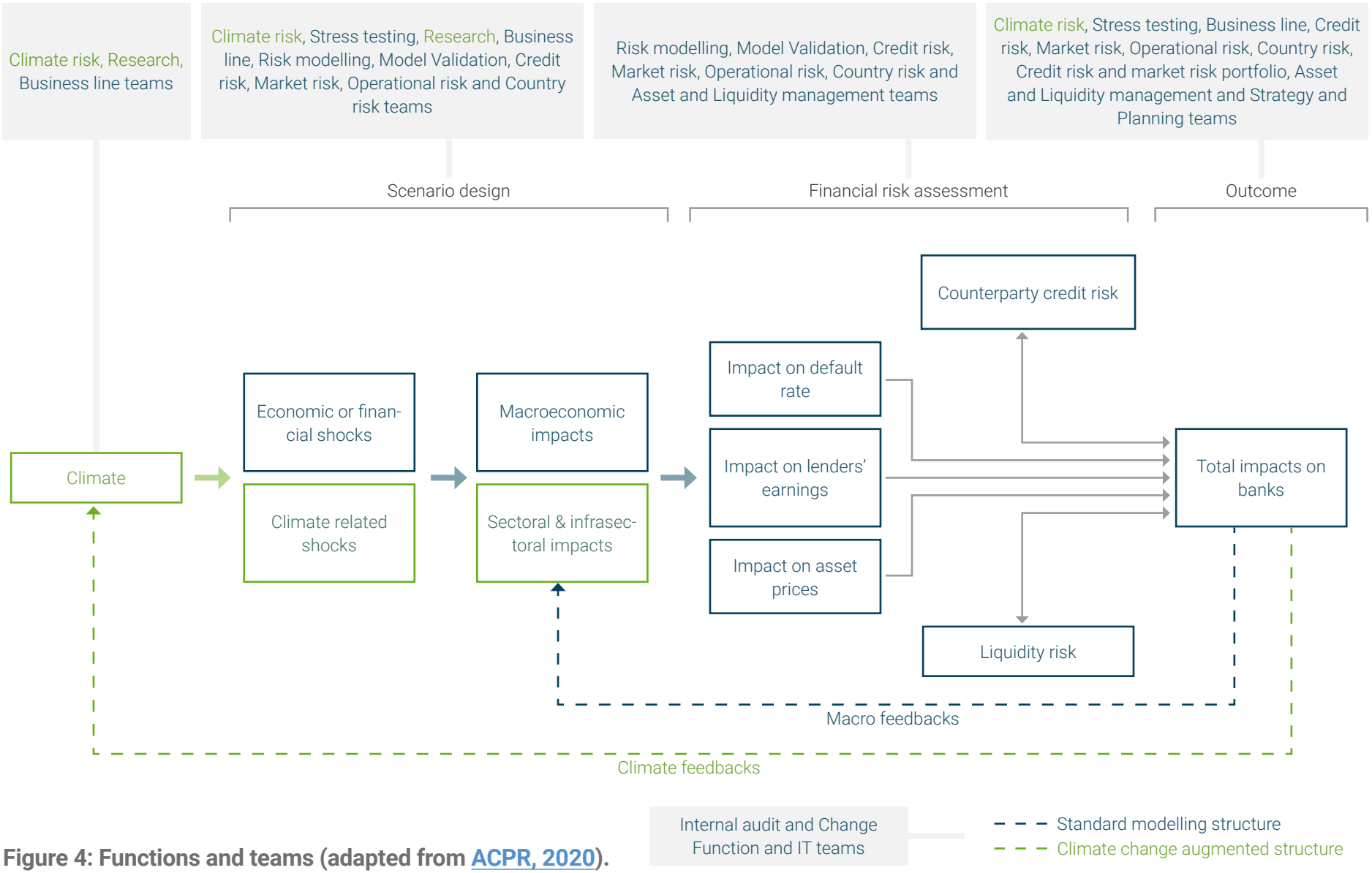

Figure 4: Functions and teams (adapted from ACPR, 2020).

Table 5 below builds on the above by providing a more detailed overview of the teams that should be involved in stress testing and their respective roles. As firms differ in their approach to their naming of teams/sub-teams, in order to aid understanding and application of these recommendations, we have included a 'team definition'.

Table 5: Suggested involvement of teams and their responsibilities in climate stress testing.

Team	Team Definition	Responsibilities
1. Climate risk team (also referred to as Sustainability or Environment, Social & Governance (ESG) team)	▪ The team whose primary focus is climate risks and their impacts. ▪ Some financial institutions may not have a dedicated climate team and instead have a Sustainability or ESG team that is responsible for issues related to climate risk.	1. Oversee, coordinate and manage the climate stress testing exercise. 2. Educate other teams involved in climate stress testing. 3. Act as the central data team to: ▫ Collect, clean and validate required data in coordination with the appropriate teams. ▫ Gather data from open-source databases. ▫ Collect data from third-parties and counterparties. 4. Provide scenario narratives to the scenario design and stress testing teams. 5. Collate the results and analyse them in collaboration with the stress testing and risk (credit, market, operational, liquidity and country) teams. 6. Build a reporting structure for the results. 7. Present the results and analysis at relevant forums.
2. Stress testing team	▪ The team that currently conducts traditional stress testing, including developing and designing scenarios for traditional stress tests and strategic planning. ▪ Instead of a single team, the responsibility may be split among various risk teams.	1. Provide the framework of a traditional stress test to incorporate climate stress tests into the framework. 2. Design scenarios based on narratives provided by the climate risk team and other teams. 3. Undertake scenario expansion. 4. Run the scenarios in collaboration with the risk modelling, climate risk and other risk teams. 5. Analyse the results of the exercise with the risk teams.

Team	Team Definition	Responsibilities
3. Research teams	▪ The teams that conduct economic and climate research. ▪ The teams that support the institution's business and strategy.	1. Support scenario design and scenario expansion. 2. Remain up-to-date with the latest developments in climate stress testing methodologies.
4. Business line team (also referred to as front-line)	The customer-facing division of the financial institution.	1. Assist the climate team in collecting data from clients. 2. Provide customer insights for counterparty analysis and scenario narratives for which their clients will be incorporated. 3. Provide feedback on the applicability of developed scenarios for the institution's clients. 4. Use the results of the stress test to gain customer insights and inform future relationships.
5. Risk modelling (Quants) team	The team responsible for developing the institution's risk models, including credit risk, market risk and operational risk.	1. Develop climate-specific counterparty models. 2. Perform sectoral intra- and extrapolation. 3. Play the key role in running and implementing the models and performing quantitative analysis of the climate risks. 4. Perform tweaks on internal models to improve suitability for the exercise.
6. Model validation team	The team responsible for validating models.	1. Validate internal models to be used for climate stress testing. 2. Provide expertise and observations to the Quants team to make the relevant changes to the models.

Team	Team Definition	Responsibilities
7. Credit risk team	The team responsible for credit risk and internal ratings and methodologies.	1. Work with the Quants team to incorporate climate risk drivers into internal credit models. 2. Collaborate with the stress testing and Quant teams to run the scenarios. 3. Run the internal ratings tool in coordination with the climate team. 4. Collate and interpret the results of the exercise from a credit risk perspective.
8. Market risk team	The team responsible for market risk.	1. Work with the stress testing team to include all relevant markets to be covered in scenarios and feed into the scenario expansion process. 2. Collate and interpret the results of the exercise to analyse the market risk results of stress scenarios.
9. Operational risk team	▪ The team responsible for operational risk. ▪ If assessing litigation risk as part of operational risk, this can also include the legal team.	1. Collaborate with the stress testing and climate risk teams to design an approach for scenarios to cover the relevant and specific operational risks. 2. Collate and interpret the results of the exercise to determine the operational risk impact of stress scenarios based on the outputs.
10. Country risk team	▪ The team responsible for country risk. ▪ Generally situated within the credit risk department but collaborating with market risk to gain a comprehensive view of country risks.	1. Design country risk methodology to be covered by scenarios. 2. Determine country risk impact of stress scenarios based on the results of the exercise.
11. Credit risk and market risk portfolio teams	The teams responsible for aggregate portfolio management of risks.	1. Determine the impact of the results of the exercise on the portfolio as a whole.

Team	Team Definition	Responsibilities
12. Asset and Liquidity Management (ALM)/ Liquidity and funding risk team (as part of Treasury)	▪ The team responsible for managing the institution's assets and liabilities, its liquidity and funding risk (among other duties). ▪ Manages high quality liquid assets (HQLA) portfolio at the institution-level.	1. Determine the impact of the results of the exercise on HQLA, the institution's liquidity, contingency funding plans and funding strategy.
13. Internal audit team	The team that provides assurance on the processes and controls associated with stress testing.	1. Audit internal processes for climate stress testing by providing an independent assessment of the methodology and effectiveness of the climate stress testing programme (OSFI, 2009).
14. Change function and IT teams	The teams responsible for implementing changes in the IT infrastructure based on user feedback.	1. Incorporate the necessary changes in the IT infrastructure to allow for processing of climate data for the exercise.
15. Strategy and planning team	The team responsible for the institution's strategy and planning.	1. Use the results of the climate stress test to develop or adapt the institution's strategy.

Notes:

The Capital Management Function (usually part of Treasury) also determines capital impacts and Enterprise Risk Management integrates this into the ICAAP including capital and financial plans and risk appetite. This integration would be a key objective in embedding climate risks into an organisation's risk framework.

Other groups that could have a role may include Economics (perhaps part of the Research team) to help with scenario design and translate climate pathways into macroeconomic and financial variable impact pathways.

4.1.3 Team resourcing

Discussions on climate stress testing with the UNEP FI TCFD programme's participating institutions show that most of the teams involved in climate stress testing only work part-time on these exercises and have other primary responsibilities.

94% of UNEP FI's TCFD programme participants have stated that they have at least one member of their organisation working part-time on climate stress testing.

For example, a credit risk modelling team at an institution works to develop models for traditional stress tests and internal assessments, and is now, in addition, tasked with developing climate risk models. The added responsibilities of the execution of climate stress testing demands the devotion of adequate resources.

Recommendation: Firms should devote the appropriate resources (financial and human) to the execution of climate stress testing, with specific focus on the activities of data collection and analysis, model development and strategic planning.

4.2 Knowledge and skills

4.2.1 In-house capabilities

It is vital for firms to improve their in-house climate risk knowledge and skills, including those specific to climate stress testing. In the results of its 2020 climate pilot exercise, the Autorité de contrôle prudentiel et de résolution (ACPR) highlighted the importance of its exercise in improving industry understanding of climate risks and their impacts on business models (ACPR, 2021). It is apparent from the discussion above and regulatory exercises that a range of climate-related skills are required across a firm. Results from a survey of UNEP FI's TCFD programme participants further emphasised the importance of climate-related skills with participants highlighting the importance of developing skills, knowledge and expertise on climate scenarios and understanding the macroeconomic impacts of climate risks. Participants also identified experience in executing traditional stress tests as a key skill.

Tables 6 and 7 provide an overview of the key climate-specific skills and knowledge required by teams and functions to ensure the effective design and execution of a climate stress test. The tables indicate the varying levels of proficiency needed by the teams for specific skills and knowledge. The table does not include the skills and knowledge typically required for traditional stress tests, which can be leveraged for a climate stress test.

Table 6: Recommended key climate-specific skills required for teams.

Knowledge level required: Basic | Intermediate | Advanced

Category	Key Knowledge	Short Description	Business (Client facing)	Economic Research Team	Treasury (ALM/ Liquidity/Funding)	Climate Risk Team	Stress Testing Teams(s)	Quant/modeling Team	Credit Risk Team	Market Risk Team	Operational Risk Team	Country Risk Team	Portfolio Risk Team(s)	Model Validation Team *	Internal Audit *	Strategy and Planning Team	Board and Executive Management
Risk Framework	Governance and Policies	Ability to collaborate with the risk framework owners to integrate climate risk stress testing into existing risk governance and policies.	Intermediate	Basic	Intermediate	Advanced	Advanced	Intermediate	Advanced	Advanced	Advanced	Advanced	Advanced	Intermediate	Advanced	Intermediate	Advanced
	Processes and Controls	Coordinate the embedding of efficient and effective climated stress tests processes, behaviours and controls.	Intermediate	Basic	Intermediate	Advanced	Advanced	Intermediate	Advanced	Advanced	Advanced	Advanced	Advanced	Intermediate	Advanced	Intermediate	Advanced
Data, Metrics and Drivers	Client Engagement	Familiarity with various client engagement processes including onboarding, annual review, deals due diligence to assist with the influencing of clients' strategies and sourcing of climate data.	Advanced	Intermediate	Basic	Advanced	Basic	Basic	Advanced	Basic	Basic	Advanced	Advanced	Basic	Advanced	Advanced	Advanced
	Metrics selection	Familiarity with selecting the appropriate metrics for climate risk data to use in a climate stress test. For example, for emissions data, the individual should be able to determine which metric, such as total carbon emissions, relative carbon emissions or carbon intesity, is the most suitable for a climate stress test.	Advanced	Advanced	Basic	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Intermediate	Intermediate
	Data Collection	Experience with collecting physical and transition risk data based on the metrics selected. Individual should be able to collect data from a range of sources, including clients, open-source data sets and external providers.	Advanced	Intermediate	Basic	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Advanced	Advanced	Intermediate	Intermediate
	Data Validation	Experience with reviewing climate data collected and assessing its coverage, quality, comparability and production methodology.	Intermediate	Intermediate	Basic	Advanced	Advanced	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Advanced	Advanced	Intermediate	Intermediate
Scenarios and Modeling	Scenario design and expansion	Ability to construct narratives for climate scenarios and to expand reference scenarios to derive the key global, sectoral, country-specific economic indicators which are used in the traditional stress scenario expansion tools.	Basic	Advanced	Basic	Advanced	Advanced	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
	Use of Models	Experience running climate models, such as IAMs, with an awareness for their assumptions. Ability to adapt variables for the scenario analysis.	Basic	Basic	Basic	Advanced	Advanced	Advanced	Basic	Basic	Basic	Basic	Basic	Intermediate	Intermediate	Basic	Basic
Analysis	Geospatial Analysis	Ability to conduct geospatial analysis for physical assets, for example familiarity with the use of GIS. Experience in downscaling methodologies.	Basic	Intermediate	Basic	Advanced	Advanced	Advanced	Advanced	Intermediate	Intermediate	Advanced	Intermediate	Basic	Basic	Basic	Basic
	Sectoral Analysis	Proficient at sectoral intra- and extrapolation for sectoral analysis in a climate stress test, use of proxies and estimates where data coverage or granularity is insufficient	Advanced	Advanced	Intermediate	Advanced	Advanced	Advanced	Advanced	Intermediate	Intermediate	Advanced	Intermediate	Intermediate	Intermediate	Advanced	Advanced
Execution of the Exercise	Coordination of multiple teams and systems	Ability to manage and coordinate between various teams, multiple systems and different environments, without perturbing other functions at the institution	Basic	Basic	Basic	Advanced	Advanced	Intermediate	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Basic	Intermediate	Basic	Intermediate
	Producing and understanding desired outputs	Experience producing the correct desired outputs for the exercise and having the ability to understand and utilise the outputs.	Basic	Basic	Basic	Advanced	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Basic	Intermediate
Application of Climate Stress Test Results	Reporting and Management Information	Ability to define, advise on or challenge the climate risk reports and management information in support of the governance and management of climate risk, focusing on material areas of risk	Intermediate	Basic	Intermediate	Advanced	Advanced	Intermediate	Advanced	Advanced	Advanced	Advanced	Advanced	Basic	Intermediate	Advanced	Advanced
	Risk Appetite Setting	Ablity to use the outputs of the cilmate stress test to advise on or challenge the metrics and thresholds for a fit-for-purpose climate risk appetite.	Intermediate	Basic	Intermediate	Advanced	Basic	Basic	Advanced	Advanced	Advanced	Advanced	Advanced	Basic	Intermediate	Advanced	Advanced
	Sectoral Strategies and Policies	Ability to devise or advise on meaningful sectoral strategies and policies in light of the stress test results to support the firm's clients and catalyse the firm's overall climate agenda	Advanced	Intermediate	Intermediate	Advanced	Basic	Basic	Advanced	Advanced	Advanced	Advanced	Advanced	Basic	Intermediate	Advanced	Advanced

w* Understanding the process and controls around the topics highlighted

Table 7: Recommended key climate-specific knowledge areas for teams.

Knowledge level required: Basic | Intermediate | Advanced

Category	Key Knowledge	Short Description	Business (Client facing)	Economic Research Team	Treasury (ALM/ Liquidity/Funding)	Climate Risk Team	Stress Testing Teams(s)	Quant/modeling Team	Credit Risk Team	Market Risk Team	Operational Risk Team	Country Risk Team	Portfolio Risk Team(s)	Model Validation Team*	Internal Audit*	Strategy and Planning Team	Board and Executive Management
Climate Impacts	Understanding of climate impacts	Knowledge of climate science, including physical and transition risks, their causes and impacts, mitigation & resilience aspects, decarbonisation challenges	Intermediate	Intermediate	Basic	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
Climate Scenarios and Modeling	Understanding of climate stress tests and scenarios	What climate stress tests are and aren't, how scenarios are constructed, what questions they can help answer, and what their underlying assumptions are	Basic	Intermediate	Basic	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Intermediate	Intermediate	Intermediate	Intermediate
	Details of regulatory and international scenarios	Knowledge of the key features and characteristics of external scenarios, granularity, horizon, main assumptions, severity and coverage	Basic	Intermediate	Basic	Advanced	Advanced	Advanced	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Basic	Basic	Basic
	Climate scenario design and expansion	Knowledge of approaches and methodologies for climate scenario design and expansion	Basic	Intermediate	Basic	Advanced	Advanced	Advanced	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Basic	Basic	Basic
	Understanding climate modeling	Knowledge and understanding of various models, such as IAMs, including their assumptions, how they compare to each other and their integration into a traditional stress test framework	Basic	Advanced	Basic	Advanced	Advanced	Advanced	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Advanced	Intermediate	Basic	Basic
Climate Data	Data sources and quality	What data sources are available, the methodologies used and their assumptions/ limitations. Information about coverage, accuracy, granularity	Basic	Intermediate	Basic	Advanced	Intermediate	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Advanced	Intermediate	Basic	Basic
	Knowledge of the relevant climate data for each sector/ industry	Knowledge of the relevant climate data and indicators used in the sector/industry concerned	For their client/ sector	Intermediate	Basic	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate	Intermediate
Climate risks and drivers	Understanding of the financial drivers and transmission channels	How climate risks impact economies and the future financial position of firms, the implications for the firms and the institution	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced
Sector & Client Climate Specifics	Sector-specific understanding of the nature of climate risks faced by clients	Understanding of physical and transition risks faced by each specific sector, how they manifest over different time horizons and their significance for each client and their sector. Decarbonisation pathways and challenges, mitigation and resilience aspects	For their client/ sector	Advanced	Intermediate	Advanced	Intermediate	Intermediate	Advanced	Intermediate	Intermediate	Advanced	Intermediate	Intermediate	Intermediate	Advanced	Intermediate
	Sector-specific knowledge of the key climate risks exposures of the institution	Across the books of the institution, what are the significant climate exposures and associated metrics per sector and geography	Advanced	Intermediate	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Advanced	Intermediate	Advanced	Advanced	Advanced
Regulatory Expectations	Knowledge on the relevant regulatory climate stress test requirements	Awareness of the appropriate regulatory requirements of climate stress testing and in-depth understanding of the regulator's climate stress test framework, including objectives, data requirements, scenarios, models and their assumptions	Basic	Intermediate	Basic	Advanced	Advanced	Advanced	Advanced	Intermediate	Intermediate	Intermediate	Intermediate	Advanced	Advanced	Intermediate	Advanced

* Understanding the process and controls around the topics highlighted

Developing institutional knowledge and skills

As highlighted in the previous section, there is a large body of knowledge and skills that need to be developed in-house to reach a satisfactory level of proficiency in conducting climate stress tests, regulatory-related or otherwise.

Set of recommendations to enhance the development of knowledge and skills for conducting climate stress tests across firms include:

1. **Establish staff roles and responsibilities related to climate stress testing.** Clearly include them in job descriptions and objectives of the employees involved.
2. **Develop policies and procedures inclusive of roles and responsibilities:** Ensure that policies are in place to provide sufficient institutional support for those executing the stress test.
3. **Appoint climate risk specialists/ambassadors in each team or function:** Drive effective coordination and collaboration across teams through appointed climate risk specialists/ambassadors in charge of interacting with the climate risk team, coordinating the climate stress tests, sharing and disseminating climate risk intelligence and insights. They may be the same individuals as the senior experts suggested in greater detail in section 4.3.1.
4. **Provide adequate training by experts:** Build capacities of specific teams on their roles and responsibilities for the climate stress testing programme.

Climate-related training and knowledge development programmes are often geared towards client-facing employees. However, a diverse set of teams across the organisation need to develop basic to advanced knowledge of the multiple facets of climate risk and climate stress testing.

Recommendations for firms to consider in their climate knowledge development programme include the following:

1. **Establish a firm-wide programme of climate knowledge development** in alignment with the required level of skills in each area (see section 4.2.1).
2. **Tailor the training curriculum** to the relevant teams to build their expertise and capabilities for climate risks and climate stress testing. Knowledge relevant to regulatory scenarios should be prioritised.
3. Set up **appropriate training incentives and requirements** for existing resources in the relevant functions.
4. **Encourage, support and finance the enrollment of staff in relevant professional certifications** (for example the Global Association of Risk Professionals (GARP)'s Sustainability and Climate Risk (SCR) certification, Cambridge Institute for Sustainability Leadership (CISL)'s sustainable leadership courses etc.).
5. **Engage with climate and data scientists, modelers and tool providers** by organising internal seminars.
6. **Establish dialogue and collaboration with local academic and research institutions,** for example to support the development of scenarios with improved regional granularity and increased applicability for financial institutions. Outputs from the collaboration should be shared internally and externally.
7. **Engage in industry forums and collaborate with peers** within the confines of applicable competition laws and participate in roundtables, seminars and share best practices with peers.
8. **Engage with professional national and international bodies** to contribute to the emergence and communication of best practices.

The above initiatives would fall within the remit of a climate research and intelligence team, which is described in detail in section 4.3.1. These initiatives can involve senior experts and ambassadors as relevant.

Exhibit 1: Monetary Authority of Singapore's Action Plan to build knowledge and capabilities in sustainable finance.

MAS is supporting Singapore Management University (SMU) and Imperial College London to open the Singapore Green Finance Centre. The research centre aims to help institutions and professionals build knowledge and skills around green finance, including climate finance and climate risk. The initiative will provide professionals with the necessary skills needed for understanding and applying climate finance. Programmes will also be offered to undergraduates, post-graduates and those continuing professional education, to build an understanding within the future workforce. The initiative is also supported by nine leading financial institutions, including Bank of China Limited, BNP Paribas, Fullerton Fund Management, Goldman Sachs, HSBC, Schroders, Standard Chartered Bank, Sumitomo Mitsui Banking Corporation, and UBS (Laura Singleton, 2020).

4.2.2 Building skills through external support

A number of participants in UNEP FI's TCFD programme noted that they had engaged external support to address skills and resourcing gaps in their climate risk programmes.

Firms described several sources of external support that are available to institutions looking to enhance their climate risk programmes and conduct a climate stress test. These include:

External consultants and contractors can provide expertise on climate risk management to support institutions on a range of activities associated with climate stress testing. External consultants can support data management and integration, support the development and implementation of climate scenarios, assist in regulatory practices, and support governance and risk reporting. They are often the preferred route to respond to regulatory demands and initiate the development of a climate risk function.

National and/or industry associations can help financial institutions comply with new regulations and understand climate risks and scenarios at the national level. They can be leveraged to influence policymakers and regulators and more generally facilitate dialogue with regulators to, for example, clarify points of uncertainty or approaches to supervision, as well as offer forums for sharing best practices and innovative approaches.

International initiatives can help financial institutions engage in dialogue with their peers and leading experts in the industry to expand their understanding of climate risks, scenario analysis and modelling, as well as address topics such as climate impacts, data availability and accessibility, risk reporting, best practices and obstacles faced.

External support in the form of consulting, contracting and the use of third-party data and models continue to be a common choice in the face of rising regulatory demands. These approaches are a good way to kickstart the process of climate stress testing

and building out a climate risk function. However, external support does bring challenges including costs, data confidentiality, continuity of the available skillset following the conclusion of contracts, the coverage provided, and the ability to transition to in-house capabilities.

Recommendation: Firms should leverage external support to develop in-house capabilities for climate stress testing at a faster pace, embed the required skills, and ensure the ability to produce meaningful climate-related risk analysis and climate-related risk disclosures.

4.3 Institutional organisation and governance

4.3.1 Changes to team organisation for climate stress testing

Embedding climate stress testing within a financial institution will require changes to the traditional team organisation of the institution. Below we provide guidance for the key changes that should be implemented by institutions for climate stress testing.

A traditional stress testing team at a financial institution consists of various risk teams which share the role of executing the exercise. They oversee key components including scenario design and expansion, performing risk analysis and analysing the results. Other teams, such as the economic research, risk modelling (Quants) and model validation teams, assist in the exercise by providing their expertise as required. When the exercise covers several risk exercises, for example, the internal capital adequacy assessment process (ICAAP) in the UK and EU, the global coordination usually rests with the firm-wide risk team.

However, a climate stress test requires a different set of skills and knowledge compared to a traditional stress test, and therefore will require institutions to make substantial changes to their organisation in order to integrate climate risk assessment into the traditional stress testing framework.

Recommended changes firms should make include the following:

Develop a climate risk team with adequate resources, executive sponsorship and authority to oversee, coordinate and manage the climate stress test

In the case of climate stress tests, a specific team should be established within the risk department or division with the skillset needed to overcome challenges of the exercise (Figure 5). Depending on the organisation of the firm, the team could be standalone, part of a wider ESG and/or sustainability team or integrated with the firm-wide or enterprise risk management team.

Climate Risk Team's Recommended Roles	
Oversee, coordinate and manage the climate stress testing exercise	Educate other teams on climate change, climate risks and their impacts
Build a reporting structure for the results and support the governance	Provide scenario narratives to the scenario design and stress testing teams
Collate the results and analyse them in collaboration with the stress testing and risk teams	Present the results and analysis at relevant forums

Figure 5: Recommended roles for the climate risk team.

Some firms may not have a climate risk team overseeing the whole exercise and instead may be structured as a working group. Though this practice may be suitable for infrequent stress testing work, it will not be conducive to the adequate integration of climate stress testing into firm-wide processes and systems.

Establish a climate research and intelligence function

The field of climate risk is rapidly evolving, pushed by the urgency of the climate situation as well as the scope and amplitude of the changes required. This is particularly the case in financial institutions, and it is paramount that firms keep abreast of:

- The latest climate science;
- Regulatory requirements, developments, non-binding standards (e.g. TCFD and Climate Financial Risk Forum) and reports across jurisdictions;
- Reports and initiatives from internationals bodies, agencies and Non-Governmental Organisations (NGOs);
- National and industry associations;
- Industry progress and peer analysis; and
- Emerging methodologies and best practices, as well as available data sources.

A dedicated climate research and intelligence function can help an institution effectively understand and process a diverse array of climate risk insights. Climate research and intelligence responsibilities could fit well within the climate risk team, the ESG team or the sustainability team, depending on the organisational structure of the institution.

Manage climate-related data centrally

Data is a cornerstone of climate risk assessments, analysis and stress testing. Climate stress testing will require institutions to collect new types of climate-related data that were not previously required for a traditional stress test. It is crucial that this data is centrally collected, processed and used to ensure accessibility by all the teams involved in the exercise. Detailed guidance on data collection is provided in section 5 (Data Requirements and Collection).

Support collaboration among a range of senior experts and establish a cross-functional project team to design and execute the climate stress test

For a climate stress test, it is very difficult for a single team in an organisation to design, run, analyse and use the outputs of the exercise on their own. Collaboration of senior experts from different areas, including business line and risk teams such as climate, credit, market, operational, liquidity and country risk of the bank is vital for the execution of the test. This point is further reinforced in the TCFD guidance on risk management and disclosure, stating "The principle of interconnections means all relevant functions, departments, and experts are involved in the integration of climate-related risks into the company's risk management processes and in the ongoing management of climate-related risks" (TCFD, 2020). The need for expertise and knowledge from across the institution makes cross-functional collaboration crucial. The broader character of its design and execution requires the involvement of resources and people from various teams.

The types of teams involved can vary depending on the type of climate stress test being conducted and the maturity of the organisation in running such processes. The importance of having a cross-disciplinary team conducting climate stress tests was also emphasised by the ACPR in their results for their 2020 climate stress test exercise (ACPR, 2021).

Six recommendations for financial institutions to implement changes in their organisation for climate stress testing

1. **Establish a climate risk team** within the risk department, with sufficient resources and the specific skills and experience required.
2. **Establish a climate research and intelligence function** in charge of collecting climate-related information, intelligence, reports and keeping up-to-date with the latest developments in this field.
3. **Assign responsibilities associated with climate-related data to a single team in the organisation,** centralising its sourcing, collection, processing (including analytics), systems and management.
4. **Ensure appropriate dialogue when implementing a climate stress test**, all experts' opinions should be challenged and checked for consistency. This process should inform the design and the implementation of the climate stress tests.
5. **Leverage the firm's implementation of firm-wide stress testing and adapt it** to cater for the specificities of climate stress tests.
6. **Clearly and widely communicate on the governance, the key roles and responsibilities of each team** involved in the climate stress testing exercise.

4.3.2 Regulatory guidance on firm-wide integration of climate stress tests

We highlight below some of the key regulatory recommendations and expectations when considering the design, implementation and embedding of climate stress tests with respect to teams and governance.

Embedding climate stress testing into existing stress testing programmes

In the decade since the GFC, many firms have developed a stress testing programme that is now strongly embedded within their organisation.

- They are designed with clear objectives to meet regulatory requirements, incorporating views from across the institution.
- The programme can include a range of methodologies and models with collaboration from a range of experts.
- Recommendations by regulators encourage a well-documented programme, including the documentation of "the reasoning and judgements underlying the scenarios chosen and the sensitivity of stress testing results to the range and severity of the scenarios" (OFSI, 2009).
- Established well-defined internal governance is vital for the effective implementation of the programme (EBA, 2018).

The firm's board is held accountable for their traditional stress testing programme and the senior management is responsible for implementing and managing the programme and its associated governance.

A climate stress testing programme will additionally require the development of relevant policies and procedures, in order to be well-established across the firm. Given how strongly traditional stress testing programmes are embedded within financial institutions, it is best for procedures and policies for climate stress testing to be developed around the current framework for traditional stress testing programmes and its regulatory guidance where applicable.

Robust governance and oversight arrangements

Regulators have highlighted the importance of active engagement by the firms' boards and senior management in traditional stress testing, as well as in climate risk management. A firm's board is expected to consider climate-related risks in developing internal strategy and the risk management framework, and to exercise oversight of these risks.

European regulators (ECB, 2020; Bank of England, 2019) have emphasised the importance of the board and senior management's understanding of financial risks arising from climate change, along with their participation in the review and identification of appropriate, well-understood, documented and sufficiently severe stress scenarios. For example, in its 2019 Supervisory Statement on enhancing banks' and insurers' approaches to managing the financial risks from climate change, the British regulator stated, "The Prudential Regulation Authority (PRA) expects a firm's board to understand and assess the financial risks from climate change that affect the firm, and to be able to address and oversee these risks within the firm's overall business strategy and risk

appetite". Similarly, in its guide on climate-related and environmental risks, the European Central Bank (ECB) detailed its expectations from senior management explaining, "The management body is expected to consider climate-related and environmental risks when developing the institution's overall business strategy, business objectives and risk management framework and to exercise effective oversight of climate-related and environmental risks."

These requirements have also been reinforced by the TCFD's recommendations that such governance arrangements and results be disclosed (TCFD, 2017), as highlighted in Figure 6 below. Therefore, the institution's risk committee or enterprise-wide risk committee should be responsible for governing the climate stress testing process (and climate risk management in general), providing effective oversight over the production of outputs and challenging the associated analyses.

Recommendations and Supporting Recommended Disclosures

Governance	Strategy	Risk Management	Metrics and Targets
Disclose the organization's governance around climate-related risks and opportunities.	Disclose the actual and potential impacts of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning where such information is material.	Disclose how the organization identifies, assesses, and manages climate-related risks.	Disclose the metrics and targets used to assess and manage relevant climate-related risks and opportunities where such information is material.
Recommended Disclosures	**Recommended Disclosures**	**Recommended Disclosures**	**Recommended Disclosures**
a) Describe the board's oversight of climate-related risks and opportunities.	a) Describe the climate-related risks and opportunities the organization has identified over the short, medium, and long term.	a) Describe the organization's processes for identifying and assessing climate-related risks.	a) Disclose the metrics used by the organization to assess climate-related risks and opportunities in line with its strategy and risk management process.
b) Describe management's role in assessing and managing climate-related risks and opportunities.	b) Describe the impact of climate-related risks and opportunities on the organization's businesses, strategy, and financial planning.	b) Describe the organization's processes for managing climate-related risks.	b) Disclose Scope 1, Scope 2, and, if appropriate, Scope 3 greenhouse gas (GHG) emissions, and the related risks.
	c) Describe the resilience of the organization's strategy, taking into consideration different climate-related scenarios, including a 2°C or lower scenario.	c) Describe how processes for identifying, assessing, and managing climate-related risks are integrated into the organization's overall risk management.	c) Describe the targets used by the organization to manage climate-related risks and opportunities and performance against targets.

Figure 6: TCFD's recommendations for governance.

Adequate resourcing for all climate stress testing functions

A generic requirement in all jurisdictions (for example EBA, 2018) is that firms must ensure that the functions involved in managing risks, including climate-related risks, have the appropriate human, material and financial resources. Both the European Banking Authority (EBA) and the Prudential Regulation Authority (PRA) (Bank of England, 2019) have highlighted the importance of board and senior management responsibility for ensuring the required resources and skills are provided for the successful execution of the exercise. In its 2018 guidelines for institutional stress testing, the EBA stated, "The management body of the institution should ensure that clear responsibilities and sufficient resources (e.g. skilled human resources and information technology systems) are assigned and allocated for the execution of the programme" (ECB, 2020).

Integration of climate stress testing into the firm's organisational structure and processes

Regulatory guidance available on traditional or climate stress testing refrains from recommending specific organisational structures as financial institutions differ in their respective set-ups. However, there are generic structures adopted by institutions that have been described in section 4.1 as the basis for integrating climate stress testing. To effectively manage climate risks, the board, executives and the relevant sub-committees need to have clearly defined roles and responsibilities. For instance, the ECB expects management at institutions to allocate roles and responsibilities for climate-related risk management to its members and sub-committees, in accordance with the three lines of defense model. Similarly, the PRA (Bank of England, 2019) expects there to be well-established roles and responsibilities for the board and its relevant sub-committees. The regulator also suggests that the board and senior executives should be in charge of allocating the responsibility of identifying and assessing climate risks to the appropriate senior management function (SMF) at the institution.

Exhibit 2: Bank of England (BoE) and Prudential Regulation Authority.

In its 2019 Supervisory Statement, the PRA highlighted the importance of the involvement of the board and senior management in managing climate-related financial risks. The regulator expects the board to understand and assess climate risks by addressing and overseeing these risks within the overall business strategy and risk appetite. The PRA specified the need for evidence by institutions to showcase effective supervision and command by the board and its relevant sub-committees in climate risk management (Bank of England, 2019).

The PRA has provided further definitive guidance on providing evidence for governance for their climate stress testing exercise. In its guidance for participants for the 2021 Biennial Exploratory Scenario, the Bank of England re-emphasised the involvement of senior management, stating, "Participants' internal governance processes around their Climate Biennial Exploratory Scenario (CBES) submissions should involve effective challenge from senior management, including by relevant committees and the board of directors." Guidance provided by the regulator on documenting governance included, "Participants should provide details of these governance... in their responses to the qualitative questionnaire" and "Participants should include a record of which committees considered and approved their responses to the exercise and should also provide board papers relating to their submissions. Participants should summarise the key issues that were challenged by senior management or relevant committees, and what changes to responses were made following this challenge." As a result, participants are encouraged to disclose details on the support provided by senior management for governance on the exercise (Bank of England, 2021).

Nine recommendations for integrating climate stress testing activities into firm-wide risk frameworks

1. **Embed climate stress tests into the institution's current stress testing programme, policies and procedures** which senior management are responsible for implementing and managing, along with the associated governance.

   | Recommended governing teams involved: Board of the institution, Board Risk Committee, executive management teams (CEO, Chief Risk Officer), senior management functions (Head of Sustainability and ESG, Head of Risk Functions) and the Climate Risk Working Group.

2. **Establish a firm-wide committee for climate risk coordination and governance.** Depending on the structure of the institution, the risk committee or the enterprise risk committee can take on the role of climate risk coordination and governance.

   | Recommended governing teams involved: Risk Committee.

3. **Provide the board and senior management with the necessary documentation.** The established firm-wide committee should be responsible for providing documents that address rationales behind decision-making for the exercise, implications of choices, key assumptions, limitations of the exercise and evaluation of the results (BIS, 2009).

   | Recommended governing teams involved: Risk Committee and the Climate Risk Working Group.

4. **Establish and document the roles and responsibilities of the board, its relevant sub-committees and the executive management**. The terms of reference of the relevant committees should be updated accordingly.

   | Recommended governing teams involved: Board of the institution, Board Risk Committee, executive management teams (CEO, Chief Risk Officer) and the Risk Committee.

5. **Ensure an adequate allocation of resources for climate stress testing**. In many cases, institutions will need to increase the resources devoted to climate stress testing.

   | Recommended governing teams involved: Board of the institution.

6. **Increase engagement of the board with senior management on climate risks** to ensure the allocation of resources for climate stress testing and engagement by teams across the institution for the exercise. The infrastructure in place at the institution needs to be robust but flexible in order to incorporate changes into the current stress testing programme.

   > Recommended governing teams involved: Board of the institution and the senior management functions (Head of Sustainability and ESG, Head of Risk Functions).

7. **Assign roles and responsibilities for the teams and senior management involved in climate stress testing by the governing authority**, leveraging the existing organisation and arrangements wherever possible.

   > Recommended governing teams involved: Executive management teams (CEO, Chief Risk Officer), senior management functions (Head of Sustainability and ESG, Head of Risk Functions) and the Climate Risk Working Group.

8. **Share the outputs of the climate stress tests** with the business and present at the relevant risk committees and to the board, to ensure that the outputs are embedded into the firm's strategy.

   > Recommended governing teams involved: Board of the institution, Board Risk Committee, Risk Committee and the Climate Risk Working Group.

9. **Ensure policies are in place and implemented by senior management** for the adequate use of the outputs of climate stress testing for business strategy and risk management.

   > Recommended governing teams involved: Senior management functions (Head of Sustainability and ESG, Head of Risk Functions).

5. Data requirements and collection

Key messages

- Data needed for a climate stress test can be divided into two main categories—traditional macro-financial (macroeconomic as well as financial data) and climate-related data (industry-specific, weather-related, etc)—however, financial institutions face numerous obstacles when attempting to collect data for climate stress testing.
- For effective climate stress testing, firms should develop policies and procedures to support the collection, processing and use of climate data.
- Good practices for collecting data involve identifying data needs, understanding the availability of data sources, implementing industry standards, validating data, identifying data gaps and adapting institutional systems.
- Best practices for securing climate data on and from clients can be divided into three categories: (i) steps firms can take in-house and through collaborations, (ii) steps requiring client engagement, and (iii) steps to build robust data collection processes in the future.
- For collecting emissions data, firms should identify internal sources through which emissions data for clients can be accessed and develop internal tools to calculate emissions data.
- When collecting data from external data providers, it is recommended that firms develop an internal policy, identify easily accessible open-source platforms, develop a questionnaire based on the institution's data needs and actively communicate with data providers.

For climate stress testing, financial institutions must collect climate-related data, in addition to much of the data required for traditional stress testing. Financial institutions need to collect data to help translate climate risk drivers into financial risks (BIS, 2021). Collecting climate-related data is often a relatively new process for many institutions and brings with it a variety of challenges. These may include limited availability, lack of quality, limited granularity and coverage, high costs, interlinking with financial data, comparability and standardisation, as well as data processing. In the face of these difficulties, this section provides best practice guidance on in-house and external data collection by firms for physical and transition risk data.

5.1 Data requirements for climate stress testing

Data needed for a climate stress test can be divided into two main categories: traditional macro-financial data and climate-related data.

Traditional macro-financial data

Traditional financial data is well-known to institutions that have undergone stress testing after the 2008–2009 GFC. This data includes a variety of financial information that enables the evaluation of portfolio-level (and sometimes counterparty-level) risk models. Types of financial data that must be collected for climate stress testing are described below.

Table 8: Types of traditional macro-financial data required for climate stress testing.

Data type	Data required	Data Sources
Finance-related data	▪ Portfolio composition by sector and geography. ▪ External and internal credit and valuation criteria. ▪ Local and global economic data. ▪ Balance sheets.	▪ Internal systems
Macroeconomic data	▪ GDP, unemployment, population growth, inflation, interest rates and exchange rates.	▪ Scenarios
Data metrics for expected losses	▪ Probability of Default (PD). ▪ Loss Given Default (LGD). ▪ Average exposure at default (EAD).	▪ Internal systems
Borrower/asset financial data	▪ Costs and revenues by scenario. ▪ Forward-looking metrics, such as OPEX and CapEx.	▪ Internal systems ▪ Scenarios

Climate-related data

Climate-related data represents additional components that go beyond the traditional financial data but are required to complete the assessment. Types of climate data that need to be collected for climate stress testing are described below.

Table 9: Types of climate-related data required for climate stress testing.

Data type	Data required	Data Sources
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

Data describing transition risk drivers	▪ Data on transition risk drivers including policy implementation, market shifts, technological changes and reputation.	▪ Scenarios
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, for example real estate ratings like the Energy Performance Certificate Rating. ▪ Data on carbon pricing by jurisdiction.	▪ Clients ▪ External providers ▪ Internal systems
Climate-related client data	▪ Identification of the physical assets owned by clients. ▪ Detailed and granular geographical/geolocational data of assets.	▪ Clients ▪ External providers
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

Regulatory exercises demand the use of both climate-related and financial data in order to appropriately translate climate risks into financial risks. Exhibit 3 below illustrates an example from Danmarks Nationalbank on the interlinking of climate and financial data types to determine the climate risks of lending to emission-intensive sectors.

Exhibit 3: Danmarks Nationalbank interlinking of climate and financial data.

In its 2020 report "A gradual green transition supports financial stability", Danmarks Nationalbank highlighted the results of their sensitivity analyses as a precursor to a fully developed climate stress test. For their analysis, the regulator used microdata to analyse the impact of climate risks on corporate and mortgage loans given by banks. For corporate lending, Danmarks Nationalbank linked accounting data of firms and emissions data at the industry-level to credit register data for bank lending. For mortgage loans, the regulator linked lending to energy labels data. Figure 7 below illustrates the linking of bank lending data to emissions data for emission-intensive sectors to understand the impact of climate risks across the financial sector (Danmarks Nationalbank, 2020).

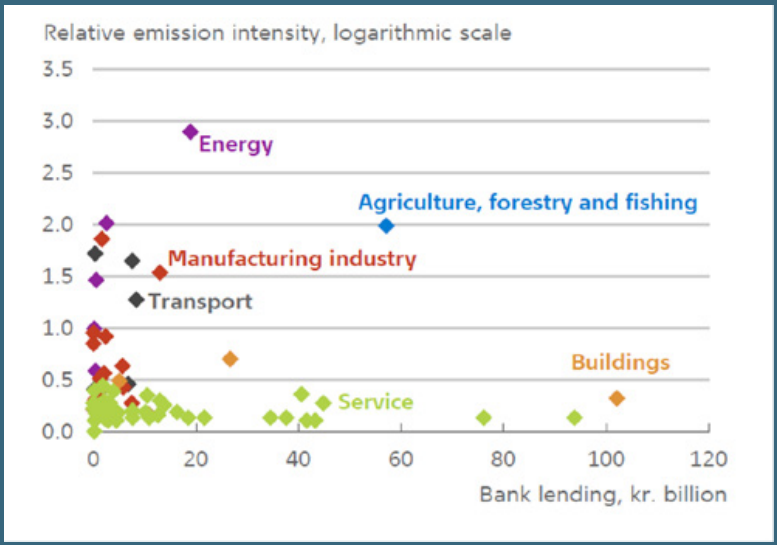

Figure 7: Bank lending for emission-intensive sectors.

The difficulties faced by financial institutions in gathering climate-related data as opposed to finance-related data can be attributed partly to the lack of availability and understanding of climate data types and financial institutions' dependence on external data providers to gather climate data. A survey with participating institutions in UNEP FI's TCFD programme concluded that banks face the greatest difficulty in collecting climate-related client data, emissions data and climate hazard data. The survey results are shown below in Figure 8. Financial institutions instead find it easier to collect data on macroeconomic factors, overall portfolio data, data metrics for credit loss (PD and LGD), borrower/asset financial data and sectoral exposure data.

UNEP FI TCFD participant responses:

Hard to collect data

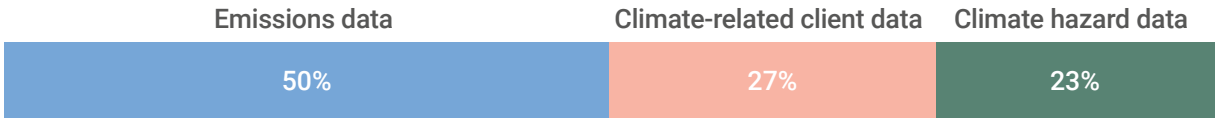

Figure 8: Survey results (2021) showing hardest data types to collect according to participating institutions in UNEP FI's TCFD programme.

Common data collection challenges

Financial institutions face numerous obstacles when attempting to collect data for climate stress testing.

60% of financial institutions in UNEP FI's TCFD programme have stated that they are somewhat unconfident or not confident at all in their ability to collect climate hazard data, with only 4% being quite confident.

Data challenges in identifying and assessing climate risks have also been addressed by the NGFS in its 2021 report 'Bridging Data Gaps' and by the Bank for International Settlements (BIS) in their 2021 report 'Climate-related financial risks—measurement methodologies'. Below we discuss the common challenges faced by institutions in collecting data for climate stress testing.

Limited Availability
- Incomplete disclosure of climate data by clients
- Lack of consensus on the climate data required for analysis

Lack of Quality
- Absence/limited use of data auditing
- Limited disclosure of methodologies/processes underlying data sets

Limited Comparability
- Unstandardized data collection approaches

Variability in Granularity and Coverage
- Variations in granularity observed at sectoral, country, regional, jurisdictional and firm-level

High Cost
- In-house solutions and external data providers are resource-intensive and costly

Difficulties in Technical Processing
- Current IT infrastructure has not been designed to process climate-related data
- Need to integrated a new category of systems and processes

Dependence on Third-Party Providers
- Data safety requirements can often restrict firms from partnering with a third-party providers
- Third party data can vary in their quality, comparability and regional and sectoral coverage.

Difficulty Interlinking Data
- Limited historical data makes it difficult to determine the relationship between climate and financial data
- Correlation from available historical data may not be reliable enough to determine future relationships between climate and finance

Figure 9: Key challenges in collecting data for climate stress testing.

Availability. Data availability can be a challenge for two reasons. Firstly, clients do not generally provide comprehensive and complete climate data disclosures. For example, data on clients' emissions, location of their assets and other forward-looking information used to understand the impacts of client transition targets and pathways can often be sparse. Secondly, the financial sector itself has yet to reach a consensus on the types of physical and transition risk data required for their analyses.

The lack of availability of climate data was something that the ACPR also highlighted in its 2020 climate pilot exercise with the regulator emphasising, "the need for better availability of climate-related data at EU level (physical damage data, transition risks)." The ACPR further noted that clarificatory questions posed by participating institutions focused on requests for additional data, especially for sectoral and international exposure (ACPR, 2021).

Exhibit 4: Availability—A key data issue identified by the NGFS.

In its 2021 'Progress report for bridging data gaps', the NGFS identified **availability** as one of three main categories in which data gaps exist. The NGFS found that large data gaps are present in forward-looking data including emissions pathways and transition targets set by firms. Carbon (emissions) data as well as geolocational data of assets for assessing physical and transition risks are limited in both their availability and granularity (NGFS, 2021).

Quality. Poor data quality can also present issues for firms conducting climate stress tests, and regulators such as the De Nederlandsche Bank (DNB) have highlighted the importance of improving data quality in the context of their stress testing exercises, highlighting, "sufficiently detailed data to study climate-related risks is not available" (De Nederlandsche Bank, 2018). Poor data quality is attributable to a range of factors, including the absence/limited use of data auditing, along with the limited disclosure of methodologies/processes underlying datasets. Banks, for example, collect data using dispersed sources but this tends to be subject to limited auditing or independent validation. Lack of auditing prevents data issues from being rectified, reducing its reliability for climate stress testing. Whilst third-party data may sometimes undergo interpolation, extrapolation or other gap-filling processes, this is not always transparently communicated to data users. The net effect of these shortcomings is that the available data may not meet the standards set by the institution for a traditional stress test exercise in terms of coverage, granularity, length and gaps (BIS, 2021).

Exhibit 5: Quality—A key data issue identified by the Basel Committee on Banking Supervision (BCBS).

In the BIS report 'Climate-related financial risks—measurement methodologies', the Basel Committee on Banking Supervision identified **quality** of data as one of the challenges faced of climate-related data. BCBS (2021) stated, "The data needed to map risk exposures and translate climate-related risks into financial risk estimates may be only partially available and may not adequately meet traditional data quality standards, such as the length of history, completeness, and granularity needed to support the risk decision-maker." Therefore, lack of quantity and quality of the climate-data collected by counterparties is a key obstacle for financial institutions for assessing climate risks (BIS, 2021).

Exhibit 6: Reliability—A key data issue identified by the NGFS.

In its 2021 'Progress report for bridging data gaps', the NGFS identified **reliability** as one of three main categories in which data gaps exist. NGFS explained that studies have shown that the data sources and metrics available can produce varying outcomes. A lack of auditing of climate-related data and a lack of transparency of the methodologies, definitions and criteria used, limits understanding of the reliability of the data (NGFS, 2021).

Comparability. Data provided by clients and third-party sources is often not standardised, making comparisons more difficult both within and between financial institutions. The BIS highlighted this issue in its recent report and noted "Progress has been less tangible in empirically capturing banks' exposures to physical risks. This may be at least partly attributable to considerable additional non-standard data requirements associated with quantifying physical climate impacts" (BIS, 2021).

Exhibit 7: Comparability—A key data issue identified by the NGFS.

In its 2021 'Progress report for bridging data gaps', the NGFS identified **comparability** as one of three main categories in which data gaps exist. A lack of standardisation has led to differences in climate-related disclosure frameworks. Various methods used to collect, process and link available data have led to a lack of consistency. A lack of standardisation and a lack consistency can make it difficult to compare data disclosed using different frameworks due to differences in definitions and technical standards, such as taxonomies and certification labels (NGFS, 2021).

Coverage and granularity. BIS also emphasised the importance of data granularity in assessing physical and transition risks. In its report on measurement methodologies for climate-related financial risk, it specifically highlighted the importance of understanding differences in exposure to such risks at different levels, including at the sectoral, regional and jurisdictional levels (BIS, 2021). Granularity of data by sector or geography may vary significantly. For example, whilst large amounts of data are available for the energy and industry sectors, this tends not to be the case for the IT or the agriculture sectors (NGFS, 2021). Similar differences in granularity can also be observed within regions and at the country level. The NGFS considered the challenge of data granularity in its recent report on data gaps. They identified the fact that different types of risks may require different levels of granularity. Table 10 below shows some illustrative examples of granularity across transition and physical risks.

Type of risk	Level of granularity	Examples of data
Transition risk	Low	Country or sector level
	Medium	Firm-level
	High	Activity level or value chain
Physical risk	Low	Country level
	Medium	District level
	High	Latitude/longitude

Partly extracted from NGFS, Guide for Supervisors, May 2020.

Figure 10: Data granularity of climate-related risks as identified by the NGFS (NGFS, 2021).

Exhibit 8: Granularity—A key data issue identified by Basel Committee on Banking Supervision (BCBS).

In the BIS report 'Climate-related financial risks—measurement methodologies', BCBS identified **granularity** of data as one of the challenges faced in relation to climate-related data, explaining that greater granularity, such as for geolocational data and climate adaptation data is needed to be able to understand the exposure of small and large institutions to climate risks. Different levels of granularity among jurisdictions and a lack of standardisation in the data to be collected has made comparability of data for financial institutions difficult (BIS, 2021).

Resourcing. Acquiring data needs resources and can be costly, for example, in-house solutions tend to be highly resource-intensive and costly to implement. Whilst banks often tend to depend on external data providers to obtain climate data, this too can be costly with firms finding that they have not allocated adequate budgets to purchase this data nor build in-house data collection capabilities.

Technical limitations. Current bank IT infrastructure and data architecture was not originally set up for the purpose of processing climate-related data. This can result in technical difficulties in integrating this data into existing systems. As an example, geolocation tools used to analyse the physical risks associated with a particular set of assets, represent a new category of systems and processes which will need to be understood and incorporated into bank data systems along with more traditional client data.

Dependence on third-party providers. Many financial institutions need to use third-party data providers to access necessary datasets for climate stress testing. This is partly attributed to many financial institutions lacking necessary expertise and resources needed in-house for collecting and processing climate-related data (BIS, 2021). Data confidentiality and safety requirements of financial institutions can often restrict them from partnering with a third-party provider to collect data. Data available from third-party providers can also vary in quality, comparability, and regional and sectoral coverage.

Exhibit 9: Limited internal expertise—A key data issue identified by BCBS.

In the BIS report 'Climate-related financial risks—measurement methodologies', BCBS identified **limited internal expertise and resources** within an institution as a challenge for processing climate data to determine economic impact. The lack of in-house expertise and resources results in financial institutions relying on external providers for data (BIS, 2021).

Interlinking of data. A lack of historical data has made it often difficult for financial institutions to determine the relationship between climate data and financial data for scenario analysis. Furthermore, correlation from historical data that is available may not be reliable enough to determine future relationships between climate and finance (BIS, 2021). When developing scenarios internally, firms have found it challenging to link traditional macroeconomic variables, such as GDP, to climate-related variables, such as GHG emissions, to determine the economic impact of climate risks. This was reiterated in the insights provided in BIS report on stress-testing banks for climate change risk (2021), stating "historical data are less relevant to climate risk assessments, even where they exist. It is therefore more difficult to estimate linkages between climate events, climate and environmental policies, the economy, the financial system and individual institutions." (BIS, 2021) The obstacle of interlinking climate and financial data has also been discussed by the NGFS to help bridge data gaps (NGFS, 2021).

Exhibit 10: Use of historical data—A key data issue identified by BCBS.

In the BIS report 'Climate-related financial risks—measurement methodologies', BCBS emphasised the **limitations of historical data** of climate risks as historical relationships between climate and the economy may not be a good representative of future relationships (BIS, 2021).

5.2 Good practices for collecting internal and external data for climate stress testing

5.2.1 Good practice steps for data collection

For effective climate stress testing, firms should develop policies and procedures to support the collection, processing and use of climate data. In the remainder of this section, we set out good practices in physical and transition risk data collection for climate stress testing. Good practices involve identifying data needs, understanding the availability of data sources, implementing industry standards, validating data, identifying data gaps and adapting institutional systems.

1. Identify data needs

Teams involved in climate stress testing should agree on the data they need, set this as a data collection target and develop a plan accordingly. To begin, firms should understand regulatory expectations that will influence their data needs. Institutions should also begin by identifying relevant sectors and regions and the associated data needs. Once data needs and requirements are determined, teams can begin to identify and analyse available sources and begin their data collection process. Institutions should also identify where data gaps exist and develop a plan to improve the scope, quantity and quality of data collected over time to fill these gaps.

2. Explore a wide range of data sources

Firms should use open-source datasets as a starting point for sourcing climate data, such as physical hazard data and climate transition scenario pathways. Open-source platforms help format various datasets into user-friendly formats and can consist of data based on both past events and forward-looking projections from climate models. For physical risk data, institutions can also use datasets released by climatological and geological survey agencies which forecast climate hazards, such as flooding and wildfires (BIS, 2021).

After exploring open-source datasets as a starting point, firms should use internally available datasets, commercial data sources and engage with clients to further collect the required data for the exercise. A firm's plan, as described in step 1, should be used as a guide for collecting data from a diverse set of available data sources to help limit data gaps and improve quality, granularity and coverage.

Firms should also assess internally available data, such as historical financial data, and determine whether this can add value to the data requirements for the climate stress test. For example, access to catastrophe data and loss events may prove useful for the exercise.

3. Select the most suitable sources

After exploring open and commercial datasets and clients as sources for collecting data, institutions should develop a procedure to compare different data sources to determine the accuracy and the reliability of the data. By understanding how data collected through these sources differ, institutions should determine which data source is the best approximation to use for the exercise.

4. Establish a data validation process

A clear data validation process should be established and documented at the institution level. The process itself will be dependent on the type of data collected. The source and methodology used to obtain each data point should be clearly identified. Furthermore, firms should be aware of and document any underlying assumptions made when using third-party data. When available, overlapping data should be cross-checked for consistency and be used to inform the collection process, to eliminate potential unsuitable methodologies or assumptions that lead to poor quality of data.

5. Fill in data gaps with sound assumptions

Data gaps should be identified and the teams involved should agree on how to best address these gaps. Where no other data is available, institutions should use estimates,

sector averages, weighting and classification schemes within a sector. They may also choose to use an overlay based on subject matter expert judgement. In order to comply with regulatory guidance on effective risk data aggregation and risk reporting (for example BCBS 239), the institution should develop and document a set of internal procedures and standards to support the acquisition, processing and use of climate data.

6. Develop methodologies to implement policies and procedures for data collection
Standardised metrics and methodologies should be applied for collecting and using data as data consistency is key to an effective climate stress test. Institutions should therefore monitor emerging and associated standards for implementation. As a starting point, financial institutions should begin to integrate their data needs into their internal processes, such as client onboarding, annual review processes, client deals and due diligence. In its 2021 BEI Client Engagement Guide, the Cambridge Institute for Sustainability Leadership (CISL) highlighted the importance of open dialogue with clients during these processes to understand the information the client is publicly disclosing (CISL, 2021). To ensure standardisation, institutions can develop a questionnaire to ask clients about specific climate risks and establish a framework to determine the best source for external data on a continuous basis. These internal processes should be used by the firm to implement policies and procedures designed to improve climate data collection.

7. Update and adapt internal systems for data processing
Current internal systems used by firms should be updated and adapted to accommodate new kinds of data that were previously not required for a traditional stress test. New data types, such as geographical data (for example longitude and latitude, topographical data and climate data) should be integrated into the system for processing. Financial institutions should also incorporate new kinds of systems, such as Global Positioning Systems (GPS) coordinated for asset location and GIS for mapping asset location and comparing them to physical hazards projections. Systems on which models currently run should also be modified, such as current credit systems used in traditional stress tests.

5.2.2 Guidance on data collection for counterparty analysis

Counterparty-level analysis is important for capturing climate risks for the financial sector. Climate risk assessment by regulators and financial institutions has centered around measuring exposure of counterparties to climate risk drivers. This was highlighted by the Bank of England in its 2021 CBES exercise where the supervisory authority asked UK banks to conduct analysis on at least 100 of their counterparties, where exposures were higher than £10 million (Bank of England, 2021).

In order to perform counterparty-level analysis, firms need to engage with their clients to collect a range of data types to assess physical and transition risks, as described in Table 10.

Table 10: Climate data required by firms to assess counterparty-specific climate risks.

Type of climate risk	Type of climate data
Physical (NGFS, 2021)	▪ Adaptive capacity data, including: ▫ Client's adaptation and resilience plans; ▫ Client's sensitivity to past climate events, including data on how the client has tackled extreme weather events in the past. ▪ Geographical data on the location of client's physical assets. Note: Hazard forecasts and mapping can be provided by third-parties.
Transition (NGFS, 2021)	▪ Alignment and transition plans (e.g. client's targets and pathways for reducing emissions). ▪ Data on a client's preparedness to transition to a low-carbon economy. ▪ Published or estimated emissions data by jurisdiction, by asset or by category of assets. ▪ Data available on exposure to carbon prices by jurisdiction. ▪ Energy efficiency and mix data by asset or category of assets.

Recommended guidance for collecting both physical risk and transition risk data from clients

Given the gaps in climate data disclosure highlighted above, we provide guidance below on securing climate data on and from clients for the purpose of counterparty analysis for climate stress testing. This is divided into the following three categories: (i) steps firms can take in-house and through collaborations, (ii) steps requiring client engagement, and (iii) steps to build robust data collection processes in the future.

Although this guidance is relevant for securing data from all clients, it is especially relevant for small and medium enterprise (SME) clients. Data on these businesses tends to be more limited than, for example, large public listed companies, and banks generally tend to have limited resources available for gathering climate-related data.

Steps for data gathering through in-house and external collaborations

1. **Attempt to collect as much relevant climate data on the client**. To do so, financial institutions should use their in-house capabilities to develop internal tools for data collection. For example, developing a carbon calculator to estimate a client's emissions data.

2. **Increase stakeholder collaboration** by collaborating with various regulators, governments, municipalities and other stakeholders to increase accessibility to data, particularly for clients where data is otherwise difficult to collect. For example, financial institutions can collaborate with local governments to gain access to flood assessments at the municipality level, in order to assess flood hazards as a physical risk in their climate stress testing exercise.

3. **Develop industry partnerships to provide the tools and support needed to clients to facilitate data collection and analysis.** Institutions can partner with various firms, including software companies to leverage the use of digital technology for data collection. Partnerships can provide financial institutions with access to cloud and Artificial Intelligence (AI) technology which can be used to better inform their understanding of their client's data by collecting large amounts of data consistently at a reasonable cost.

   Recognising the importance of AI technology for data collection, a new initiative known as OS-Climate, was launched by the Linux Foundation, in collaboration with Amazon, Allianz, Microsoft and S&P Global, channeling AI technology with open-source analytics and open data for assessing climate risks.

Steps requiring client engagement

1. **Facilitate open and effective communication with the client about data requirements.** Institutions should take steps to increase communication with their clients to ensure they understand data requirements and that they disclose the correct data. Effective communication on data collection can be facilitated through workshops, courses and materials to build clients' understanding in this area. Open communication will also help the financial institution to understand the client's current progress in disclosing data, their capabilities and the obstacles they face in data production. This will mean firms are better placed to support clients going forward.

2. **Update current client engagement processes** such as underwriting, know your customer (KYC) and other due diligence processes, and integrate the climate stress test data requirements. Data collection from clients should be set-up to be made as painless as possible to ensure the data needed is disclosed by clients.

Steps to build robust data collection processes in the future

1. **Develop a questionnaire based on the data needed from the client**. The questionnaire should act as a guide for financial institutions and clients to ensure that necessary information is collected for a climate stress test. Detailed examples of the types of questions that should be asked in the questionnaire are included in Appendices and should vary depending on the data type. A questionnaire will help financial institutions overcome challenges related to data availability, comparability, coverage and quality. The questionnaire can be provided during the onboarding process, annual review, due diligence process or ad-hoc climate related discussions. Appendix 1 provides examples of key questions which can serve as a mini questionnaire.

2. **Adopt the use of GIS** to gather geospatial data related to clients and their assets, to identify at-risk locations. New kinds of systems and data will require firms to upgrade their IT infrastructure.

See Appendix 1 for key questions and topics to address when collecting physical risk data from clients

See Appendix 2 for key questions and topics to address when collecting transition risk data from clients

Figure 11: Examples of low-carbon transition initiatives that clients can participate in.

Exhibit 11: Counterparty data guidance by the Bank of England.

For participants of the 2021 Climate Biennial Exploratory Scenario, BoE has provided in-depth guidance with examples of when corporate counterparty adaptation plans should be included into climate stress testing analysis by institutions. Below we have summarised the guidance provided by the supervisor.

Examples where corporate counterparty adaptation plans should not be included in the analysis include where the counterparty:

- Does not have an adaptation plan or is not implementing an adaptation plan.
- Is implementing an adaptation plan but it is not likely to be completed.
- Belongs to a regulated industry with upcoming regulatory changes for transition, but the adaptation plan is not currently being implemented.

Examples where counterparty adaptation plans might be included in the analysis include where the counterparty:

- Has adaption plans, began implementing them before the end of 2020 and the plans are highly likely to be completed.
- Is implementing long-term adaptation plans, which they began implementing before the end of 2020.

Examples where counterparty adaptation plans might be broken down and only certain parts are included in the analysis include where the counterparty:

- Has implemented adaptation plans that are highly likely to be completed and include unachievable long-term targets.
- Has implemented certain parts of their adaptation plans but other parts should not be accepted.

(Bank of England, 2021)

Additional guidance on collecting emissions data

63% of institutions participating in UNEP FI's TCFD programme ability. are either somewhat or not at all confident in their ability to collect emissions data, with only 4% of the institutions extremely confident in their ability.

Below we have provided additional recommendations for collecting emissions data for a climate stress test

1. **Identify internal sources through which emissions data for clients can be accessed**. For example, firms can calculate emissions data by accessing electricity consumption payments made by the client through them.
2. **Develop internal tools to calculate emissions data**, such as a carbon calculator. A carbon calculator is a useful and easy-to-use tool to estimate a client's GHG emissions and determine their carbon footprint by using information from their banking accounts related to their electricity, gas and fuel payments. Simple tools like a carbon calculator do not require additional information from clients.

Exhibit 12: Example—GHG Emission Calculation Tool by the Greenhouse Gas Protocol.

The GHG protocol launched a free to use and publicly available GHG Emission Calculation Tool. The excel-based tool was developed in partnership with the World Resource Institute (WRI) to help calculate companies' GHG emissions.

The tool uses default emission factors but also allows users to provide custom emissions factors as shown in Figure 12 below. Users are also able to adjust the default global warming potential metric.

Custom Emission Factors

The tool uses default emission factors, which vary by country. These are free to use and publicly available, and the tool includes links of where to obtain them. Currently, separate sets of emission factors are available for the UK and US. Location-based Scope 2 emission factors are also available for the US, Canada and Australia, while market-based residual mix emission factors are available for the US, Canada and all European countries. For all other emission factors, links are provided from where they can be purchased from and then put in the table below.

Custom Emission Factors											
				Emission Factors							
Name of Custom EF	Scope	Activity Type	Source of Emission Factor	Fossil CO_2	CH_4	N_2O	Biofuel CO_2	CO_2e	Unit of Emission Factors (numerator unit)	Unit of Emission Factors (denominator unit)	Notes
Example S1	Scope 1	Stationary Combustion	Company operations	5	0.1	3.05		22,400	kg	mWh	
Example S3	Scope 3	Transportation	National transport website	3	0.01	0.001		3,648	kg	mile	
Example S2	Scope 2	Purchased Electricity - Market Ba	Utility provider	3	0.05	3.62		30,230	kg	kWh	
Example S1 - Mobile	Scope 1	Mobile Combustion	Vehicle information	2	0.02	0.002		3,096	kg	gal (US)	
Example S2 - heat	Scope 2	Heat	Heat provider	1	0.01	0.005		2,740	kg	kWh	
								0.000			
								0.000			
								0.000			
								0.000			
								0.000			

Figure 12: Custom emissions factors for companies

The carbon calculator allows the calculation of Scope 1, 2 and 3 emissions. The tool calculates stationary combustion, mobile combustion and refrigerants as Scope 1 emissions, purchased electricity as Scope 2 emissions and transportation as Scope 3 emissions. Below shows the methods used by the tool to calculate emissions.

S1 - Stationary Combustion

Includes fuel consumption at a facility to produce electricity, steam, heat, or power. The combustion of fossil fuels by natural gas boilers, diesel generators and other equipment emits carbon dioxide, methane, and nitrous oxide into the atmosphere.

Data required:
1. Fuel type
2. Fuel Usage
3. Units for usage (volume or weight)

Emissions $_{GHG, fuel}$ = **Fuel Consumption** $_{fuel}$ * **Emission Factor** $_{GHG, fuel}$

Figure 13: Example of Scope 1 emissions calculations.

S2 - Purchased Electricity

Electricity and other sources of energy purchased from your local utility (that is not combusted on-site). Examples include electricity, steam, and chilled or hot water. To generate this energy, utilities combust coal, natural gas, and other fossil fuels, emitting carbon dioxide, methane, and nitrous oxide in the process.

Data required:
1. Energy source
2. Energy usage
3. Units (kWh for electricity)

Emissions $_{GHG, fuel}$ = **Fuel Consumption** $_{fuel}$ * **Emission Factor** $_{GHG, fuel}$

- User has the option to choose between market-based or location-based emissions
- The tool includes data for grid average emission factors for the US, Canada, Australia and China; residual mix factors are provided for the US, Canada and EU countries
- Market-based emissions hierarchy: Custom emission factors, residual mix, location based/grid average

- Country-level location based emission factors are available for other countries from the IEA. These factors may be purchased from: http://data.iea.org/payment/products/122-emissions-factors-2017-edition.aspx

Figure 14: Example of Scope 2 emissions calculations.

S3 - Transportation

Fuel consumption by vehicles used to conduct company-financed travel. Examples include commercial air travel and use of rented vehicles during business trips (travel using company-owned/leased vehicles are included in Scope 1).

Data required:
1. Method of travel
2. Travel distance and units/weight distance and units/passenger distance and units

$$\text{Emissions}_{GHG,\,fuel} = \text{Fuel Consumption}_{fuel} * \text{Emission Factor}_{GHG,\,fuel}$$

- Emission factors database includes emission factors from EPA (US based) and DEFRA (UK based)
- US EPA is recommended for use in calculating emissions in the US; UK DEFRA is recommended for emission activities in the UK

Figure 15: Example of Scope 3 emissions calculations.

Below is an example of the emissions summary provided for a company by the excel tool.

GHG Emissions Summary

Name of Business
Prepared By

Boundary for results: Company
Year (optional): 2020

Scope	Activity Type	Year 2018	2019	2020	2021	2022	2023
Scope 1	Stationary combustion	0.00	5.52	0.00	0.00	0.00	0.00
	Mobile combustion	0.41	0.00	0.00	0.00	0.00	0.00
	Fugitive emissions from air-conditioning	1.62	0.00	0.00	0.00	0.00	0.00
	Other fugitive or process emissions						
	Scope 1 - Total	**2.04**	**5.52**	**0.00**	**0.00**	**0.00**	**0.00**
Scope 2	Purchased electricity - location based	0.00	0.00	0.00	0.00	0.00	0.00
	Purchased electricity - market based	0.53	0.00	0.00	0.00	0.00	0.00
	Purchased heat and steam	0.06	0.00	0.00	0.00	0.00	0.00
	Scope 2 - Location based + heat and steam	**0.06**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
	Scope 2 - market based + heat and steam	**0.59**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Scope 3	Purchased goods and services						
	Capital goods						
	Fuel-and energy-related activities (not included in scope 1 or scope 2)						
	Upstream transportation and distribution	0.18	0.00	0.00	0.00	0.00	0.00
	Waste generated in operations						
	Business travel	0.00	0.00	0.00	0.00	0.00	0.00
	Employee commuting	0.00	0.03	0.00	0.00	0.00	0.00
	Upstream leased assets						
	Downstream transportation and distribution						
	Processing of sold products						
	Use of sold products						
	End-of-life treatment of sold products						
	Downstream leased assets						
	Franchises						
	Investments						
Scope 1 (Biogenic)		0.00	0.00	0.00	0.00	0.00	0.00
Scope 2 (Biogenic)							
Scope 3 (Biogenic)		0.00	0.00	0.00	0.00	0.00	0.00

Figure 16: Example GHG emissions summary for a company.

(Greenhouse Gas Protocol calculation tool, 2021)

3. **Attempt to collect emissions data reported by a client** in their environmental reports and official fillings. The Partnership for Carbon Accounting Financials (PCAF) (PCAF, 2020) recommends the use of the most recent data disclosed by companies in their official filings and environmental reports.

4. **Develop an additional questionnaire** focused on published and estimated GHG emissions for companies. The questionnaire should cover methodology, sources and the shortcomings of the data on emissions. In the appendices, we have provided examples of key questions which can serve as a mini questionnaire.

See Appendix 3 for additional questions to include when collecting emissions data from companies.

5. When emissions data is not available from clients, especially SME clients, **firms should use sectoral or industry averages** and assign them to the client, with the possible overlay of subject matter expert judgement as to the specificities of the client. PCAF encourages the use of estimation models to determine GHG emissions emitted by a company when they do not disclose their data. For example, PCAF suggests the use of emission factors from production-based models and revenue-based models to fill in data gaps (PCAF, 2020).

6. **Collaborate with various groups and stakeholders to collect emissions data for companies**. For example, financial institutions can collaborate with grid regulators to obtain the energy usage of a certain local area.

5.2.3 Types of third-party data available

Financial institutions also need to buy from or partner with external data providers to access available data, to meet climate stress test data requirements, as shown previously in Table 9. In its guidance for climate stress testing, the BoE provided the participating firms with benchmark physical risk data from external data providers such as the UK Met Office, NGFS and the Oasis Hub. Below we have highlighted the data types needed for climate stress testing, which financial institutions can obtain through partnerships with external providers (Table 11). Data from external providers can either be open data sources, as described in section 5.2.4, or commercial data sources. Data can also be obtained from scenarios and models, which will be discussed in section 6.

Table 11: Climate data accessible through third-party providers

Type of climate risk	Type of climate data
Physical	▪ Past and future projections of frequency and severity of acute and chronic physical events, including physical risk hazards at the: ▫ Regional level; ▫ Sector-level; and ▫ Industry-level. ▪ Geolocation of assets.
Transition	▪ Country-level data on carbon pricing. ▪ Carbon footprint and GHG emission data at the: ▫ Firm-level; ▫ Country level; ▫ Sector-level; and ▫ Industry-level. ▪ Pledges, targets and commitments announced by firms and countries.

Exhibit 13: Internal data collection by the European Central Bank.

In March 2021, the ECB released the results of its internally conducted climate stress testing exercise. For the exercise, the regulator constructed a dataset by combining financial and climate data for four million global firms, as illustrated in the Figure 17 below. They used external services to collect data, deriving data from 427 datasets for physical risks and Urgentem datasets for emissions data. Emissions data was collected for these firms to determine the impact of climate policies. The emissions data included past and future emissions taking into account reduction targets set by the firms. ECB also used geolocation data for matching potential climate hazards to the physical address of the firm to calculate a physical risk score for each firm. Various data sources were used to interlink climate data with financial variables for analysis.

The datasets generated by the ECB helped highlight the difference in vulnerability to climate risks among sectors and regions, emphasising the importance of granularity of the data collected. The firm-level data were combined with the NGFS scenarios to identify and quantify climate risk exposure of firms globally.

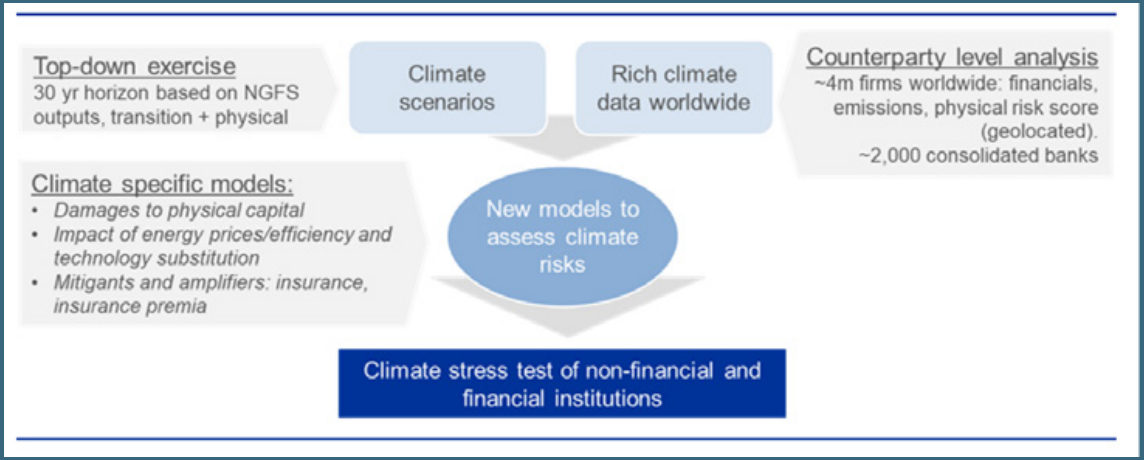

Figure 17: Key features of the ECB climate stress.

(ECB, 2021)

Gathering data from third-parties

Recommendations for gathering physical and transition risk data from external data providers

1. **Develop an internal policy** for gathering climate risk data from external data providers. The recommendations below should be considered when developing these policies.
2. **Identify open-source platforms that can provide access to climate-related data**, including climate hazards data and transition risk data. For example, the GHG Protocol (World Resources Institute & World Business Council for Sustainable Development, 2004) recommends the use of GHG registries which have been established as open databases for firms to report their GHG emissions. These registries are often established by governments, NGOs, or industry groups.
3. **Identify potential data providers to work with.** Institutions should be fully aware of the suitable data providers available in their local region, with whom they can collaborate with.
4. **Develop a questionnaire based on the institution's data needs from the data provider.** The questionnaire should be designed to determine coverage and methodologies used by the providers of interest to the institution. Institutions should incorporate the questionnaire into their selection process for external data providers as a guide to determine which provider or database best matches the data requirements for the climate stress testing exercise. In the Appendices, we have provided examples of key questions which can serve as an initial questionnaire.
5. **Actively communicate with data providers** and determine which provider to collaborate with or buy from. Financial institutions should take part in initiatives designed to assist institutions in their data collection for climate risk management from a range of different data sources. Dialogue on data collection can be initiated through initiatives such as the Future of Sustainable Data Alliance.

See Appendix 4 for key questions to address when gathering physical risk data from external providers

See Appendix 5 for key questions to address when gathering transition risk data from external providers

Third-party public data sources for physical risk data.

Financial institutions should access and analyse all open source/public platforms to collect data on physical risk hazards free-of-charge. Below is a non-exhaustive list of publicly available global data sources on physical risk hazards.

Table 12: Open data sources available for physical risk hazards.

Data Source	Physical hazards covered	Geographical Coverage
Climate Central	Extreme sea levels, storm surge data, high tide events, coastal flooding, sea level changes and severe winds.	Global
PREPdata	Temperature rise, precipitation, coastal risk, water risk and other extreme events.	Global coverage with low granularity for specific countries
UNEP Global Risk Data Platform	Tropical cyclones, storm surges, drought, earthquakes, fires, floods and landslides.	Global
KNMI—Climate Explorer	Temperature, droughts, cyclones and precipitation.	Global
World Bank Climate Change Knowledge Portal	Temperature rise, seasonal precipitation, sea level rise, extreme weather events, such as floods, droughts and heat waves.	Global
WRI Aqueduct Water Risk Atlas	Water risks, including flood and drought risk.	Global
CDP Open Data Portal	Storms, extreme heat, sea water intrusion, drought, floods and forest fires.	Global coverage of CDP cities
GFDRR ThinkHazard!	Extreme heat, floods, earthquakes, landslides, sea level rise, water scarcity, and wildfires.	Global
Oasis Hub	Flooding, cyclones, earthquakes, extreme weather and landslides.	Global
Open Data for Resilience Index	Flooding and cyclones.	Estimated 55 countries covered
Google dataset search	Hurricanes, sea level rise and temperature rise.	Global

Third-party public data sources for transition risk data

Financial institutions should access and analyse all open-source platforms to collect data on transition risks free-of-charge. Below is a non-exhaustive list of publicly available data sources on transition risks.

Table 13: Open data sources for emissions data

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
The Carbon Monitoring for Action (CARMA) database	GHG emissions estimates for power plants.	United States of America, European Union, Canada, India, and South Africa, as well as data from the International Atomic Energy Agency
Greenhouse Gas Protocol	Product life cycle and corporate value chain (Scope 3) GHG inventories.	Global
The Lowdown v2.0	Coal capacity for countries.	Global
UNdata	Methane, Carbon Dioxide, Hydrofluorocarbons, Nitrous oxide, Nitrogen trifluoride, Perfluorocarbons and Sulphur hexafluoride.	43 countries however data is only available for 29 years

6. Models and scenarios

Key messages

- Adapt reference scenarios geographically and sector-wise and derive the impact on key drivers to develop a relevant scenario narrative.
- Implement a process to integrate the latest scenario developments and emerging methodology standards into the scenario design for climate stress testing.
- Undertake scenario expansion to extrapolate the additional scenario variables required for the climate stress test.
- The modelling process in a climate stress test consists of modelling climate variables, measuring the impact of climate risks on macroeconomic variables, breaking down the macroeconomic impacts per sector or per portfolio and quantifying the impact on the financial institution.
- To improve modelling capabilities, a firm should identify gaps in current in-house models and increase communication with external modelers and academics on scenario expansion and improve understanding of different models. Firms should develop criteria to enhance their coordination with these groups.
- Adapt existing downstream models, for example loss forecasting models, to incorporate climate-related variables

6.1 Climate scenarios for stress testing

6.1.1 Overview of climate scenarios

In the financial sector, scenario analysis is a commonly used tool by risk managers. A scenario provides an alternative state that is plausible in the future under a given set of assumptions and constraints. In its 2017 technical guide on scenario analysis, the TCFD defined climate scenarios as:

> **"A path of development leading to a particular outcome. Scenarios are not intended to represent a full description of the future, but rather to highlight central elements of a possible future and to draw attention to the key factors that will drive future developments"**
>
> **TCFD, 2020**

Climate scenario analysis has been growing in importance for climate risk assessment, especially for climate stress testing.

22% of UNEP FI's TCFD programme participants are using climate scenarios for their climate stress testing exercises.

In a traditional stress test, scenarios are used to understand the potential impact of a stress event on a financial institution using macroeconomic variables. In a climate stress test, scenarios include physical and transition risk variables, which are translated into macroeconomic variables to understand the potential impact of climate stress events on a firm. The physical and transition risks included in the scenarios are those that are likely to have a material impact on a financial institution. The Financial Stability Institute's report "Stress-testing banks for climate change—a comparison of practices" further explained that scenarios "need to take into account cumulative and feedback effects arising from both sets of risks and economic impacts." A climate stress test can require a higher number of scenarios due to uncertainty in the physical and transition risk variables used. A greater number of scenarios produces a greater range of outcomes to help financial intuitions understand the potential impacts of climate risks (BIS, 2021). Below we describe some of the common climate scenarios used for scenario analysis and climate stress testing.

Network for Greening the Financial System reference scenarios

In June 2020, the NGFS, a global group of central banks and supervisors, released its Phase I of climate "reference" scenarios. The NGFS climate scenarios examine various futures in relation to climate change—an orderly transition to a low-carbon economy, a disorderly transition and a 'hot house' no action world. Each reference scenario has a storyline with a set of characteristics, such as temperature targets or deployment of carbon dioxide removal (CDR) technologies. Figures 18 and 19 show the classifications and storylines of the NGFS scenarios.

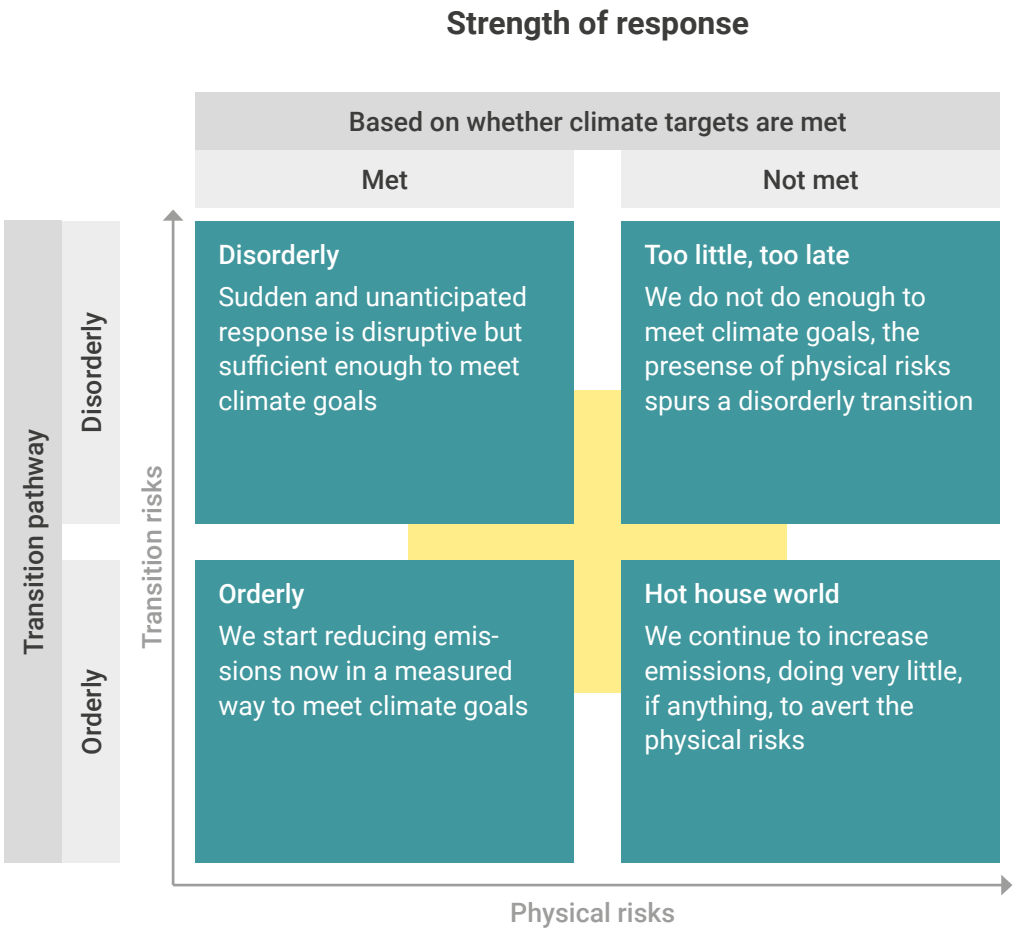

Figure 18: Classification of the NGFS Reference Scenarios.

Scenario	Classification	Storyline
Current policies	Hot house world	Current climate policies are followed for all regions, similar to IEA's current policies scenario, implies rise of approx 4°C by 2100
Nationally deter-mined contribu-tions (NDCs)	Hot house world	Nations follow unconditional nationally determined contribu-tions based on the Paris Agreement, implies rise of approx 3°C by 2100
Immediate 2°C	Orderly transition	Collective action is taken now to reduce emissions towards a 2°C target, very similar in structure to the old 2°C scenarios
Immediate 1.5°C	Orderly transition	Collective action is taken now to reduce emissions towards a 1.5°C target, very similar in structure to the old 1.5 scenarios°C
Immediate 2°C (low CDR)	Orderly transition	Agressive collective action begins now on 2°C pathway, limited use of negative emissions
Delayed 2°C	Disorderly tran-sition	Agressive collective action only begins after 2030 to align with a 2°C
Delayed 2°C (low CDR)	Disorderly tran-sition	Agressive collective action only begins after 2030 to align with a 2°C, limted use of negative emissions
Immediate 1.5°C (low CDR)	Disorderly tran-sition	Agressive collective action begins now on 1.5°C, limited use of negative emissions

Figure 19: Storylines of the Phase I NGFS Reference Scenarios.

In June 2021, the NGFS released Phase II of its climate reference scenarios. These scenarios have been improved and updated to capture the latest developments in climate data and analysis. The scenario narratives now include regional policies to reach net zero by 2050 to limit warming to 1.5°C. Phase II has six scenarios instead of the eight scenarios from the previous phase and still sits within the NGFS scenario framework of orderly, disorderly and hot house world pathways. Figure 20 highlights the key changes in scenarios from Phase I to Phase II by the NGFS.

Phase I name	Phase II name	Changes
▪ Orderly (1.5°C with CDR)	▪ Net Zero 2050	This scenario still reaches 1.5°C and net zero by 2050. Individual regional pathways are updated.
▪ Orderly (rep) (2°C with CDR) ▪ Orderly (2°C with limited CDR)	▪ Below 2°C	This scenario still leads to warming between 1.5–2°C. CDR has been limited in the new scenario.
▪ Disorderly (1.5°C limited CDR)	▪ Divergent Net-Zero Policies	This scenario now reflects the impact of divergent policies across sectors and regions represented as carbon price variation.
▪ Disorderly (rep) (2°C delay with limited CDR) ▪ Disorderly (2°C delay with CDR)	▪ Delayed 2°C	Delay to policies still occurs until 2030. CDR has been limited in the new scenario. In addition, the scenario includes regional carbon price variation, i.e. regions with net-zero targets are more ambitious than regions without them after 2030
▪ NDCs	▪ NDCs	Emission and temperatures are lower due to increased climae policy commitments
▪ Current Policies (rep)	▪ Current Policies	Overall emissions and temperature increase is lower due to lower baseline growth assumptions and more policies already implemented.

Figure 20: Comparison of Phase I and Phase II NGFS Scenarios.

International Energy Agency (IEA)

The IEA has developed numerous scenario energy projections for the medium and the long-term using its World Energy Model (WEM) (IEA, 2020). The transition scenarios developed by the IEA represent various policy outcomes, temperature rise and energy and economic pathways.

Stated Policies Scenario (STEPS)

STEPS provides a detailed picture of the direction of current policy initiatives and ambitions and their impact on the energy sector through to 2040, exploring climate-related transition risks. Considering existing policies and commitments impacting the energy market, the scenario aims to provide a benchmark to assess the potential achievements and limitations of developments in energy and climate policies. The pathway includes decreased renewable costs, changes in the global reliance on oil, and the effects on demand, prices and emissions predictions. (IEA, 2020).

Sustainable Development Scenario (SDS)

SDS maps out a pathway that requires rapid and widespread changes across all aspects of the energy sector to meet sustainable energy goals through to 2050. The SDS holds temperature rise to below 1.8°C with a 66% probability and takes into account the impact that investment may have on supply-side and demand-side processes, such as to ensure a reliable energy supply and allow firms to take advantage of the vast potential for energy efficiency (IEA, 2020; IEA, 2021).

Net-Zero Emissions by 2050 (NZE2050)

The NZE2050 scenario shows what more is needed to be done beyond the SDS pathway for the global energy sector to be on a pathway to net-zero emissions by 2050. The scenario is in line with the current pathways used by the IPCC and includes detailed modelling of what would be needed over the next ten years to put CO_2 emissions on track for global net-zero emissions by 2050. The scenario places less emphasis on carbon capture, utilisation and storage (CCUS) and more emphasis on low-carbon, renewable energy sources that can supplement the scenario's objectives (IEA, 2020).

Intergovernmental Panel on Climate Change IPCC

In its Fifth Assessment Report published in 2013, the IPCC developed scenarios to project possible future pathways relative to radiative forcings. Radiative forcings measure the combined effect of GHGs and other factors which increase the trapping of additional heat due to climate change. Each scenario, known as a Representative Concentration Pathway (RCP), shows one of the many possible pathways for a certain level of radiative forcing (Carbon Brief, 2019).

RCP 2.6

RCP 2.6 scenario pathway was developed by the IMAGE modelling team of the PBL Netherlands Environmental Assessment Agency and aims at limiting the global temperature rise to likely below 2°C (IPCC, 2021). It is a stringent mitigation scenario that requires a major turnaround in climate policies and concerted climate action globally (Van Vuuren et. al., 2011). The pathway spans from 2010-2100, with CO_2 emissions peaking by 2020 but significantly declining over time (RCP Database, 2021).

RCP 4.5

Developed by the GCAM modelling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI) (Van Vuuren et. al., 2011), RCP 4.5 is one of the intermediate scenarios used by the IPCC (IPCC, 2021). It assumes that all countries undertake emissions mitigation simultaneously and effectively and share a common emissions price (Thomson et al., 2011). In RCP 4.5, the pathway sees emissions peak mid-century at ~50% higher than 2000 levels (Van Vuuren et. al., 2011).

RCP 6

Developed by the Asia-Pacific Integrated Model (AIM) team at the National Institute for Environmental Studies (NIES) (RCP Database, 2021), RCP 6 is one of the intermediate scenarios used by the IPCC. In this scenario emissions double by 2060 and then dramatically fall due to use of innovations in the energy sector and assumptions of lower technology costs, but remain well above current levels. CO_2 concentration continues increasing, though at a slower rate in the latter parts of the century (IPCC, 2021).

RCP 8.5

This scenario is the worst-case scenario in which emissions continue to increase rapidly through the early and mid-parts of the century. Developed using the MESSAGE model and the IIASA Integrated Assessment Framework by the International Institute for Applied Systems Analysis (IIASA), in this scenario, emissions continue to increase rapidly through the early and middle of the century. The pathway represents no climate change mitigation, therefore no mitigation measures are implemented (Carbon Brief, 2019).

Table 14 highlights how climate scenarios from different modelers can vary in their features and assumptions. The table compares the NGFS scenarios to other climate scenarios, such as those by the IEA and the IPCC.

Table 14: Comparison of NGFS scenarios to other climate scenarios.

Feature	NGFS Phase II Scenarios	Other Scenarios
Timeframe	▪ Up to 2100 for climate impacts and transition pathways. ▪ Up to 2050 for economic impacts (NiGEM).	▪ RCPs (IPCC) go up to the year 2100. ▪ NZE2050 (IEA) goes up to the year 2050.
Scenario Risk Drivers and Level of Policy Ambition	▪ Net Zero 2050—limits warming to 1.5°C ▪ Below 2°C—limits warming to 1.7°C. ▪ Divergent Net Zero—limits warming to 1.5°C. ▪ Delayed transition—limits warming to 1.8°C. ▪ Nationally Determined Contributions (NDCs)—limits warming to 2.5°C. ▪ Current Policies—warming to occur up to 3°C or higher.	▪ NZE2050 (IEA)—limits warming to 1.5°C. ▪ SDS (IEA)—limits the temperature rise to below 1.8°C with a 66% probability without reliance on global net-negative CO_2 emissions. ▪ RCP 2.6 (IPCC)—temperature rise is not likely to exceed 2°C. ▪ RCP 4.5 (IPCC)—temperature rise more likely than not to exceed 2°C. ▪ RCP 6.0 (IPCC)—temperature rise likely to exceed 2°C. ▪ RCP 8.5 (IPCC)—temperature rise as likely as not to exceed 4°C.
Policy Reaction	▪ There is a large variation in the policy (carbon price) depending on the scenario. ▪ A higher emissions price indicates more stringent policies. ▪ For the net zero by 2050 scenario, IAMs suggest a carbon price of around USD160/ tonne by the end of the decade. ▪ This price indicates overall policy intensity. In reality, governments are pursuing a range of fiscal and regulatory policies.	▪ STEPS (IEA) scenario considers all existing or announced carbon pricing schemes. ▪ SDS (IEA) scenario assumes that carbon pricing is established in all developed economies and reach the price USD140/ tonne in 2040.
Technology Change	▪ Net Zero 2050 and divergent net-zero scenarios assume fast technological changes. ▪ Below 2°C scenario assumes a moderate change. ▪ A delayed transition scenario assumes slow/fast change. ▪ Nationally Determined Contributions (NDCs) and current policies scenarios assume a slow change.	▪ NZE2050 (IEA)—majority of reductions in CO_2 emissions up to 2030 are due to technologies currently available. Half of reductions in CO_2 emissions 2050 come from technologies currently being developed.

Feature	NGFS Phase II Scenarios	Other Scenarios
Carbon dioxide removal (CDR)	▪ The NGFS scenarios assume low to medium availability of CDR technologies. ▪ Afforestation is heavily dependent on the scenario and is high for MESSAGE under all scenarios.	▪ In the IPCC RCP scenarios, CO_2 emissions captured and stored from bioenergy and direct air capture range from 3.5-16 Gt CO_2 in 2050. ▪ In the IPCC RCP scenarios, land use varies from net reforestation to deforestation.
Population Assumption	▪ Scenarios are based on Shared Socioeconomic Pathway (SSP) 2. ▪ SSP 2 assumes that society evolves in line with past trends and the global population will peak around 2070.	▪ IEA (WEM)—population growth is based on United Nations Population Division report (UNPD, 2019). In WEO-2020, world population is projected to grow from 7.7 billion in 2019 to 9.2 billion in 2040. ▪ IPCC RCP scenarios do not include socioeconomic narratives.
Economic Assumption	▪ Scenarios are based on SSP 2 . ▪ The GDP pathway was adjusted to take the COVID-19 pandemic into account.	▪ IEA (WEM)—For the short and medium-term, economic growth assumptions are in line with the latest estimates from the IMF. In the long-term, growth across various regions is assumed to convert to an annual rate, with the effects of COVID-19 taken into account. ▪ IPCC RCP scenarios do not include socioeconomic narratives.
Models Used	▪ Climate models participating in the ISIMIP project: ▫ CLIMADA ▫ REMIND-MAgPIE ▫ GCAM ▫ MESSAGEix-GLOBIOM 1.1 ▫ NiGEM ▫ IAMs	▪ IEA scenarios use the World Energy Model (WEM). ▪ IPCC Fifth Assessment Report (AR5) featured climate models of the Coupled Model Intercomparison Projects (CMIP) 5. ▪ IPCC Sixth Assessment Report (AR6) featured models from CMIP 6.

6.1.2 Regulatory scenarios and the NGFS

For supervisory climate stress tests, most supervisors have leveraged NGFS reference scenarios from Phase I and II and have expanded from those for their climate scenario analysis. Reference scenarios need to be adopted by regulators and firms to increase the relevance of the scenarios to geographies, markets and financial systems (IFF, 2021).

Survey responses show that 100% of UNEP FI's TCFD programme participants feel that under stress conditions, the NGFS scenarios assess a portfolio only slightly or somewhat well.

Therefore, it is important for scenario users to adapt reference scenarios for their institution.

Below we have provided examples of supervisory exercises that have used or plan to use NGFS scenarios as a foundation.

- **Australian Prudential Regulation Authority (APRA):** For its Climate Vulnerability Assessment, APRA has designed its scenarios based on two of the NGFS Phase II scenarios. The first scenario aligns with the NGFS delayed transition scenario, and the second scenario aligns with the NGFS hot house world: current policies scenario, with the regulator stating, "Nevertheless, there will be some differences that arise in the implementation of the NGFS scenarios, due to the limited sector and regional resolution of the scenarios as well as the selection of models within the NGFS scenarios" (APRA, 2021).
- **Hong Kong Monetary Authority (HKMA):** For its pilot exercise, HKMA has considered the NGFS reference scenarios, as well the RCP scenarios by the IPCC. Transition scenarios will capture both a disorderly transition and an orderly transition. The physical risk scenario will focus on the projected climate situation of Hong Kong in the 21st century, including temperature increase, rise in sea levels and severe cyclones (HKMA, 2020).
- **Monetary Authority of Singapore (MAS):** MAS has stated that it "will reference climate scenarios developed by the NGFS" when conducting its climate stress test at the end of 2022. The exercise will use a range of physical and transition risk scenarios (MAS, 2021).
- **Autorité de Contrôle Prudentiel et de Résolution (ACPR):** NGFS Phase I reference scenarios were used as a starting point for the climate pilot exercise (ACPR, 2020).
    - Reference scenario: Reflects the NGFS orderly transition scenario. It corresponds to the National Low Carbon Strategy (SNBC) for France to comply with its Paris Climate Change Agreement commitments and reach net-zero emissions in 2050.
    - Late reaction: Reflects the NGFS disorderly transition scenario. The GHG emission reduction objective is not reached in 2030 and requires additional measures.
    - Scenario of swift and abrupt transition: Carbon prices are revised from 2025, which leads to a productivity shock. It is assumed that renewable energy production is not as mature as in the reference scenarios. Higher energy prices and needing greater investments have negative effects on productivity with the economy.
    - Business as usual: Mitigation efforts are limited. Measures that were taken between now and 2050 have very little or no impact on the physical risks. It is the most pessimistic scenario.
- **Bank of England (BoE):** The climate stress test exercise builds upon the NGFS Phase II scenarios with three distinct scenarios (Figure 21) (Bank of England, 2020).
    - Early policy action scenario: Early and decisive action to gradually reduce global emissions to limit a global temperature change to below 2°C. Prices are reallocated in an orderly fashion by financial markets. No macroeconomic shock due

to structural reallocation of the economy to reduce emissions. Physical hazards increase in frequency but are under control.

- Late policy action scenario: A 10-year delay in addressing climate change which results in an abrupt action to reduce global emissions and limit the global temperature change to below 2°C. The financial markets hastily reallocate prices and reprice assets. There is a significant macroeconomic shock that disrupts the economy. Physical risks increase with high transitional risks.
- No additional policy action scenario: No new policies are introduced to combat climate change. Transition to a low-carbon economy is insufficient to meet climate goals. The global temperature rises to more than 2°C. Material shocks occur later in the century. Transition risks are low, but there are extremely high physical risks. Figure 21 summarises the impacts of the scenarios used by the BoE in its climate stress test exercise.

	Early action	Late action	No additional action
Transition risks	Medium	High	Limited
Transition begins in	2021	2031	n.a.
Nature of transition	Early and orderly	Late and disorderly	Only policies that were in place before 2021
Peak UK shadow carbon tax (carbon tax and other policies (2010 US$/tonne carbon dioside equivilent)	900	1,100	30
Physical risks	Limited	Limited	High
Mean global warning relative to pre-industrial times by the end of scenario (°C)	1.8	1.8	3.3
Mean sea level rise in the UK (m)	0.16	0.16	0.39
Impact on output	Temporarily lower growth	Sudden contraction (recession)	Permenantly lower growth and higher uncertainty
Average annual output growth in the UK 9per cent)	1.4, 1.5, 1.6 (Yr 6–10, Yr 11–15, Yr 26–30)	1.5, 0.1, 1.6 (Yr 6–10, Yr 11–15, Yr 26–30)	1.4, 1.4, 1.2 (Yr 6–10, Yr 11–15, Yr 26–30)

Source: Met Office, Network for Green the Financial System and Bank calculations

Figure 21: Summary of impacts of the CBES Scenarios.

- **European Central Bank (ECB):** The scenarios used in ECB's internal climate stress test exercise complement the NGFS Phase I reference scenarios, covering the orderly, disorderly and hot house world pathways (ECB, 2021, ECB, 2021).
  - Orderly scenario: Assumes a transition to a low-carbon economy occurs in an orderly manner to reduce global emissions by 3% annually until 2030 to limit the global temperature rise to below 2°C. Emission prices gradually increase due to the implementation of cost-effective policies, which causes companies to change

their business models and consumers to change their consumption habits.

- Disorderly scenario: Delayed and sudden implementation of policies to limit the global temperature rise to below 2°C. Implementation of more stringent policies from 2030 leads to higher transition risk.
- Current policies: No new policies are implemented, which results in a temperature rise of approximately 3.5°C by 2100. Transition risks remain low. However, a lack of transition to a low-carbon economy results in increased physical risks, with climate hazards increasing in frequency and severity.

Exhibit 14: Bank of England: Drawing Climate Scenarios from NGFS for the Climate Biennial Exploratory Scenario (CBES).

Due to the global accessibility and need for transparency of NGFS scenarios, the scenarios have been designed to be simple. Therefore, scenario users are at times required to modify the scenarios to improve their relevance for the institution. For its climate stress testing exercise, the BoE made some key changes from the NGFS scenarios, which have been described below.

- **Global and regional macroeconomic environment**
  - Additional transmission channels that had not been captured by the NGFS were added to capture all relevant climate risks. Though the scientific basis of these transmission channels may not be as developed, BoE believes there are good reasons to assume that certain transmission channels may occur.
  - Dips in the UK GDP are much steeper in CBES than in NGFS to explore a severe climate market disruption scenario (Figure 22).

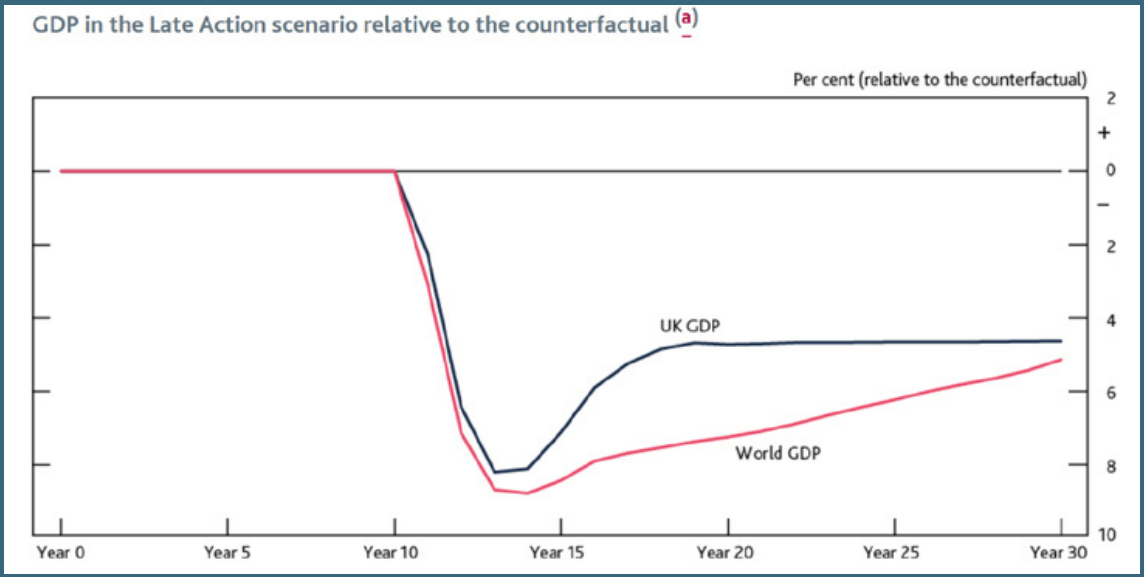

Figure 22: Decrease in GDP in the late action scenario.

- **Carbon prices and energy mix**
  - BoE included net-zero commitments specific to the UK as the country has set out additional policies that need to be captured.
  - For the NGFS scenarios, nuclear energy is completely phased out due to technological advancements which allow renewable energy to outcompete nuclear energy. However, CBES needs to consider the geopolitics and long-term contracts in relation to nuclear energy. As a result, the scenarios were adapted to include nuclear energy into the UK's energy mix (Figure 23).

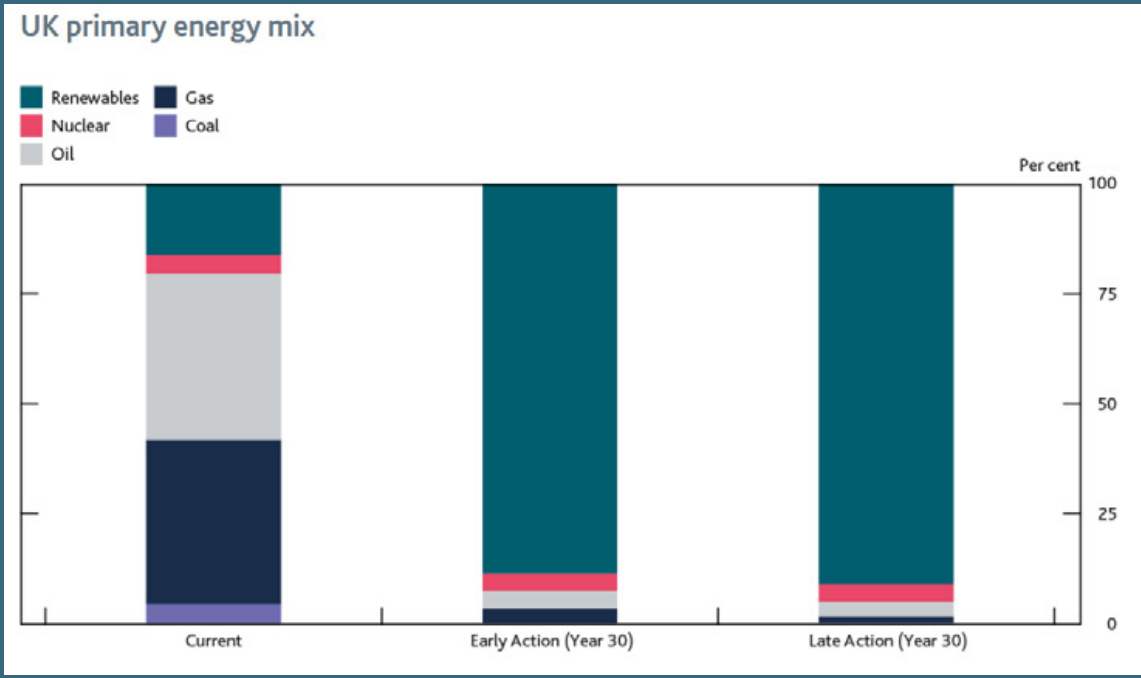

Figure 23: UK primary energy mix for current, early action and late action scenarios.

- **Physical risks**
  - Localised physical risks needed to be incorporated, therefore additional physical risks relevant to the UK with enough evidence to support them were included.
  - Physical risks tend to underestimate transition risks. To account for the uncertainty, future risks were included to the present day.

6.1.3 Scenario design and expansion

Scenario analysis for a climate stress test requires four key steps—selection of scenarios to use, variable selection, quantification of risks through modelling and using the outputs of the analysis for risk assessment. In this section, we provide guidance for scenarios and variables selection, scenario expansion and modelling approach for climate stress tests. Figure 24 below highlights these key processes for scenario analysis in a climate stress test.

Scenario selection	Variable selection and narrative	Quantification and modelling	Risk Assessment
▪ Identify the purpose of this climate stress test exercise ▪ Identify the scenario horizon ▪ Decide the relevant sectors and regions for the exercise ▪ Determine which of the reference scenarios, e.g. NGFS and IEA scenarios, are the most suitable to use	▪ Identify key physical and transition risks relevant to the financial institution ▪ Select suitable physical and transition risk variables ▪ Determine macroeconomic and financial variables to be used as inputs during modelling ▪ Design scenario pathways using reference scenarios based on the risks identified for relevant regions and sectors	▪ Select the combination of models to be used ▪ Design quantitative pathways of the scenarios to be modelled ▪ Understand key assumptions for the scenario pathways and the models being used ▪ Identify the inputs required for each model used ▪ Determine the key outputs wanted from each model used	▪ Determine the impact of climate risks on the institution by running financial models ▪ Results can be provided in a disaggregated manner for the relevant sectors ▪ Use of financial metrics to determine an institution's resilience to climate stress scenarios ▪ Modelling outputs should be both quantitative and qualitative

Figure 24: Key Processes for Scenario Analysis in a Climate Stress Test.

Selecting scenarios for climate stress testing

Reference scenarios are used by regulators when designing climate stress tests. However, they are also used by financial institutions for internal climate stress testing exercises.

54% of UNEP FI TCFD's programme participants prefer to use NGFS scenarios for their internal climate stress tests. In comparison, 13% of the participants prefer to use IEA scenarios and IPCC scenarios.

NGFS scenarios are industry recognised, robust and have the capability to be built around. One of the main reasons provided by financial institutions for choosing NGFS scenarios as reference scenarios is because they are used by regulators, indicating regulatory backing as an important factor in scenario selection. The NGFS scenarios have been designed for the purpose of meeting the needs of regulatory authorities and central banks in assessing the potential impact of climate risks on the financial sector. The scenarios are also publicly accessible and are used by a range of authorities globally which allows for comparability and consistency across different jurisdictions (BIS, 2021).

Below we describe ten recommended steps for scenario selection for an internal climate stress test. These recommendations have taken into account discussions with participating institutions from UNEP FI's TCFD programme, literature reviews and regulatory stress tests.

Ten recommended steps for scenario selection for an internal climate stress test

1. **Conduct portfolio analysis from a climate perspective.** Institutions should understand which portfolios they need to stress test and identify sectors of concern and the geographical distribution of the portfolio.
2. **Select a relevant scenario horizon** if not provided by the supervisory authority or if performing the test internally.
3. **Identify key climate and economic drivers applicable to the institution.** Begin with generally characterising climate risks of concern (e.g. high temperature, flooding, net-zero policies) and then identify specificities of these drivers (geographies, jurisdictions etc.)
4. **Develop a range of criteria to select reference climate scenarios** (e.g. NGFS, IPCC and the IEA) developed by research institutions that anchor on (or are closely related to) the drivers/variables identified in Step 3. Criteria should include regional and sector coverage, types of risks covered by the reference scenarios, relevant temperature and emissions pathways, applicability and supervisory support of the scenarios.
5. **Determine the combinations of regions and sectors** relevant to the institution for climate stress testing.
6. **Consider what assumptions are made in relation to the scenario pathways**, for example, assumptions needed for policy changes, technological developments and energy use.
7. Where insufficient granularity is offered off-the-shelf, **adapt/expand the reference scenarios geographically and sector-wise.**
8. If not already in the scenarios, **derive the impact on the identified key drivers to develop a relevant narrative.** It is important to ensure that plausibility limits are applied to the narrative.
9. **Assign responsibility to a team to keep up-to-date with the latest developments in scenario development.** This role is suitable for the climate research and intelligence function of the climate risk team.
10. **Implement a process to integrate the latest scenario developments and emerging methodology standards into the scenario design** for climate stress testing.

Variables for scenario analysis

In a climate stress test, physical and transition risk variables are combined with macroeconomic and financial variables to quantify the impact of climate risks in a scenario. Physical and transition risk variables are included in climate scenarios which are then translated to macroeconomic and financial market variables. These variables are then used to understand the impact of a given scenario on the financial institution (BIS, 2021).

It is important that the variables selected for the exercise link to the scenario narrative (IIF, 2021). Variables for a climate stress test should provide sectoral and regional coverage for climate scenarios.

A survey for UNEP FI TCFD participants showed that 74% of financial institutions believe it is very important that relevant variables are broken down by sector, and 63% of financial institutions believe it is very important that relevant variables are broken down by region.

The greater the climate and financial risks covered, and the greater the number of portfolios and regions covered in a climate stress test, the wider the range of variables needed to be specified by the institution. Climate risk variables commonly include physical hazards, carbon price and GHG emissions. Macroeconomic variables commonly include GDP, unemployment and inflation (BIS, 2021). Figure 25 from the BoE provides an indicative list of scenario variables proposed for CBES in 2019 (Bank of England, 2019).

Climate risk variables		Macrofinancial variables	
Physical variables	**Transition variables**	**Macroeconomic variables**	**Financial markets variables**
▪ Global and regional temperature pathways. ▪ Frequency and severity of specific climate-related perils in regions with material exposure (including UK flood, subsidence and freezez). ▪ Longevity. ▪ Agricultural productivity.	▪ Carbon price pathways. ▪ Emissions pathways (aggregate, and decomposed into world redions and sectors). ▪ Commodity and energy prices (including renewables), by fuel type. ▪ Energy mix.	▪ Real GDP (aggregate and decomposed by sector). ▪ Umemployment. ▪ Inflation. ▪ Central bank rates. ▪ Corporate profits (aggregate and decomposed by sector). ▪ Household income. ▪ Residential and commerical property prices.	▪ Government bond yields for major companies. ▪ Corporate bon yields for major economies (investment grade and high yield). ▪ Equity indices. ▪ Exchange rates. ▪ Bank Rate.

Figure 25: Key variables indicative list by the Bank of England.

For a regulatory climate stress test, it is essential for the regulatory authority to specify the key variables. Financial institutions will need to derive variables that are not provided but are useful to analyse for their institution. This was also stated by the BoE in its discussion paper on the 2021 Biennial Exploratory Scenario (BES) exercise, explaining "The BES would not provide every variable that participating firms would need to model the scenarios. In line with other Bank stress tests, participating firms would have to undertake scenario expansion to extrapolate additional scenario variables needed to estimate impacts on individual counterparties." (Bank of England, 2019). Regulators, such as the ACPR and PRA, have provided variable pathways for

their exercises at both the regional level and the global level. Variables were designed to be applicable at the country, regional and sector-level. Physical variables included sea level rise, changes in storm patterns and temperature rise. Transition pathways include carbon price and emissions pathways. The main macroeconomic variables provided by the ACPR included France, US and EU GDP, inflation rate and unemployment rate (ACPR, 2020).

Variables needed may vary depending on the scenario, as different scenario narratives will require different variable pathways with varying degrees of material impact. For example, in the update provided by BoE on its approach to the Climate Biennial Exploratory Scenario, the regulator explained, "In the Early Policy Action scenario the Bank does not expect the paths of macroeconomic variables to differ much from trend, so they are not expected to have a material impact. By contrast, structural changes to the economy related to the transition from reducing emissions will be crucial. The Late Policy Action scenario will include some macroeconomic disruption, but structural changes will continue to be important. For both those scenarios, physical damages will be part of the scenario. The No Additional Policy Action scenario will involve both macroeconomic changes and physical damages from climate change." (Bank of England, 2020).

Based on group discussions with UNEP FI's programme participants and taking into consideration the variable requirements of various supervisors, below we provide suggested variables for a climate stress test.

Table 15: Recommended variables for climate stress testing.

Variable Type	Variable
Price	▪ Carbon price ▪ Commodity and energy prices: ▫ Primary energy price (oil, coal, gas) ▫ Secondary energy price (electricity and gas) ▫ Renewable energy price ▪ Government policies and other taxes
Production	▪ Input costs ▪ Total primary energy (EJ) ▪ Total energy consumption ▪ Amount of fossil fuels used ▪ Amount of renewables used
Investment	▪ Energy efficiency ▪ Energy supply ▪ New technology investments
Emissions	▪ GHG emission targets and pathways (region and sector-wise) ▪ Energy mix (coal, gas, oil, renewables) ▪ Total energy consumption ▪ Government policies ▪ Sectoral GHG emissions (e.g. transportation capacity and cropland)

Physical risk	▪ Temperature (global and regional) ▪ Precipitation and flood risk ▪ Drought risk ▪ Other physical hazard risks ▪ Agricultural productivity, crop yields and food security
Macro-financial and socio-economic	▪ Household income ▪ Residential/commercial property prices ▪ Unemployment rate ▪ GDP ▪ Corporate profits ▪ Bond yields ▪ Inflation rate ▪ Trade flows ▪ Interest rates and exchange rates ▪ Bank rate ▪ Equity indices ▪ Credit growth (Household, Business) ▪ Credit spreads

If a financial institution is conducting an internal climate stress test or has not been provided with a complete set of useful variables, it will be required to undertake expansion to extrapolate additional variables for the scenarios. Firms can undertake additional methods to obtain the scenarios with the pathways required for effective analysis, depending on the scope of the exercise. Below we have provided a set of recommendations for financial institutions to follow when undergoing scenario expansion.

Nine key recommendations for scenario expansion

1. **Select a baseline reference scenario.** If conducting an internal climate stress test, select a reference scenario that will be expanded for a suitable financial assessment. Typically, a baseline scenario does not assume transition and physical risks.
2. **Characterise the reference scenario,** including understanding the narrative of the scenario and its assumptions, such as its macroeconomic and financial factors.
3. **Conduct a portfolio analysis** to understand clients' assets, business models and operating locations.
4. **Identify potential climate and financial risks that are relevant to the portfolio** based on the portfolio analysis conducted in Step 3. Risk drivers, especially macro-financial drivers, that are not covered by the reference scenarios will need to be expanded, in order to be covered in the scenario analysis.
5. **Identify relevant scenario variables for performing granular risk assessment** on the selected portfolio. The financial institution should develop a range of criteria to assess the relevance of various scenario variables to determine the ones which are the most relevant. The criteria should analyse the coverage of variables for a company's revenues and costs. The criteria should also be used to understand the variables provided by the regulator.
6. **Determine the combinations of regions and sectors** most suitable to the institution for climate stress testing. This will help institutions break down relevant variables by sectors and regions and project important sectors and regions not captured by the reference scenario.
7. Using the criteria, **determine the variables that are needed but missing from the list of variables provided by regulators** if performing a regulatory climate stress test. Variables should be selected that will provide the expanded scenario with adequate characterisation to translate the potential impacts of climate change into financial impacts.
8. **Undertake scenario expansion to extrapolate the additional scenario variables required for the climate stress test**. For effective extrapolation, the institution should determine the relevant assumptions for extrapolating scenario variables.
9. **Leverage the firm's current processes and infrastructure for scenario expansion.** The climate scenario expansion framework should be tailored into traditional stress testing scenario expansion frameworks as well as the institution's computation systems (e.g. pricing engines).

6.2 Models for climate stress testing

6.2.1 Types of models used

Different financial institutions have come up with a range of different approaches to model climate risks. For example, some institutions are developing in-house models while others are acquiring models externally. For a climate stress test, financial institutions should adopt current modelling methods used in a traditional stress test to translate climate risks into financial impacts.

Survey responses from UNEP FI's TCFD programme participants show that only 7% of participants are quite confident using their current models for a climate stress test.

This was further emphasised by the ECB in their climate stress testing exercise stating:

> **"Modelling frameworks, therefore, need to incorporate plausible representations of both the economy and the climate in a way that clarifies how they interact, as well as how policies to prevent or mitigate climate change affect them both over the long run."**
>
> **ECB, 2021**

However, modelling methodologies for a climate stress test are still in their infancy.

The modelling process for a climate stress test consists of—modelling climate variables, measuring the impact of climate risks on macroeconomic variables, breaking down the macroeconomic impacts per sector or per portfolio and quantifying the impact on the financial institution (Figure 26). The modelling approach is complex, creating uncertainty in the analysis as it involves combining different models that were not designed to work together. Climate scenario models are needed to project pathways for the selected physical and transition risk variables. Macroeconomic models are then required to translate climate variables from the climate model to selected macroeconomic variables. Macroeconomic models are an important component of the climate stress test as they help translate climate risks into financial impacts. Climate stress testing requires the use of models to breakdown the macroeconomic impacts down to the sector-level, for which sectoral and portfolio models are commonly used. Following this, financial models at an institution-level can be used to calculate a bank's exposures to climate risks. Internal models can be used to assess changes in metrics, such as probabilities of default (PD) and loss given default (LGD). Table 16 provides descriptions of the commonly used models for climate scenario analysis.

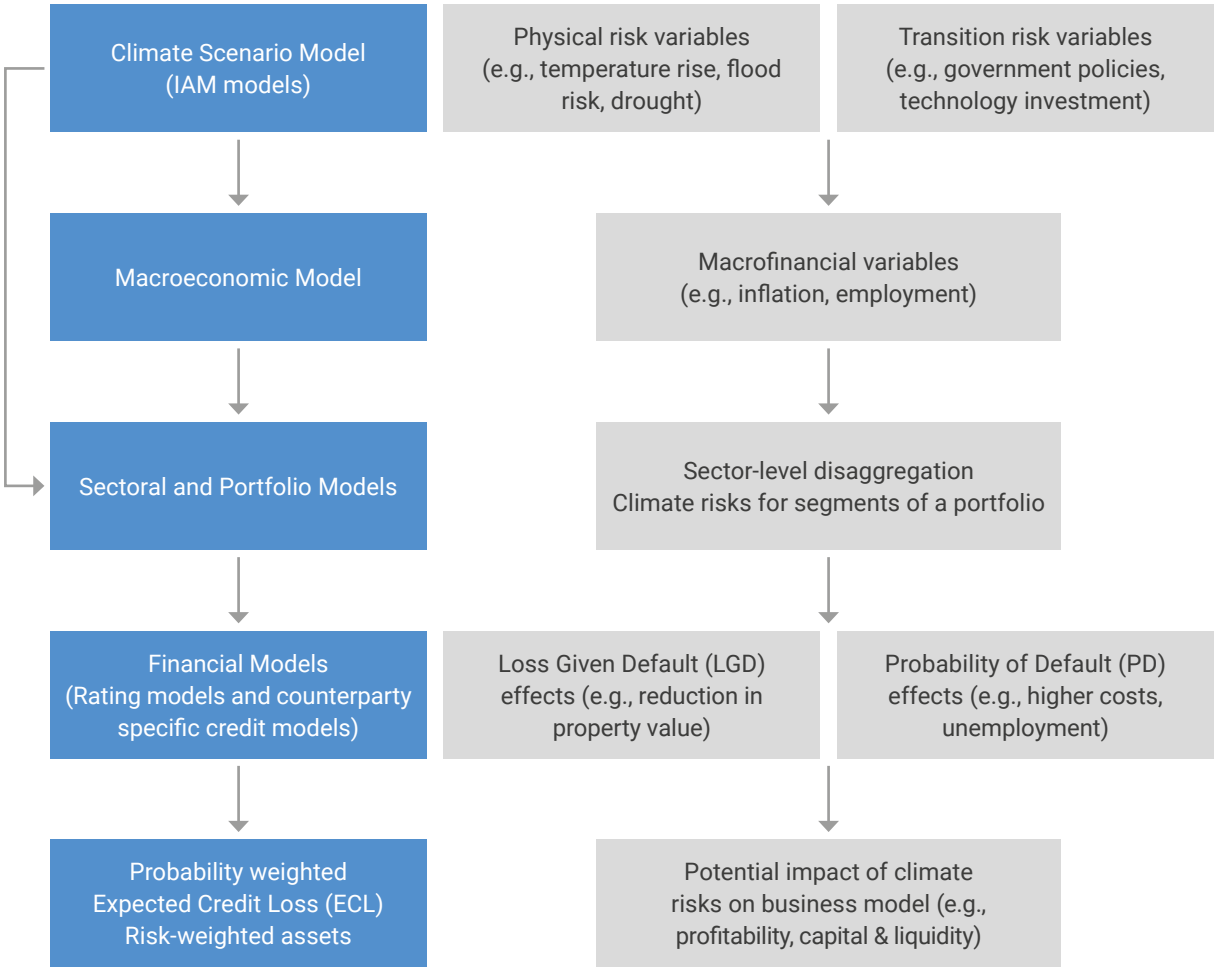

Figure 26: Modelling approach for climate stress testing.

Table 16: Commonly used models for climate scenario analysis.

Potential models	Description	Open-source/ License required
REMIND-(PIK)	Integrated assessment model, combines socio-economic, climate and land-use assumptions. Used in NGFS reference scenarios and initial climate stress test scenario design.	Fully open-source
MESSAGE-(IIASA)		
GCAM - (PNNL-UMD)		
IMAGE - (PBL)	Integrated assessment model, combines socio-economic, climate and land-use assumptions.	
World Energy Model (IEA)	Granular energy system model, used to set IEA's world energy outlook forecasts. Forthcoming net-zero scenario.	License required, some assumptions proprietary
Energy Technology Perspectives (IEA)	Bottom-up model covering energy supply and technological development in the energy sector.	

NiGEM (NIESR)	General equilibrium model used to produce macro-economic variables. Now working with NGFS to produce macro outputs for their scenario pathways.	License required, some assumptions proprietary, NGFS data open-source
GTAP (Purdue)	General equilibrium model, multiple regions and sectors available.	Fully open-source
G-Cubed (McKibben)	Macroeconomic model used by IMF for economic scenarios on mitigating emissions and warming.	License required, some assumptions proprietary
One Earth Climate Model (UTS)	Bottom-up model designed to provide specific sectoral decarbonisation pathways for members of the UN Net-Zero Asset Owners' Alliance (NZAOA).	Some data and assumptions open-source
En-ROADS/C-ROADS (MIT)	Dynamic model allowing users to alter numerous assumptions around technology and economics to attain particular temperature outcomes.	Tool open-source, data/assumptions proprietary
AIM (NIES)	Assesses the economic impact of policies to reduce GHG emissions, with a focus on the Asia-Pacific region.	Free-of-charge
Industry models (Shell, BP, etc.)	Used by fossil fuel firms to forecast future demand, now expanded to function as decarbonisation path-way models.	Data open-source, some assumptions proprietary

Climate scenario models

Climate scenario models project pathways for selected physical and transition risk variables in a climate stress test. Integrated Assessment Models (IAMs) are computer-based models that generate emission pathways that can be integrated into climate models. These climate scenario models study potential changes to the climate system and show changes in production and use of energy over time, technological changes, natural resource use, and impacts of climate policy (NGFS, 2020). The model combines varying parameters and metrics to model human society alongside parts of the climate system. Financial institutions have adopted IAMs more recently due to their ability to describe the interactions between economic activity, GHG emissions and climate change. IAMs provide global coverage, have long time horizons and give adequate details on mitigation pathways that provide high-level overviews of tradeoffs and constraints. The model optimises behavior across costs, performances, and producer and consumer responses. IAMs do not consider non-monetary preferences, energy security and potential sociopolitical interactions. As a result, cost-optimal pathways may be less desirable and less politically viable than non-optimal pathways (UNEP FI, 2021). In their climate stress testing activities, the ACPR and the BoE used IAMs to project trajectories for GDP, carbon price and GHG emissions for each scenario. The outputs from the IAMs were then used as inputs for the macroeconomic models.

Examples of IAMs include GCAM, MESSAGE-GLOBIOM, REMIND-MAgPIE, WITCH, AIM and IMAGE. Responses from financial institutions participating in the TCFD programme showed that 67% of the institutions are using the REMIND model for their analysis and 33% of institutions are using the MESSAGE model. None of the participating institutions are using the other available IAMs for their modelling. The NGFS scenarios have been developed to run on three IAMs, namely GCAM, MESSAGE-GLOBIOM and REMIND-MAgPIE. These models can differ in respect to other assumptions and coverage (BIS, 2021).

Macroeconomic models

Macroeconomic models are required to translate climate variables from the climate model to selected macroeconomic variables. Macroeconomic models are an important component of the climate stress test as they help express climate risks as financial impacts. A common macroeconomic model used for climate stress testing is the NiGEM model. ACPR, BoE and DNB have used/are using the multi-country model for their climate stress test exercises. The model uses a range of macroeconomic variables such as GDP, inflation, unemployment and interest rates, to determine the economic impacts of climate risks. The dynamic nature of the model allows the projection of pathways over a long timeframe. A multi-country model like NiGEM allows financial institutions to assess both their international exposures, but also exposures at the country level. In their 2018 energy transition risk stress test, the DNB emphasised, "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." (DNB, 2018) Countries are linked through trade prices, domestic prices, exchange rates, assets held and income flows. According to the ACPR, the NiGEM model was appropriate to use for their climate stress test exercise because "Although NiGEM is not a climate model, it has benefitted from extensions to simulate macroeconomic scenarios for climate transition analysis, mostly associated with public policy". The use of demand variables like consumer prices and public spending helps the NiGEM model complement sectoral models for analysis (Banque de France, 2020).

Sectoral and portfolio models

Climate stress testing requires the use of models to breakdown the macroeconomic impacts to the sector-level. Sectoral models are used by financial institutions to downscale the aggregate outputs from a macroeconomic model to the sector-level. The Financial Stability Institute's report "Stress-testing banks for climate change—a comparison of practices" (2021) further explains that the "contribution of each sector to the aggregate becomes the sector's gross value added." For example, for the BoE's pilot climate stress test exercise, the regulator developed vulnerability factors that account for physical risks and emission profiles to identify the sectors that were highly exposed. The vulnerability factors were then used to calculate the gross value-added paths for each sector. To downscale macroeconomic aggregates to the sector-level for its climate pilot exercise, ACPR used an in-house multi-country and multi-sector framework (SSRN, 2020) to assess the impact of carbon prices and productivity shocks on 55 sectors classified by the World Input-Output Database (WIOD). For its climate stress test, DNB developed transition vulnerability factors (TVFs), based on carbon emissions, for 56 sectors to determine their vulnerability. Using stock prices determined from the NiGEM model, they determined the impact of transition risks on sectoral stock prices to calculate potential sectoral losses (BIS, 2021).

Financial models

Financial models can be used to calculate a bank's exposures to climate risks. These models can assess changes in metrics, such as probabilities of default (PD), loss given default (LGD) and exposure at default (EAD), due to climate risks. Firms use PD analy-

sis to calculate expected loss and it is represented as a percentage of the likelihood of default. LGD represents the share of an asset lost by a firm when a borrower defaults on a loan. EAD predicts the amount of loss a bank might face when a debtor defaults on a loan (Investopia, 2020). PD, LGD and EAD models are important for climate stress testing to translate the impact of climate scenarios into financial variables for the institution. Using in-house rating and risk models can help financial institutions determine the potential impact of climate risks on lending to borrowers and potential losses (IIF, 2021). A bank can adopt the use of internal models to measure the exposure of counterparties to climate risk and incorporate their internal ratings-based approach, to measure counterparty credit risk and EAD by financial institutions to meet regulatory requirements (BIS, 2020).

Exhibit 15: Modelling strategy for the ACPR and Banque de France climate stress test exercise.

In July 2020, Banque de France (BdF) released a proposed analytical framework for its pilot exercise. The supervisor combined climate models, a macroeconomic model, a sectoral model, a rating model and financial modules for the exercise.

The modelling strategy began with inputs from IAMs which were used to obtain trajectories of the climate scenarios used. The models generated trajectories for GDP, carbon prices and GHG emissions for several countries, including country blocks (France, EU, USA and the rest of the world). Carbon price trajectories were then used as inputs for the multi-country macroeconomic model, NiGEM. Outputs from IAMs were used to set the carbon tax rate in the NiGeM and sectoral models. To show how these models link together, BdF stated, "for the baseline and the delayed transition scenario (Scenario 1), productivity shocks are calibrated in both NiGEM and the sectoral model so that the combined impact of carbon tax and productivity shocks matches the GDP trajectories given by the IAMs, ensuring consistency across the three models. For the sudden transition scenario (Scenario 2), we depart from the GDP trajectory implied by the IAMs: we assume no productivity gains in the sectoral model, and let GDP adjust endogenously to the carbon tax shocks."

The NiGEM model provided macroeconomic and financial variables for the global economy. The in-house sectoral model is used to translate variables from the scenarios into potential impacts at the sector-level as value-added. Results from the NiGEM model are coupled with the sector model to provide a disaggregated output for France, EU, USA and the rest of the world.

BdF then ran the outputs from its sectoral model through a ratings model to assess the financial impact of climate risks at the firm-level. The further disaggregation of results helps determine which firms are the most vulnerable to climate risks and pose the greatest credit risk for the financial institution. The ratings model was used to assess credit risk for France. The regulator also developed financial modules in order to "translate the macroeconomic, sectoral and firm-level projections into financial variables, such as yield curves, asset prices and interest rate spreads of corporate bonds." For example, a dividend discount model was used to estimate asset prices for sectors and regions and corporate credit spreads were calculated for sectors and economic areas.

Figure 27 below shows the modelling framework developed by BdF/ACPR for their pilot exercise.

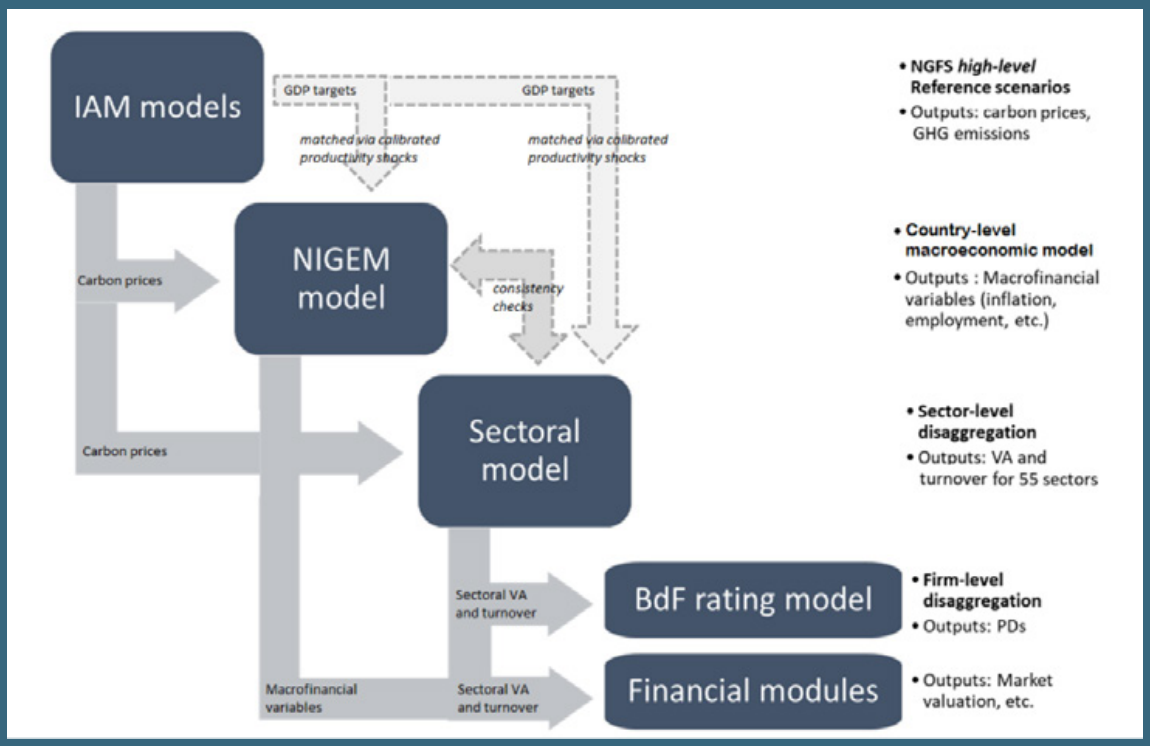

Figure 27: The modelling framework developed by BdF/ACPR for the pilot exercise.

(Banque de France, 2020)

6.2.2 Challenges of using existing models for climate stress testing

Models required for a climate stress test were not initially designed for this purpose. As a result, financial institutions face numerous obstacles when using models for the exercise. Below we have identified some key challenges when using existing models.

Lack of granularity: For modelling, IAMs depend on simplified assumptions. As a result, the output of the analysis might lack the granularity and details needed by risk managers for decision-making. The long time horizon of the model, as well as its global cover also limits the depth of the details provided by the model (UNEP FI, 2021).

Uncertainty: UNEP FI's Pathways to Paris report concluded that simplified assumptions about the real world and a long time horizon create uncertainty in the outputs of IAMs. Furthermore, IAMs are complex models that require numerous assumptions. As a result, it is very difficult to determine which assumptions have led to a given IAM output, further adding uncertainty to modelling (UNEP FI, 2021).

Design limitations: The Climate Financial Risk Forum (CFRF) has highlighted the limitations of economic modelling of climate impacts for high temperature warming scenarios, such as those for warming at 3–6°C, explaining, "economic models tend to have mild or simplistic damage functions that fail to respond in a way that is consistent with the scientific analyses and expectations." For example, many economic models project net economic growth at 5°C warming or greater (FCA, 2020). Similarly, in its energy transition risk stress test exercise, DNB highlighted the limitation of the NiGEM model, like other macroeconomic models, explaining, "they are not really designed to simulate the type of structural economic shifts that may follow from the transition to a low-carbon economy". Macroeconomic models typically assume that economic relationships remain stable over time, using historical data (DNB, 2018).

Historical data: Models used for climate stress testing are often calibrated using historical data or statistical relationships (BIS, 2021). The use of historical data and statistical relationships can reduce the accuracy of a climate risk assessment as the models may not be able to capture the full impact of potential climate risks. For an accurate assessment of climate risks, models need to use forward-looking data (IIF, 2021).

Lack of understanding: Due to a lack of understanding of the relationship between climate risks and macro-financial variables, financial institutions find it difficult to calibrate and validate models (IIF, 2021). Greater efforts need to be directed towards linking climate science and financial modelling (BIS, 2021).

Considering the challenges faced by financial institutions when using existing models, below we provide recommendations for climate stress test modelling.

Key recommendations for modelling approaches in a climate stress test

1. **Determine the parameters required for modelling**. The financial institution should decide the countries that need to be modeled individually, the regions that need to be modeled in aggregate and the sectors that will be modeled.
2. **Define the objective, inputs and outputs and the required components** for each model in the modelling approach.
3. **Develop a range of criteria** to determine the types of models to use.
4. **Survey existing models and providers** and determine which to use using the criteria developed. Financial institutions should use criteria to assist them in deciding which models are the most appropriate for them to use in translating climate risks into financial impacts at the firm-level.
5. **Identify gaps in the current in-house models** using the criteria. Institutions should be able to identify areas in which their current modelling architecture can be adapted to incorporate climate variables and identify credit risks. For example, internal credit rating models can be adapted to identify credit risks from climate change and perform analysis at the counterparty-level.
6. **Increase communication with external modelers and academics for scenario expansion and to improve understanding of different models**. Increase expertise on modelling in-house through initiating dialogue with industry experts.
7. **Improve collaboration with climate local modelers and research institutions** to develop internal models and improve applicability of internal models to external models needed for climate stress testing.
8. **Further develop in-house modelling capabilities with the guidance and specifications for models provided by supervisory authorities**.

7. Outputs and applications of climate stress testing

Key messages

- Supervisory climate stress tests have a wide range of applications, including being a learning exercise to mobilise and raise the firm's awareness of climate risks, encouraging boards to understand the challenges and take a strategic approach to managing risks, improving a firm's climate risk management, modelling and data, and improving a firm's climate-related disclosures.
- Firms need to ensure clear, consistent and wide-ranging communication and ensure climate stress tests are a key opportunity to learn and trigger action.
- A climate stress test approach should initially be kept simple and focused on material exposures.
- Results can be further leveraged to improve a firm's climate risk management and help set the risk appetite, support the firm's strategy, customer engagement and investment, and support the firm's external disclosures and compliance.

7.1 Expected outputs of regulatory climate stress tests

As shown in Table 3 in section 3.3.1, the climate stress test exercises initiated by central banks and regulators are not identical and exhibit common features in terms of quantitative and qualitative outputs. Whether it is a regulator-mandated or internal exercise, the identification of vulnerable sectors in the institution's global portfolio is one of the key outputs.

Quantitative outputs: For the banking book, the regulators have been looking to ascertain the impact of scenarios on the expected credit losses, probabilities of default (PD) and loss given default (LGD) and the stock (or flow) of credit provisions at different points in the scenarios. The BoE exercise added the requirement to account for the mitigation and adaptation plans of counterparties if they are underway and highly

likely to be completed. Participants are also required in some exercises to submit their projected Risk-Weighted Assets (RWAs) and Common Equity Tier 1 (CET1) ratio.

Where the trading book is included in the exercise, regulators have requested fair value revaluations based on the instantaneous application of the scenarios' market shocks and their analysis by sector. This expectation will often be a challenge for market risk systems which are largely based on individual risk factors and portfolio views, and thus require substantial manual adjustments and aggregations. The impact of the scenario shocks on counterparty credit risks may also be included.

Qualitative outputs: All regulatory and internal exercises to-date have also included a qualitative component to provide an overarching narrative around the participants' results and methodological choices, to describe in detail the management actions they would anticipate taking under each scenario, and to capture how business models could change and how sustainable they are. Qualitative questionnaires are used to let participants provide their qualitative views of the climate-related risks and opportunities they have identified and their progress towards climate-focused and alignment metrics. A set of questions may be dedicated to obtaining the participants' present (planned) and future (anticipated) approaches to managing climate risk. For example, for its 2021 Climate Biennial Exploratory Scenario (CBES), the BoE and the PRA have designed a questionnaire for participants to capture climate risks for financial institutions and to understand current and future plans of participants for managing these risks (Bank of England, 2021).

Exhibit 16 offers a summary of the key outputs of the ACPR 2020 Climate Pilot Exercise.

Many factors and variables can influence the outputs of climate stress tests but some of the most impactful drivers are the assumptions around having a static or dynamic balance sheet. By allowing, or disabling, the impact of the institutions' strategies, policies and management actions, these assumptions may result in significant changes in terms of balance sheet structure and credit exposures to climate risk.

Exhibit 16: Qualitative and quantitative outputs from ACPR 2020 climate pilot exercise.

For reference, a schematic representation of the transition and physical risk scenarios included in the ACPR exercise is given below.

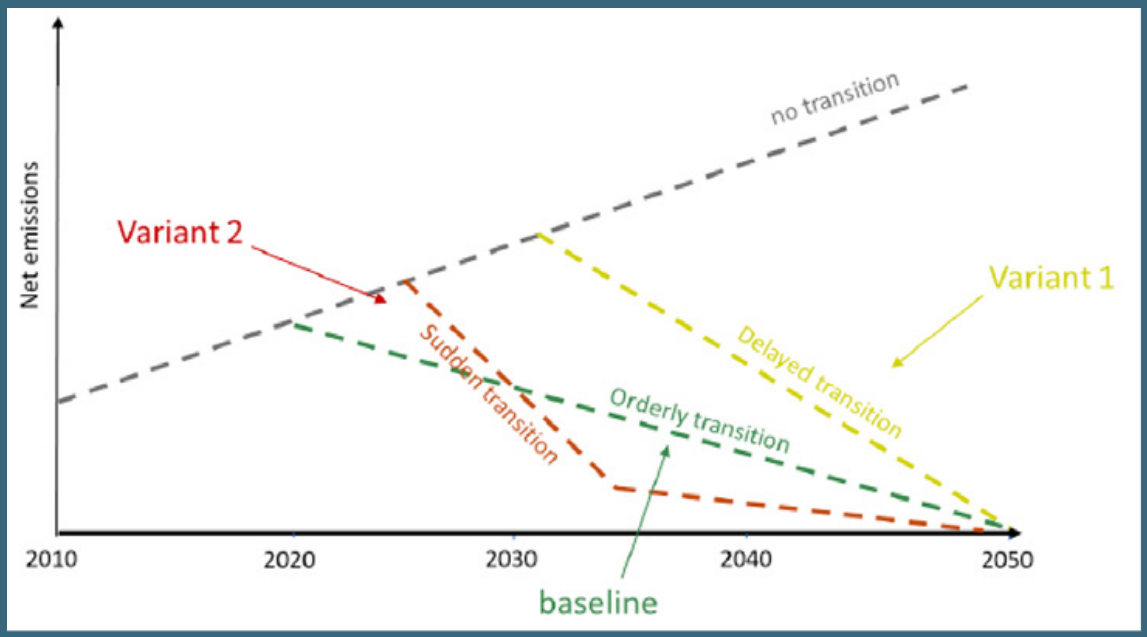

Figure 28: A schematic representation of the transition and physical risk scenarios included in the ACPR exercise.

- Based on the exercise, the ACPR concluded a "moderate" exposure of the involved French banks and insurers to climate risks. The results stated that for the tested institutions 50% of the exposures were in France and 75% were in Europe, which are less affected than exposures in other regions such as the United States, which appeared more sensitive to transition risk.
- As identified in this exercise, the exposure of French financial institutions to sectors most impacted by transition risks is relatively low. Under a dynamic balance sheet assumption, the sectoral structure of the credit exposures for the six banking groups shows a distortion under the sudden transition scenario, as shown in Figure 28, to the detriment of the sectors negatively affected by the transition scenarios.

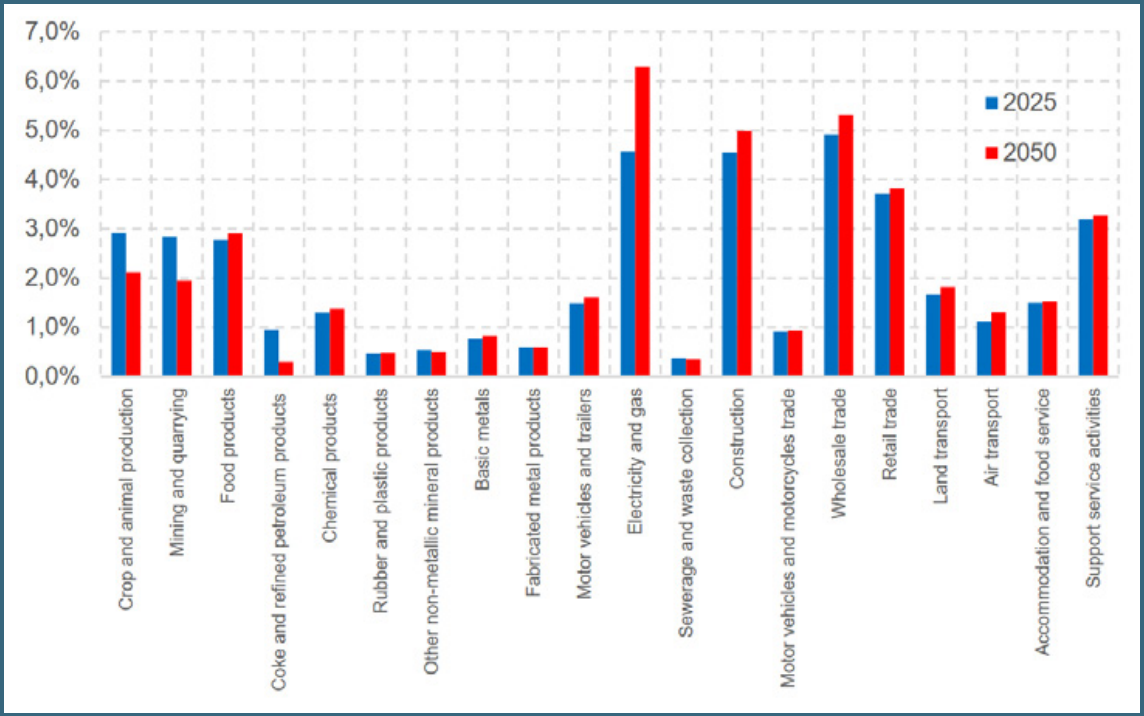

Figure 29: Evolution of the sectoral structure of credit exposures under the sudden transition scenario.

- The dynamics of the results in Figures 29 and 30 show the significant impact associated with an increase in the price of carbon and a slow-down in GDP growth.

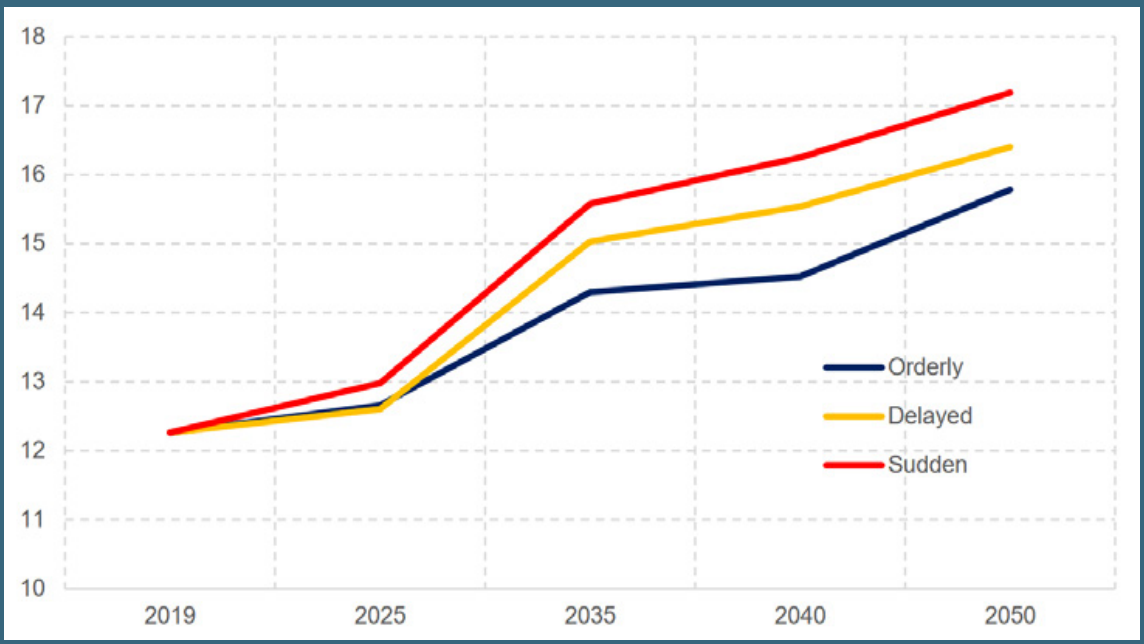

Figure 30: Evolution of the aggregated annual cost of risk for participating banks.

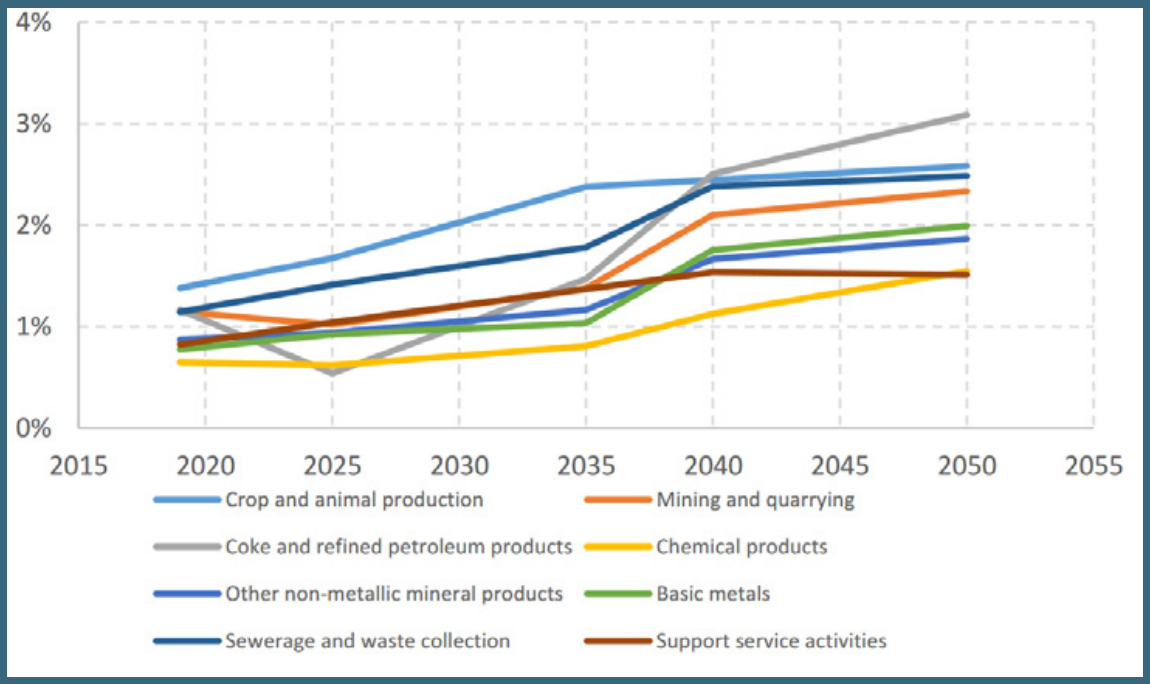

Figure 31: Weighted average of the probabilities of default (PD) by sector over time.

- The exercise determined that participating institutions are at risk from various physical hazards, including droughts, floods and cyclones; yet the progress made in taking physical risk into consideration is very limited, with only two institutions able to quantify the impact of an increase in the lack of insurance coverage on its credit risk parameters. The report linked this result to the difficulty of obtaining a precise geographical location of their exposures at a consolidated level.
- Banks and insurers need to step-up their efforts to integrate climate risks into their current risk management processes, taking the exercise results into account and promoting a better allocation of their resources.
- The outputs of the exercise also helped identify methodological limitations in need of improvements, including improving the models and data sources used, better integration of physical risks into the analysis and improving the hypotheses used for creating scenarios and identifying at-risk sectors.

(ACPR, 2021)

7.2 Applications and uses of climate stress tests outputs for supervisors

In a July 2021 report (BIS, 2021), the Financial Stability Institute at the Bank for International Settlements discussed the challenges that emerge when trying to adapt traditional stress tests to banks' climate-related risks. Using recent stress tests exercises (DNB, BdF/ACPR and BoE/PRA), the report reviewed how these challenges have been addressed in practice and provided some reflections about the possible implications

for prudential requirements. Exhibit 17 summarises the key outcomes of climate stress testing identified in this report. We further develop the key applications of climate stress tests below.

Exhibit 17: Key takeaways on climate stress testing outcomes from the BIS report 'Stress-testing banks for Climate Change—a Comparison of Practices'.

- A climate stress testing exercise provides an initial assessment of climate risks, exposures and vulnerabilities to which institutions are exposed. The report states that "these initial exercises are primarily a learning opportunity for banks and the authorities".
- Quantification of exposures to climate risks can "guide banks in rebalancing their exposures, and/or adjust their risk management accordingly" and can help authorities to "gauge the financial stability implications of climate risk".
- Outcomes of a climate stress test can measure the significance of anticipated impacts, illustrate sensitive regions and sectors, and help assess corrective actions.
- Results of climate stress tests are not currently being used to set capital requirements for banks. The exercises which have taken place to-date have not quantified solvency ratios at the bank level and have reported their results at the aggregate level.
- Regulatory authorities are not disclosing the results publicly at the firm-level due to high uncertainty surrounding the produced estimates. These can nevertheless be useful on a system-wide level and, for banks, as a way to benchmark their own calculations.

(BIS, 2021)

A learning exercise to mobilise and raise institutions' awareness of climate-related risks

With expertise in modelling climate-related risks still in its infancy, regulators anticipate or have reported significant benefits of such exercises in developing the capabilities and resources of both the regulator and participating banks. The ACPR (2021) stated that:

> **"...participating institutions (in the ACPR pilot climate stress test) commended the benefits of this pilot exercise and the progress it has fostered in terms of cross-functional mobilisation of teams, internal reflections on risk analysis and the limits of the models currently used, but also in terms of strategic guidelines and towards a better understanding of the issues and the impact of climate change on their business model."**

Climate stress tests provide an initial identification and assessment of the climate-related risks and vulnerabilities that institutions could be exposed to and the potential costs of their non-compliance with the objectives of the Paris Climate Change Agreement.

A way to encourage boards to understand the challenges and take a strategic, long-term approach to managing climate risks

Climate stress tests will shed light on the financial risks arising from climate change and focus the attention of institutions on impacts including potential losses or degradation of the credit quality of exposures. Climate stress tests can also create the impetus for boards to understand the challenges that climate risks represent for their business models and consider strategy changes and other management actions that might be taken, as well as define the likely triggers and thresholds for their implementation under each scenario.

With the knowledge of such anticipated corrective actions, regulators may be able to identify some of the expected tensions, as highlighted by ACPR (2021), for example between exit strategies and market share retention objectives or the desire to maintain a customer relationship. These may lead to the retention of an exposure to transition or physical risks for a longer period of time than anticipated.

A contribution to improving institutions' climate risk management, modelling and data

Climate stress tests allow banks and regulators to identify data and resource gaps, any shortcomings in existing measurement tools, as well as the appropriate indicators and metrics to measure and monitor the impact of climate risks on the financial sector.

In doing so, regulators help improve the banks' abilities to anticipate and manage these risks by developing each institution's capabilities to integrate the climate risk in their risk measurement, assessment and management tools and frameworks. For example, in the results for its 2018 energy transition risk stress test, DNB (2018) concluded: "The stress test results suggest that financial institutions can mitigate their vulnerability to a disruptive energy transition by including energy transition risks in their risk management." Although not explicitly stated, it is likely that regulators will use the results of climate stress tests to benchmark banks within their remit, using the best approaches to set the expected standard, the level of which will increase as banks' approaches develop and mature.

A contribution to improving banks' climate-related disclosures

A key benefit is also that such climate stress testing exercises will encourage banks to improve their climate-related disclosures on a comparable basis which will increase transparency on the risks and opportunities for the financial sector. Improved disclosure will also inform investors and market actors in general on the resilience and sustainability of institutions, progress towards targets and their alignment with the goals of the Paris Climate Change Agreement.

For now, a supervisory tool with no direct regulatory capital implications

As argued in a 2020 research note by the Bank Policy Institute (BPI, 2020) the challenges in stress testing for climate change are significant and it thus seems premature "to link climate stress tests to capital requirements" despite the fact that "the underlying analysis and research will gather valuable information for public policy on climate change".

As part of all such exercises to-date, the regulators have insisted on the absence of direct implications in terms of regulatory capital or remedial actions to be taken by banks as a result of projected losses. In its report, the Financial Stability Institute does not expect this initial round of climate stress exercises to lead to new capital requirements, explaining that "such a requirement is considered premature given the preliminary nature of the exercises and the high-level of uncertainty attached to their results". Yet, regulators see the exams as a prudential supervision tool: in addition to the goals described above, stress tests also help regulators benchmark firms, assess to what extent the current regulatory framework is sufficient to manage climate risks and whether regulatory capital is the most appropriate tool to address them. For example, the BoE/PRA stated that the 2021 CBES "may inform the Financial Policy Committee's approach to system-wide policy issues, the PRA's approach to supervisory policy, and guide further work between participants and supervisors to address any issues highlighted" for their business model, internal governance and risk management.

Exhibit 18: Desired outcomes of the 2021 CBES by the BoE and the PRA.

The objective of the 2021 CBES exercise is to understand how resilient current financial institutions and the financial system are to climate risks. The BoE released the key elements of its 2021 CBES exercise, in which the supervisory authority has outlined its desired outcomes, which are:

- Sizing the financial exposures of participating financial institutions and the financial system to climate risks;
- Understanding the challenges that the business models of participating financial institutions will face from climate risks, determining likely responses and understanding the potential implications; and
- Assisting participating financial institutions in enhancing climate risk management, including the engagement of counterparties to support them in understanding their vulnerability to climate risks.

These desired outcomes have also been illustrated in the Figure 32 below.

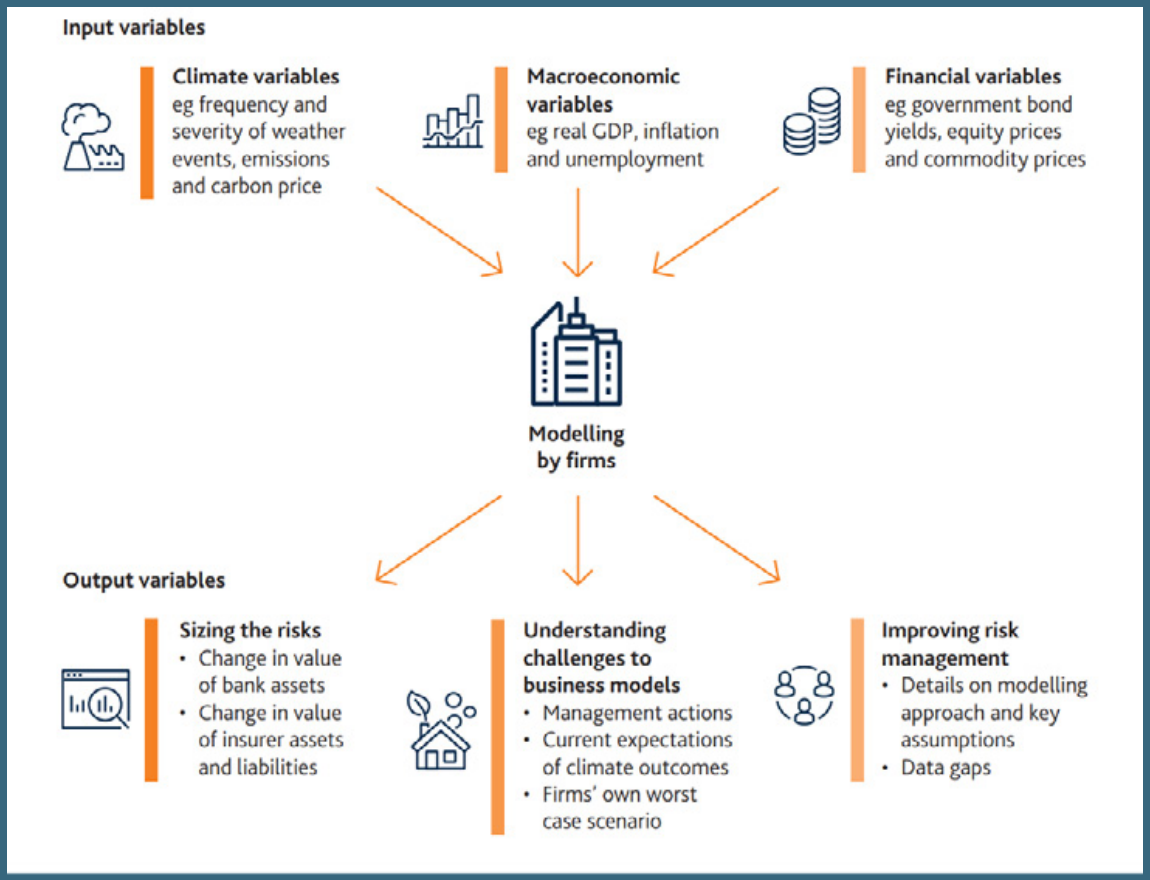

Figure 32: Desired outcomes of CBES.

(Bank of England, 2019)

Whilst it may occur at different times in different jurisdictions, it is certain that climate risks will be included in all relevant supervisory requirements, as any other risk, at some point in the future. The ECB has made its expectations clear and asked the banks within its remit to assess themselves against climate risks, with a view to benchmarking the banks and developing the ECB's approach to a "dedicated Supervisory Review and Evaluation Process (SREP) methodology that will eventually influence banks' Pillar 2 requirements" (ECB, 2021). In June 2021, the EBA published its report on management and supervision of ESG risks for credit institutions and investment firms. The report provides "a comprehensive proposal on how ESG factors and ESG risks should be included in the regulatory and supervisory framework for credit institutions and investment firms". It proposes an enhancement of the SREP, with an extension of the time horizon of the supervisory assessment of the resilience of institutions' business models, "applying at least a 10-year horizon to capture physical risks, relevant public policies or broader transition trends" (EBA, 2021).

The PRA also made clear since 2019 that they expect banks in its remit to include climate risks in their ICAAP and thus consider the capital implications of the associated exposures and risks. They also mentioned that the CBES exercise will "guide further work between participants and supervisors to address any issues highlighted" (Bank of England, 2021).

Although climate risks are not accounted for directly through capital requirements for now, these processes might result in an indirect capital impact. Banks across the EU and the UK therefore have a strong incentive to identify and quantify their exposures to climate risks and to understand how well their business model would withstand significant climate-related stress through their ICAAP and Internal Liquidity Adequacy Assessment Process (ILAAP), as well as their recovery and resolution planning processes.

7.3 Recommendations on the use of climate stress tests outputs for financial institutions

Currently, only a small number of climate stress testing exercises have taken place, like the ACPR pilot exercise, or are ongoing, like the BoE CBES exercise. Though climate stress testing exercises are becoming common across the financial sector, with more exercises anticipated to take place over 2021 and 2022 across several jurisdictions (see section 3.3.1 for the list of regulatory stress tests announced), climate stress testing is still in its early days. Banks need to develop their capabilities, including internal climate stress tests, to anticipate how they will use their outputs to integrate this thinking into their climate programme.

In the first part of this section, high-level guidance regarding the climate stress test process will help frame the thinking around its design and how to approach it. The second part focuses on how to best use the climate stress tests outputs and provides guidance and recommendations on six key areas.

7.3.1 Overarching recommendations for the climate stress test process

1. Ensure clear, consistent and wide-ranging communication

UNEP FI TCFD programme participants stressed the importance and difficulty of internal communication: if traditional stress tests can already be challenging to communicate about, climate stress tests, because of the time horizon involved, present another level of challenge.

Climate stress testing exercises need to be effectively communicated across the firm and at all levels of management. The board and executive management need to be clear about what the climate stress tests can and cannot do, what the outputs mean and what outputs can and cannot be relied upon. To improve communication on climate risks, HKMA recommends that senior management should both actively take part in international conferences and initiatives on climate risks to demonstrate their institution's commitment to tackling climate change. HKMA also recommends that firms enhance internal communication to raise awareness of climate risks across their teams through a range of practices, including circulating articles on climate change and its impacts (HKMA, 2021).

As described in section 4 (Team Organisation and Skills), management at the firm plays an important role in effectively communicating the results, as well as the limitations and challenges of the exercise. Regulators also stress (for example in the 2018 European Banking Authority (EBA) 'Guidelines on institutions' stress testing') that the management body should ensure that the outputs of a climate stress test are taken into account for decision-making, business planning and strategy (EBA, 2018). BCBS recommends that senior management clearly discloses the use of climate stress outputs as a guide when making decisions, taking into consideration the vulnerabilities shown by the exercise (BIS, 2009).

2. Ensure climate stress tests are a key opportunity to learn and trigger action

Though climate stress testing is in its early stages, there are useful lessons to be learned from such exercises. Qualitative and exploratory views can greatly benefit firms by triggering action, for example they can prompt early discussions on climate risks and opportunities, and they can help devise and test strategies to address potentially problematic exposures. As institutional approaches to climate stress testing mature and become more sophisticated, climate risks need to be increasingly embedded into decision-making, risk management, business models and strategy. These improvements should be reflected in disclosures.

A survey of the UNEP FI TCFD programme participants confirmed the regulatory views discussed in the previous section: banks anticipate that the key applications of climate stress test results will primarily be to further their understanding of the impacts of climate risks on the bank's portfolios (24%), to inform their risk appetite (20%) and risk management policies (19%).

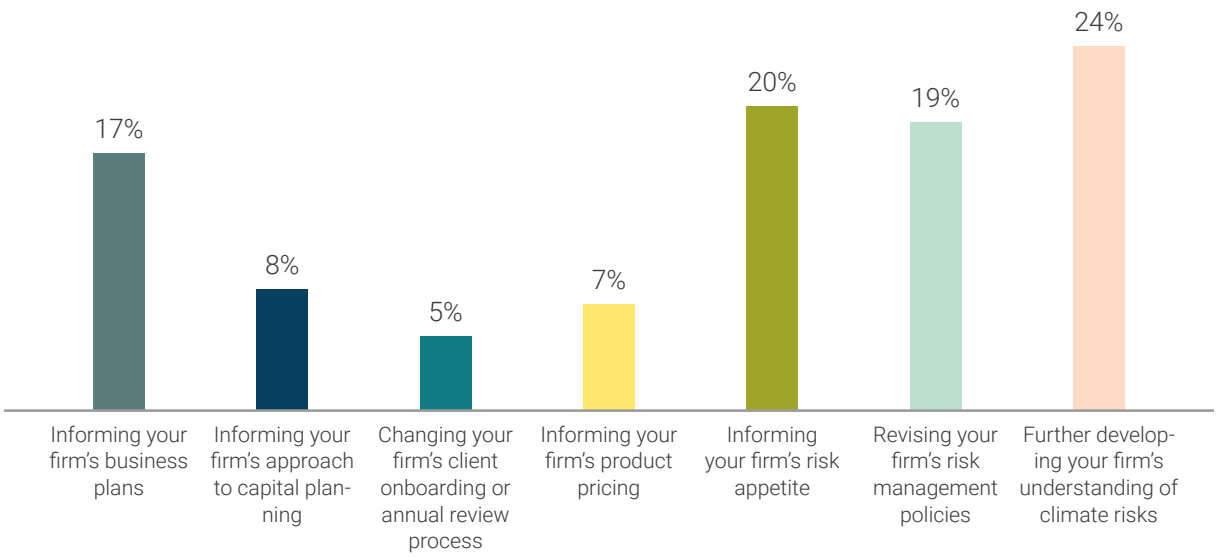

Figure 33: Anticipated primary uses of the climate stress test results by the UNEP FI TCFD programme participants.

This aligns well with the benefits regulators anticipate: raising awareness of the board and executive management of the potential impacts, providing an understanding of climate risk drivers and initiating their inclusion in risk management frameworks and processes. Importantly, running climate stress tests also allows institutions to recognise how much progress needs to be made on data, infrastructure and capabilities, and provides incentive to devise plans to improve these.

3. Initially keep the approach simple and focus on material exposures

Unless required otherwise, institutions that have some experience with climate stress tests tend to adopt a risk-based approach by focusing on the most carbon-intensive sectors in their portfolios. This is a reasonable approach when resources are limited, and a significant part of the stress testing process relies on trial-and-error and manual adjustment processes. These banks have kept things simple, looked to avoid any undesirable extension of the scope, been clear on their modelling approach and the assumptions involved, and have pushed increased levels of sophistication to a later date. They have gone through a lessons-learned process to help drive both investment and improvements in their capabilities.

4. Look for opportunities to leverage the outputs

The responses from UNEP FI TCFD programme participants also reflect that, while some banks are more advanced than others, much remains to be done to reach a level of maturity that would allow them to fully leverage climate risk assessments and analyses to drive their strategies.

The more advanced banks are already looking into how climate stress tests can support client engagement, identify winners and losers within material sectors under the assumptions set out by the scenarios and thus inform client strategy. Some institutions are also developing their thinking as to how the outputs could usefully inform risk appetite, be used to set constraints (for example limits on certain sectoral exposures) and ultimately reshape capital allocation. These points will be specifically addressed in the next section and banks are encouraged to leverage the analyses derived from the outputs to improve the sustainability and performance of their business.

7.3.2 Leveraging climate stress tests outputs

The most immediate output of the analysis and interpretation of the climate stress test results is the set of insights derived on the impact of physical and transition risks at different points in the future, along determined pathways. These insights allow financial institutions to identify which sectors and counterparties are most at risk in portfolios under the scenario assumptions and identify the climate drivers for these risks.

Beyond the immediate benefit of identifying and quantifying such risks, both regulatory and ad-hoc climate stress test results present a range of potential benefits which banks should fully take advantage of. This section provides guidance on how these exercises and their outputs could be developed, focusing on the six points schematically represented in Figure 34.

Figure 34: Six key uses of a climate stress test.

These intrinsically linked uses can be grouped around three themes:

1. Improving climate risk management and helping set the firm's risk appetite;
2. Supporting the firm's strategy, customer engagement and investment; and
3. Supporting the firm's external disclosures and compliance.

Theme 1. Improving climate risk management and helping set the firm's risk appetite

Developing climate stress testing capabilities will allow institutions to identify and understand their vulnerabilities, develop appropriate risk management approaches, and integrate climate risks in their risk appetite. While the outputs of climate stress tests allow institutions to build value-adding management information and dashboards, they can also lead to improved external reporting and disclosure. Climate stress tests hold the potential for further uses in probing the tails of the risk distributions and gaining greater understanding of the impacts different pathways can lead to.

Key use 1. Better understanding of vulnerabilities to incorporate into the risk appetite

The identification and understanding of business vulnerabilities ultimately aims to inform risk appetites and helps set targets and limits. Climate stress tests allow institutions to understand what may lie ahead for each sector and material counterparty or country exposure, how the results vary with the portfolio composition over time, and how sensitive they are to changes in the data, modelling or assumptions. Understanding vulnerabilities and how they translate in terms of financial parameters for institutions and their clients will expand and deepen with experience in running climate stress tests.

Recommendation. Beware of unwarranted precision. Climate scenario analysis and stress testing can be used to estimate the sensitivity of firms' portfolios to specific drivers and understand their potential non-linear effects. In conducting such analyses, relative and order-of-magnitude assessments can yield useful insights. Institutions should not attempt to claim spurious precision in their outputs.

As institutions and practitioners have grown accustomed to seeing in the literature, there are an infinite number of shapes that the future could take, of paths our climate and economies could follow, and no one can predict which will effectively unfold. Climate scenario analysis and stress testing hold tremendous potential in that they allow institutions to simulate distinct realisations of the future and—crucially—the path taken to get there. This in turn can be used to determine their potential impacts on the firms.

Recommendation. Do not limit your analysis to regulatory scenarios. While regulatory scenarios are a good starting point, each firm should work to establish its own set of climate scenarios, increasing the level of detail in the sectors and geographies most relevant to its portfolio and ensuring a relevant variety of pathways for the key drivers to be explored.

Once climate vulnerabilities, drivers of risk and sensitivities have been identified, analysed and quantified through stress tests, and the pathways relevant to each scenario have been understood, they are expected to inform the choice of which sectors to include in the risk appetite, which controls to set up, which metrics to use and which constraints or trigger levels to apply. This will be an evolving process in which expert and qualitative judgment is likely to be initially predominant over modelling and quantitative assessments. In addition, the uncertainty around climate stress test results is expected to represent a challenge for embedding climate metrics in firms' risk appetite.

Whether their risk appetite has been articulated or is still a work in progress, banks may wish to implement some form of limitation on exposures to sectors or counterparties which do not align with their climate strategy or their risk appetite. Ideally, such limits translate directly to the risk appetite statement or contribute to it in a straightforward and unequivocal way. Nevertheless, it may prove challenging to translate a qualitative risk appetite statement into metrics and quantitative limits.

Recommendation. Use metrics derived from the key drivers to define your risk appetite and leverage existing guidance on climate metrics.

The TCFD released its guidance on the use of forward-looking metrics for the industry in October 2021. The guidance report provides information on selecting and disclosing metrics, as well as the set of metrics that the Task Force considers important to disclose (TCFD, 2021).

The UK Climate Financial Risk Forum also published guidance on forward-looking metrics in October 2021 (FCA, 2021). The guidance identifies key climate-related metrics and their primary use cases, as well as guidance on developing metrics to better understand system-wide risks.

The March 2021 EBA consultation on Pillar 3 ESG disclosures (EBA, 2021) introduced the Green Asset Ratio (GAR) in addition to Key Performance Indicators (KPIs) and quantitative disclosures on climate-change transition and physical risk. The GAR provides information on what part of an institution's exposures "contribute to or enable the objectives of climate change mitigation and adaptation and help to mitigate climate change related risks".

Some institutions may prefer to start their journey with qualitative or relative constraints which can meaningfully influence the evolution of a portfolio. For example, limits could be set on the percentage of lending to counterparties whose operations are based in locations subject to increased probability of floods or wildfires or are classified as carbon-intensive. A portfolio could be constrained to have at least a certain percentage allocated to green or sustainable assets. Such constraints need not be based on an accurate quantitative assessment but could rely on a high/medium/low classification. They may also not be directly linked to climate-derived metrics but reflect a policy, such as imposing a shorter maximum maturity or a lower loan-to-value requirement for undesirable products or counterparties.

An institution's understanding of its climate-related risks and opportunities would not be complete without considering all possible sources. Regulatory climate stress tests have so far heavily focused on credit risk as the key risk for institutions, with the BdF/ACPR exercise also including market risk. As shown in Figure 35, climate risks lead to many financial risks and all material risks need to be considered in climate stress tests.

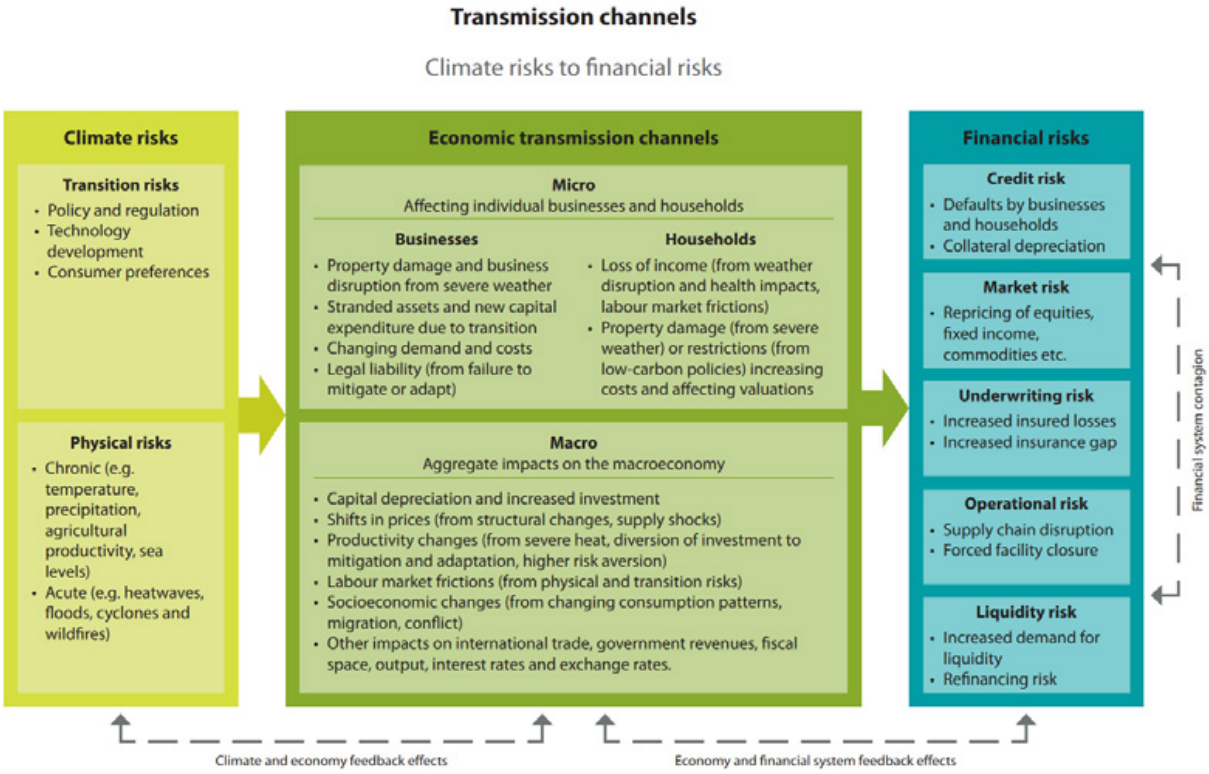

Figure 35: Transmission channels for climate risks into financial risks (NGFS, 2021).

Market risk. Climate events may trigger extreme market movements such as (but not only) volatility in commodity prices. Sudden policy changes, such as the imposition of a carbon tax or technological changes, may cause the equity prices of companies in carbon-intensive sectors to fluctuate. As climate events continue to occur with increasing frequency and severity, market risk will be impacted by climate change.

Liquidity risk. Banks suffering climate-related losses may face difficulties in refinancing and could face a liquidity run due to customer needs for cash in light of climate risks. Therefore, climate risks have the potential to cause net cash outflows and depletion of liquidity buffer for banks (ECB, 2020). Furthermore, as credit rating agencies focus increasingly on ESG risks, poor management of climate-related risks could adversely impact the bank's credit rating and consequently affect its ability to obtain liquidity from the market.

Operational risk. Climate change has had a clear impact on operational risk, as extreme weather may force office closures or damage crucial physical infrastructure such as buildings, data centres, call centres or bank branches, and impact critical third-parties. New climate-related technologies also need to be evaluated for the operational risk they carry for the organisation.

In addition to the above financial risks, reputational risk and legal risk should be considered, especially in areas where the number of litigations based on climate considerations is increasing or the potential for greenwashing is present.

Recommendation. Early in the process, consider the requirements and implications of including all material risks in the climate stress test framework and risk appetite. Climate risk is a "transverse" risk that will manifest itself through existing risk channels. Credit risk is the main one in the banking industry, but other risks could potentially inflict serious losses on an institution and need to be included in the climate risk assessments.

Key use 2. Develop mitigation strategies and push the analysis further

Once a picture of the size and extent of its climate risk exposure starts to emerge from risk assessments, climate scenarios and stress tests, an institution will look to develop risk management and mitigation strategies and take advantage of the opportunities. This can take many shapes, from a planned reduction in trades that adversely contribute to climate risk in a given sector, to active hedging of climate-induced counterparty risk, to the development of green financing products, as addressed in the below section about strategy and customer engagement.

Institutions can also look to further embed stresses in their day-to-day risk management practices, including defining some benchmark scenarios that run regularly and are monitored for progress against a target or risk indicators. For example, developing a set of specific scenarios aimed at key climate-related exposures or vulnerabilities for given sectors or industries, or highlighting the specificities of a given region or country, could be valuable tools in monitoring how an institution's risk profile evolves. In a similar way, acute physical risk scenarios depicting plausible, yet catastrophic hurricanes, floods or wildfires should find their way into every institution's scenario arsenal. Finally, public policy-linked scenarios would allow institutions to simulate the impact of the implementation of one (or several) key policies, simulating different timings, extent or intensity.

Finally, the Reverse Stress Test approach (Exhibit 19) could prove a valuable tool in identifying the tail events likely to cause serious issues to institutions in the absence of any relevant historical occurrence.

Exhibit 19: Probing the tails with Reverse Stress Tests.

Reverse Stress Tests (RST) are a hypothetical exercise in which an institution aims to find scenarios that would lead to a failure of its business model and cause the market to lose confidence in its ability to function, leading to its demise. By their very definition, the scenarios generated are extreme and their plausibility is often questioned. Yet they can be useful to identify vulnerabilities that may have been overlooked by other stress testing approaches.

Climate change events would qualify well for such an exercise, looking at what a catastrophic climate event(s) would lead to. While traditional stress tests largely rely on historical data as their basis, devising stress events of a magnitude well beyond anything that ever happened is appropriate in the current climate change context, given the increasing frequency and severity of such events.

Such an approach could allow institutions to answer questions like, what level of severity would be required for a climate-related event to cause a loss in excess of a given amount? Or, for a mainly coastal or flood-exposed mortgage portfolio, what level of severity would cause the portfolio to experience an unsustainable level of defaults and mostly worthless collateral?

Transition-related climate risks could also be captured in RSTs. During the global economic recession caused by the COVID-19 pandemic, exposures to troubled shale oil producers forced US banks to set aside large provisions for non-performing loans. An example of a transition-related RST question could be: what level of newly imposed carbon tax or level of oil price would cause a pre-determined proportion of such a portfolio to fall into arrears?

Recommendation. Develop and adopt actionable mitigation plans and adapt them for the specificities of each sector. The institution should consider questions of overall strategy, climate commitments and client engagement in considering how to most effectively support a resilient, low-carbon future.

Recommendation. Develop internal climate stress tests catering to the specificities of the firm's portfolio and exposures. Embed transition and physical risk scenarios into day-to-day risk management, monitoring and reporting processes.

Theme 2. Supporting the firm's strategy, customer engagement and investment

Climate stress test outputs will likely identify one or more sectors for which increasing or even maintaining the current level of exposure might lead to adverse outcomes in one or more scenarios. This should lead to discussions about the current business strategy, inform any proposed changes, as well as the extent and timeframe of the decarbonisation of the lending portfolio. These elements will, in turn, drive the engagement of key clients.

Going a step further, by embedding climate stress test outputs into governance, risk management processes and policies, a firm can make informed, risk-based business decisions, improve its resilience to climate change and seize the opportunities as they arise.

Key use 3. Inform proposed shifts in business strategy

While there is an intense focus on the risks associated with it, climate change also creates opportunities. The TCFD identified several areas of opportunity, including improvement in resource efficiency, adoption of low-emission energy sources, development of new low-emission products and services, access to new markets, and resilience-building along the supply chain. These opportunities create increasing demand for green funding and require a shift in many institutional strategies.

Shifts in business strategies, actions to tackle the identified sector vulnerabilities and leverage business development and growth opportunities, should be reviewed in each institution in the context of its organisational strengths, market position and competitive landscape with the support of climate stress tests. Shifts should also account for shareholders' and stakeholders' expectations, climate-related policies and external commitments such as science-based targets. Climate stress test results could add significant value by informing the choice of metrics derived from the key risk driver and helping to define the risk appetite against the targets supporting the firm's strategy. A climate stress test can contribute to strengthening the link between a bank's current climate commitments and its desired outcomes, as well as supporting the development of clear management outcomes in the case of each scenario to support the development of the firm's overall climate strategy.

An appropriate climate stress testing set-up should also allow the firm to identify opportunities and test the impact of business options. It could include scenarios focusing on a particular driver, with various options, to help answer the business and management's questions and support the decision-making process. For example, what would be the impact on the firm's current portfolio if a particular type of government or regulatory policy was adopted in 2025, 2030, or 2040, assuming the balance sheet structure does not change? Or how would a proposed internal strategy, for instance in terms of substantially increasing or decreasing lending to a particular sector—thus changing the balance sheet structure—play out under the scenarios considered?

As discussed earlier in this section, stress tests should also allow the exploration of vulnerabilities of the current (or a proposed) business model to future climate pathways, for example describing a more or less abrupt reduction of carbon emissions and

associated economic and social repercussions. It will help identify the potential risks posed to this business model over time under various hypotheses and thus contribute to building the firm's resilience.

Often less considered, are the potential impacts of climate change on banks' liquidity, collateral and capital management. Climate stresses could usefully inform the management of these areas and risks under various scenarios and support the discussions on strategic planning and sustainability. Regulators have started to set out their expectations for the ICAAP, ILAAP as well as the recovery and resolution planning processes (as discussed in section 7.2).

Recommendation. Embed the use of climate stress test outputs in discussions about business strategies across the organisation. Use outputs to support and challenge business plans, ensure their compatibility with the risk appetite approved by the board and bring focus to both growth opportunities and resilience.

Key use 4. Informing client engagement, especially in vulnerable sectors

Financial institutions know their clients' businesses in detail and are thus in a unique position to fully understand and anticipate their financing needs, combining this knowledge with the understanding of climate-related risks obtained from climate risk assessments and stress tests. Institutions can use climate stress test outputs in their discussions and engagements with their clients, bringing together net-zero discussions and climate risk discussions. Such engagement will lead to the identification of business opportunities in the form of new strategies and tailored products and will also help define the institution's strategy with respect to clients in vulnerable segments.

As part of their credit assessments, annual reviews and ongoing monitoring processes, banks should review their clients' business activities and transition plans against their own climate strategy or risk appetite. Where they are misaligned, institutions can adopt one of two approaches, or a mix of both. Firstly, banks can look to put in place mitigation measures to allow a reduction in exposure over a certain time horizon. Secondly, banks can look to support their client in transitioning to a low(er)-carbon business model. Mixing the two approaches may, for example, take the form of agreeing on specific targets or milestones in their transition plans, providing financing for a shorter period, introducing stringent covenants on climate-related metrics, or making a refinancing offer conditional on achieving climate-related targets. In this example, the climate elements are included at the transaction level for a particular client. This could prove a very effective approach to both support and encourage the transition of a client while minimising the risk to the bank.

Climate stress tests can inform these approaches by providing a set of metrics on which targets can be set, to introduce some limitation on exposures to sectors or clients that do not align with firms' climate strategies or risk appetites.

Consistency in defining and applying such rules across the organisation is key and the sector-specific adopted limitations, for example, should be included in the relevant policies and procedures, describing the climate-related considerations or criteria to account for. Any exclusion policy (such as the financing of thermal coal in most EU banks) should also filter down into credit approval processes, including any gradual measures to be adopted as relevant. Exhibit 20 explains how climate stress tests can lead to adjustments in the internal credit rating and thus the pricing of climate risk in firms.

Exhibit 20: Adjustment to credit ratings and pricing of climate risks.

Once a risk has been identified and quantified, an institution would ideally need to include its impact in the pricing of its products where relevant and material. Banks should step-up their efforts to use the climate stress test modelling and outputs to incorporate climate factors into their Internal Ratings-Based (IRB) credit models and review the pricing of the firm's current product offering to ensure climate risks are accounted for, at least to the extent possible.

The uncertainty around the outputs may not yet fully allow this and a first step towards this goal could be to use the outputs of the stress tests as a qualitative or semi-quantitative way to inform lending decisions. This would allow changes to the business strategy, to encourage or discourage lending to certain key sectors, charging more to counterparties whose business increases the probability of adverse outcomes for the bank, or does not contribute to the diversification of the portfolio in terms of climate risks, for example.

Recommendation. Define how climate stress test outputs will be used in the firm's client engagement strategy and ensure easy access to sector-specific and client-specific analyses.

Key use 5. Provide direction for the institution's climate data and infrastructure investments

Undertaking climate stress testing will allow an institution to identify suitable approaches to transition and physical risk modelling, evaluate the amount of work required and plan for future improvements.

In the same way, data gaps and data quality challenges will be identified. Section 5 highlighted the challenges to be expected in collecting and processing climate data. Once candidate solutions, internal or external, have been explored and analysed, they should be included in specific investment plans and budgets for approval by the executive management and the board, hence reinforcing their importance.

It is also likely that the early attempts at running climate stress tests will highlight at least some limitations of the institution's current systems in incorporating and manipulating climate-related data and metrics. The tools to manage climate stresses and analyse their outputs are highly likely to be ad-hoc in the early stages and this should drive the development of a programme of work to address the institution's deficiencies in its infrastructure and tools.

Theme 3. Supporting the firm's external disclosures and compliance

In addition to data representing the extent of key climate exposures, climate stress tests can help emphasise the quantum of risk, through value-adding management information and dashboards. The themes developed above are good candidates to populate these dashboards and allow management and the board to monitor the impact and progress of actions they are taking to mitigate climate risk, take advantage of new opportunities and inform business strategy and decision-making on an ongoing basis.

Key use 6. Provide value-adding management information and enhanced external reporting and disclosures

The use of climate change scenario analysis is a core TCFD recommendation. However, only the largest banks in the developed markets are currently at the forefront of using climate scenarios in their disclosures. The situation is improving each year, as disclosures increasingly include more granular and quantitative information and more institutions join the initiative, which is also increasingly being made mandatory by regulators.

As banks mature in their approaches and develop their climate stress testing capabilities, they will increasingly see benefits in leveraging the results of their stress tests to improve their disclosures. In turn, providing more detailed and insightful data and analysis will help them meet the expectations of their shareholders and stakeholders and support their advocacy and communication efforts. It will also facilitate compliance with regulatory disclosure expectations and potentially limit exposure to climate risk litigation in relation to material omissions or misstatements of climate risks they are exposed to. The variety of approaches and metrics across banks makes comparative assessments difficult. For example, if an analyst is looking to assess the relative climate exposure profile to a particular sector across banks, they are unlikely to find common, audited and detailed climate metrics or assumptions across the board. Regulators have so far provided little guidance as to what approach(es) should be preferred and a market standard has yet to emerge. There is however some progress, notably with disclosures in line with the TCFD recommendations becoming mandatory in the UK for publicly quoted companies, large private companies and limited liability partnerships (LLPs) (GOV.UK, 2021).

In June 2021, the FCA issued a consultation on proposals to extend mandatory TCFD reporting to (i) asset managers, life insurers, FCA-regulated pension providers; and (ii) issuers of standard listed equity shares, as part of the UK's ambition to have fully phased-in TCFD reporting by 2025 (FCA, 2021). This comes as an extension to the requirement from January 2021 for all premium listed UK companies to comply with TCFD recommendations and disclose how they are considering the impacts of climate change, and on a comply or explain basis report against the TCFD framework (FCA,

2021). A phased implementation between January 2022 and January 2023 is scheduled, with a final policy statement expected in Q4 2021.

As already mentioned above, in March 2021 the EBA launched a consultation proposing draft Implementing Technical Standards (ITSs) for comparable quantitative disclosures and KPIs on transition and physical risks, and the establishment of a Green Asset Ratio (EBA, 2021). The consultation closed in June 2021.

The International Financial Reporting Standards Foundation (IFRS) formed a working group in March 2021 (IFRS, 2021) "to accelerate convergence in global sustainability reporting standards focused on enterprise value and to undertake technical preparation for a potential international sustainability reporting standards board under the governance of the IFRS Foundation". Its goal is to provide technical recommendations, based on the TCFD recommendations, as a potential basis for the new board to build on existing initiatives and develop standards for climate-related reporting and other sustainability topics.

Recommendation. Early in the process, consider adhering to international standards and frameworks in climate-related financial disclosures. Adopting and embedding the available reporting standards at the earliest possible opportunity as they emerge, will be key to reaping the rewards of this work. Banks should look to adhere to alignment and disclosure initiatives on a voluntary basis, in anticipation of their adoption by regulators and before they become mandatory. Beyond the mandatory requirements for external disclosures, banks should look to develop their internal dashboards based on their internal climate stress tests, metrics and targets.

8. Conclusion and suggested enhancements

8.1 Conclusion

With the growing recognition of the importance of climate stress testing by the financial sector, an increasing number of financial institutions are taking part in climate stress test exercises to identify and assess their resilience to physical and transition climate risks and to support the firm's strategy and planning. For financial institutions, there are four key applications of current climate stress tests:

- Mobilising and raising the firm's awareness of climate-related risks;
- Encouraging boards to understand the challenges of climate change and take a strategic, long-term approach to managing climate risks;
- Developing a firm's capabilities to integrate climate risk into their risk measurement, assessment and management tools and frameworks; and
- Improving climate-related disclosures of financial institutions.

This report identifies obstacles currently faced by institutions and provides recommendations to help overcome these challenges for four specific components of the test—team organisation and skills, data requirements and collection, selecting scenarios and models, and meaningful applications of climate stress testing outputs.

Climate stress testing is a much broader exercise than traditional stress testing and therefore requires institution-wide team engagement, with firms assigning responsibilities to a large number of teams across the organisation. For an effective execution of a climate stress test, firms should devote appropriate resources (financial and human), with a specific focus on the activities of data collection and analysis, model development and strategic planning. A large body of knowledge and skills are needed in-house to reach a satisfactory level of proficiency in running the test. Firms should therefore gear their climate-related training and knowledge development programmes towards a range of teams across the organisation. Substantial organisational changes should be made to run the climate stress test, including the development of a climate risk team. With adequate resources, the climate risk team should have executive sponsorship and authority to oversee, coordinate and manage the climate stress test. Firms should also integrate climate stress testing into the firm's organisational structure and processes with robust governance and oversight.

Climate stress testing requires new kinds of data that were previously not needed for traditional stress tests. However, when collecting climate-related data, such as emissions data, financial institutions face numerous obstacles. To improve their data collection capabilities for a climate stress test, firms should develop policies and procedures to support the collection, processing and use of climate data. Good practices for collecting data include firms identifying data needs and available sources, implementing industry standards, implementing data validation processes, identifying data gaps and adapting institutional systems to process these new kinds of data. To overcome limitations for securing climate data on and from clients, this report recommends firms to follow best practice steps that they can implement in-house and through collaborations, steps requiring client engagement and steps to build robust data collection processes. For collecting emissions data, firms should also identify internal sources through which emissions data for clients can be accessed and develop internal tools to calculate emissions data. When collecting data from external data providers, it is recommended that firms develop an internal policy, identify easily accessible open-source platforms, develop a questionnaire based on the institution's data needs and actively communicate with data providers.

Selecting scenarios and models to use for climate stress testing is a multi-step process. It is important for firms to adapt reference scenarios geographically and sector-wise and to derive the impact on key drivers to develop a relevant scenario narrative. Firms should also implement a process to integrate the latest scenario developments and emerging methodology standards into the scenario design for climate stress testing. Financial institutions may also be required to undertake scenario expansion to extrapolate additional scenario variables that may be required for the climate stress test. The modelling process in a climate stress test consists of modelling climate variables, measuring the impact of climate risks on macroeconomic variables, breaking down the macroeconomic impacts per sector or per portfolio and quantifying the impact on the financial institution. To improve modelling capabilities, a firm should identify gaps in current in-house models and increase communication with external modelers and academics on scenario expansion to help improve their understanding of different models.

Supervisory climate stress tests have a wide range of applications, as mentioned above. A climate stress test approach should initially be kept simple and focused on material exposures. However, going forward as the financial sector further expands climate stress testing, there are six additional uses of a climate stress test:

- To better understand vulnerabilities to incorporate into the firm's risk appetite;
- To inform proposed shifts in business strategy;
- To inform customer engagement, especially in vulnerable sectors;
- To provide direction for the institution's climate data and infrastructure investments;
- To provide value-adding management information and informative external reporting and disclosures; and
- To develop mitigation strategies and push further analysis.

8.2 Next steps for climate stress testing

Understanding the current landscape of climate stress testing, it is important to look at the future of climate stress testing. This section will discuss the current limitations of the test and suggest ways for supervisors to continue developing the exercise in the future. Below we highlight some of the key issues that have been identified in this report that need to be addressed by the financial sector to allow for an effective execution of a climate stress test.

Lack of skills and internal expertise

Executing a climate stress test requires teams across the organisation to be proficient in a range of climate-related skills. However, many teams currently lack the skills and knowledge needed to understand and assess the financial impacts of climate risks. Often the majority of climate-related training at firms is geared towards client-facing employees. However, as climate stress tests require the collaboration of multiple teams from across the organisation, it is important for institutions to build internal expertise on climate risks and climate stress testing much more widely.

Lack of data availability

Currently firms find it difficult to obtain the necessary client-related data since a large proportion of clients do not provide comprehensive and complete climate data disclosures. Furthermore, the financial sector has not yet reached a consensus on the types of physical and transition risk data that should be used for a climate stress test.

High costs and resource intensity

Climate stress testing is a highly resource-intensive process with firms needing to devote a sufficient amount of resources and capital for designing, implementing and executing the exercise. This as a result can be costly. For example, counterparty analysis is resource-intensive and can be expensive to implement. Furthermore, firms may also rely on third-parties to support them in various activities, such as data collection, modelling and auditing, which can also be costly.

Climate scenario selection

To increase relevance of scenarios for climate stress tests, scenarios need to be adapted with features relevant to the firm's business model. As climate scenarios were not initially designed for use by the financial sector, they may not sufficiently link climate drivers to economic impacts for analysis by financial institutions.

Limited model design and their uncertainty

Models used for climate stress testing were not initially designed for the purpose of translating climate risks into financial impacts for financial institutions. As a result, when executing a climate stress test, firms face many challenges, including the uncertainty of modelling outputs. These complex models are run on long time horizons with multiple assumptions which lead to uncertainties.

Based on this, the box below lists guidance for regulators as climate stress tests are further developed.

Seven recommendations for regulators to assist firms in their climate stress testing journey

1. **Help build institutional expertise on climate change and climate risks by providing workshops, trainings and certified courses for firms.**
2. **Require mandatory disclosures by clients on necessary data** needed for climate stress testing, such as emissions data.
3. **Implement policies on disclosing required data, like emissions data, in standardised formats** to allow for comparability. Standardised global taxonomies will allow firms to collect comparable data across sectors and regions.
4. **Provide free open-source data to firms for a climate stress test.**
5. **Engage with financial institutions to modify current systems used to run models** to make them suitable for running climate stress tests.
6. **Engage with financial institutions to design scenarios** for supervisory climate stress tests that are relevant to the firm's scope and business model, in terms of risks and exposures assessed, time horizon, regions and sectors.
7. **Initiate communication between financial institutions and climate scientists, academic and research institutions, modelers and tool providers** to support firms in building their capacity for climate stress tests.

Though still in its early stages, climate stress tests are continuing to grow as a tool used by the finance sector for risk assessment. With the growing threat of climate change and increasing pressure by supervisory authorities, an increasing number of financial institutions are beginning to conduct climate stress tests to assess their resilience to physical and transition risks. As climate stress tests are more broadly implemented, central banks, prudential regulators and various initiatives around the world are continuing their work to address the limitations of climate stress tests and expand the scope of the exercise. UNEP FI will continue to work with our partners and members across the financial sector to further develop sophisticated approaches to climate stress testing and scenario analysis as part of our TCFD programme, helping financial institutions build their capabilities to assess climate risks and develop meaningful climate risk disclosures.

9. Appendices

Appendix 1

Key questions and topics to address when collecting physical risk data from clients:
These questions and topics can be addressed in the form of a questionnaire.

- What kinds of climate hazards is the client typically exposed to? Hazards can include flooding, drought, cyclones etc.
- Does the client have adaptation and resilience plans relevant to these climate hazards? If so, what data is available on these plans?
- Does the client have data available on previous exposures to extreme weather events and their impacts?
- Description of the physical assets owned by the client and information on their geographical location, including address, postal code, coordinates and availability of geographical maps.
- What methodologies have been used by clients to gather the data and what are the underlying assumptions and limitations of these methodologies?

Appendix 2

Key questions and topics to address when collecting transition risk data from clients:
These questions and topics can be addressed in a questionnaire.

- Does the client have transition plans, if so, what data is available on the transition plans and pathways to reduce emissions? If the client does not have transition plans in place, how and when do they intend to develop them?
- Does the client have data available on plans for decarbonisation targets or pledges?
- Is the client part of a low-carbon transition initiative and if so, which one? Does the client plan to join any initiatives in the future? Examples of some of these initiatives are provided in Figure 11.
- What data does the client have available to determine its carbon sensitivity? Data can include its current GHG emissions, the client's productive capacity in relation to its emission production and a client's ability to decrease its emissions.

- Has the client identified its exposure to carbon prices? If so, what data and/or assumptions have been used to quantify it?
- What kinds of data does the client have available on energy efficiency and mix?
- What methodologies have been used by the client to gather the data and what are the underlying assumptions and limitations of these methodologies?

Appendix 3

Additional questions for collecting emissions data include:

- What kinds of data are available on a client's emission-releasing activity?
- Which of the six GHGs from the Kyoto Protocol are emitted by the client? What kinds of data are available on these GHGs?
- What expenditure data is available regarding client purchases of goods or services? This data will be useful in estimating the emissions of a client.
- Identification of sources used by the client to obtain data and their limitations, since the PCAF (PCAF, 2020) recommends that emissions data be reported using a standardised framework, for example the CDP framework or the firm's official disclosures and environmental reports.
- What methodologies have been used by the client to gather the data and what are the underlying assumptions and limitations of these methodologies? Clients and data providers can have their own methodologies for estimating GHG emissions (PCAF, 2020).

Appendix 4

Key questions to address when gathering physical risk data from external providers:

- Does the external data provider provide data on historical extreme weather events?
- Does the external data provider provide data on future projections for extreme weather events?
- What is the geographical coverage and resolution of the data available and does the data provider cover regions of interest for the financial institution?
- What geographical data on the location is available, including the type of land, elevation, composition of soil and land cover?
- Does the data provider cover sectors of interest for the financial institution?
- Which sources and methodologies are used by the data provider to obtain the data? What are the assumptions and limitations of these sources and methodologies?

Appendix 5

Key questions to address when gathering transition risk data from external providers:

- Does the external data provider provide data on carbon pricing by jurisdiction?
- Does the external data provider provide granular data on Scope 1, 2 and 3 GHG emissions?
- Does the external data provider provide data on pledges, targets and commitments?
- What is the geographical coverage of the data available and does the data provider cover regions of interest for the financial institution?
- What is the sectoral coverage of the data available and does the data provider cover sectors of interest for the financial institution?
- Which sources and methodologies are used by the data provider to obtain the data?
- What are the assumptions and limitations of these sources and methodologies?

10. Glossary

Climate-related risk
The potential negative impacts of climate change on a financial institution.

Credit Risk
Possibility of loss resulting from borrower's inability to repay loans.

Stranded Assets
The premature write-off of assets incompatible with a sustainable economy.

GHG Protocol
The GHG Protocol establishes comprehensive global standardised frameworks to measure and manage greenhouse gas emissions from private and public sector operations, value chains and mitigation actions.

Sustainable Finance
The provision of finance to investments taking into account environmental, social and governance considerations.

Bottom-up
A bottom-up approach to climate stress testing is when a firm uses its own framework as part of a system-wide or supervisory exercise.

Climate-related disclosures
Disclosures that promote more informed investment, credit and insurance underwriting decisions, vis-à-vis climate risk, and in turn enable stakeholders to better understand the concentrations of carbon-related assets in the financial sector and the financial system's exposures to climate-related risks.

Climate stress test
A climate stress test is a forward-looking exercise designed to measure a financial institution's exposure to climate risks, using scenario analysis including severe climate risks, to assess the potential impact of climate change on the institution's business model.

Counterparty
A counterparty is the other party participating in a transaction, which could be a legal entity, unincorporated entity or collection of entities to which an exposure of financial risk may exist.

Exposure at Default
Exposure at default is the total value a bank is exposed to when a loan defaults. Exposure at default is calculated taking account of the underlying asset, forward valuation, facility type and commitment details.

Geographic Information Systems
A GIS is a computer system that enables the capturing, analysis and display of spatial and geographically referenced data.

Liquidity risk
Liquidity risk is a financial risk that for a certain period of time a given financial asset, security or commodity cannot be traded quickly enough in the market without impacting the market price. Climate risks may impact a bank's and its clients' abilities to raise funds and liquidate assets.

Litigation risk
Litigation risk is the risk an individual or company will face legal action.

Loss Given Default
Loss given default is the share of an asset that is lost if a borrower defaults.

Market risk
Market risk is the possibility that an individual or other entity will experience losses due to market volatility and change in asset prices, such as interest rate risk, commodity price risk, corporate bond spreads, and equity price risk.

Net zero
Net zero is shorthand for 'net-zero CO_2 emissions by 2050' and is derived from the science-based definition of net zero which means that all accumulated emissions over the next 30 years remain within the emissions budget required and set out by the IPCC to align with a 1.5°C pathway (stabilising planetary warming at no more than 1.5°C above pre-industrial levels by 2100–50 years after net zero is achieved).

NiGEM
NiGEM is a leading global macroeconomic model maintained by NIESR used to create country economic forecasts, scenarios and simulations, allowing the evaluation of the impact of specific economic shocks and alternative scenarios.

Operational risk
Risk of loss resulting from ineffective internal processes that can disrupt the flow of business operations, caused by uncontrollable events, gaps in business flows, damage to physical assets, and/or business disruptions.

Physical risk
Physical risks are risks associated with the impact of changes in weather and climate, on the economy. Physical risks can be acute in nature, like floods, heatwaves and wildfires, or chronic in nature, such as sea level rise, temperature changes and precipitation changes.

Probability of Default
Probability of default is the risk/likelihood that the borrower will be unable or unwilling to repay its debt in full or on time.

Risk Appetite
Risk appetite is the amount of risk that an institution is willing to accept in order to achieve its objectives.

Risk-weighted asset
Risk-weighted assets are used to determine the minimum amount of capital needed to be held by banks in order to maintain solvency.

Supervisory authority
An independent public authority responsible for monitoring the application of regulation and key supervisory frameworks.

Transition risk
Transition risks are related to changes in legislation, policies, technology and the market, during the transition towards a low-carbon economy.

Traditional stress test
Traditional stress tests are an integral part of a financial institution's risk management toolkit with regulators conducting large-scale supervisory stress tests. A traditional stress test is used to measure the capital resiliency of a financial institution to severe, hypothetical scenarios. The results of a stress test are then used by central banks and regulators to understand risks, adjust capital requirements and develop policy for financial resilience.

Top-down
A top-down approach is when a supervisory authority performs the test themselves, using their own framework, which includes a homogenised methodology, assumptions, scenarios and models.

11. Bibliography

ACPR (2020). *Scenarios and main assumptions of the ACPR pilot climate exercise.* Banque de France. Available at: acpr.banque-france.fr/sites/default/files/medias/documents/20200717_main_assumptions_and_scenarios_of_the_acpr_climate_pilot_exercise.pdf. [Accessed: 05.10.2021]

ACPR (2021). *A first assessment of financial risks stemming from climate change: The main results of the 2020 climate pilot exercise.* Banque de France. Available at: acpr.banque-france.fr/sites/default/files/medias/documents/20210602_as_exercice_pilote_english.pdf. [Accessed: 05.10.2021]

BIS (2021). *Climate-related financial risks—measurement methodologies.* Bank for International Settlement. Available at: bis.org/bcbs/publ/d518.pdf. [Accessed: 05.10.2021]

Bank of Canada (2020). *Bank of Canada and OSFI launch pilot project on climate risk scenarios.* Available at: bankofcanada.ca/2020/11/bank-canada-osfi-launch-pilot-project-climate-risk-scenarios/. [Accessed: 11.10.2021]

Bank of England (2016). *Stress testing of banks: an introduction*. Available at: bankofengland.co.uk/-/media/boe/files/quarterly-bulletin/2016/stress-testing-of-banks-an-introduction.pdf. [Accessed: 11.10.2021]

Bank of England (2019). *Enhancing banks' and insurers' approaches to managing the financial risks from climate change.* Available at: bankofengland.co.uk/prudential-regulation/publication/2019/enhancing-banks-and-insurers-approaches-to-managing-the-financial-risks-from-climate-change-ss. [Accessed: 05.10.2021]

Bank of England (2019). *Supervisory Statement | SS3/19 Enhancing banks' and insurers' approaches to managing the financial risks from climate change.* Available at: bankofengland.co.uk/prudential-regulation/publication/2019/enhancing-banks-and-insurers-approaches-to-managing-the-financial-risks-from-climate-change-ss. [Accessed: 05.10.2021]

Bank of England (2019). *The 2021 biennial exploratory scenario on the financial risk from climate change.* Available at: Discussion Paper: The 2021 biennial exploratory scenario on the financial risks from climate change (bankofengland.co.uk). [Accessed: 05.10.2021]

Bank of England (2020). *Update on the Bank's approach to the Climate Biennial Exploratory Scenario in selected areas.* Available at: bankofengland.co.uk/-/media/boe/files/stress-testing/2020/update-on-the-banks-approach-to-the-climate-biennial-exploratory-scenario. [Accessed: 05.10.2021]

Bank of England (2021). *Guidance for participants of the 2021 Biennial Exploratory Scenario: Financial risks from climate change*. Available at: bankofengland.co.uk/-/media/boe/files/stress-testing/2021/the-2021-biennial-exploratory-scenario-on-the-financial-risks-from-climate-change.pdf?la=en&hash=2E5CAECE75E701315B51B09303F99FCF8D21C8E2. [Accessed: 05.10.2021]

Bank of England (2021). *Key elements of the 2021 biennial exploratory scenario: Financial risks from climate change.* Available at: bankofengland.co.uk/stress-testing/2021/key-elements-2021-biennial-exploratory-scenario-financial-risks-climate-change. [Accessed: 05.10.2021]

Banque de France (2020). *Climate-Related Scenarios for Financial Stability Assessment: an Application to France.* Banque de France. Available at: publications.banque-france.fr/sites/default/files/medias/documents/wp774.pdf. [Accessed: 05.10.2021]

BIS (2009). *Principles for sound stress testing practices and supervision.* Available at: bis.org/publ/bcbs155.pdf. [Accessed: 05.10.2021]

BIS (2020). *Calculation of RWA for credit risk.* Bank for International Settlement. Available at: bis.org/basel_framework/chapter/CRE/53.htm. [Accessed: 05.10.2021]

BIS (2021). *Stress-testing banks for climate change – a comparison of practices.* Bank for International Settlement. Available at: bis.org/fsi/publ/insights34.htm. [Accessed: 05.10.2021]

BPI (2020). *Challenges in Stress Testing and Climate Change.* Available at: bpi.com/challenges-in-stress-testing-and-climate-change/. [Accessed: 05.10.2021]

Carbonbrief (2019). *Explainer: The high-emissions RCP8.5 global warming scenario.* Available at: carbonbrief.org/explainer-the-high-emissions-rcp8-5-global-warming-scenario. [Accessed: 05.10.2021]

CDC (2021). *Climate Effects on Health.* Available at: cdc.gov/climateandhealth/effects/default.htm. [Accessed: 11.10.2021]

CICERO (2017). *Shades of Climate Risk: Categorizing climate risk for investors*. Available at: pub.cicero.oslo.no/cicero-xmlui/bitstream/handle/11250/2430660/Shades%20of%20Climate%20Risk%20nyformatting%20(Sistetil%20web13%2002%202016).pdf?sequence=1&isAllowed=y. [Accessed: 12.10.2021]

CISL (2021) *The essential guide to bank-client engagement.* Cambridge University. Available at: cisl.cam.ac.uk/resources/sustainable-finance-publications/lets-discuss-climate-the-essential-guide-to-bank-client-engagement. [Accessed: 05.10.2021]

Climate Risk Review (2020). *One direction: which way to effective climate stress tests?* Available at: climateriskreview.com/p/one-direction-which-way-to-effective. [Accessed: 05.10.2021]

Danmarks Nationalbank (2020). *A gradual green transition supports financial stability.* Available at: nationalbanken.dk/en/publications/Documents/2020/11/ANALYSIS_No.21_A%20gradual%20green%20transition%20supports%20financial%20stability.pdf#search=climate. [Accessed: 05.10.2021]

Deloitte (2020). *Climate change stress testing*. Available at: www2.deloitte.com/cn/en/pages/risk/articles/climate-change-stress-testing.html. [Accessed: 11.10.2021]

De Nederlandsche Bank (2018). *An energy transition risk stress test for the financial system of the Netherlands.* Available at: dnb.nl/media/pdnpdalc/201810_nr-_7_-2018-_an_energy_transition_risk_stress_test_for_the_financial_system_of_the_netherlands.pdf. [Accessed: 05.10.2021]

EBA (2018). *Final report: Guidelines on institutions' stress testing.* EBA. Available at: eba.europa.eu/sites/default/documents/files/documents/10180/2282644/2b604bc8-fd08-4b17-ac4a-cdd5e662b802/Guidelines%20on%20institutions%20stress%20testing%20(EBA-GL-2018-04).pdf?retry=1. [Accessed: 05.10.2021]

EBA (2018). *Guidelines on stress testing*. Available at: eba.europa.eu/regulation-and-policy/supervisory-review-and-evaluation-srep-and-pillar-2/guidelines-on-stress-testing2. [Accessed: 05.10.2021]

EBA (2021). *EBA launches public consultation on draft technical standards on Pillar 3 disclosures of ESG risks.* Available at: eba.europa.eu/eba-launches-public-consultation-draft-technical-standards-pillar-3-disclosures-esg-risks. [Accessed: 05.10.2021]

EBA (2021). *EBA published its report on management and supervision of ESG risks for credit institutions and investments firms*. Available at: eba.europa.eu/eba-publishes-its-report-management-and-supervision-esg-risks-credit-institutions-and-investment. [Accessed: 05.10.2021]

ECB (2020). *Guide on climate-related and environmental risks: Supervisory expectations relating to risk management and disclosure.* European Central Bank Banking Supervision. Available at: bankingsupervision.europa.eu/ecb/pub/pdf/ssm.202011finalguideonclimate-relatedandenvironmentalrisks~58213f6564.en.pdf. [Accessed: 05.10.2021]

ECB (2021). *Climate-related risk and financial stability.* European Central Bank. Available at: ecb.europa.eu/pub/pdf/other/ecb.climateriskfinancialstability202107~87822fae81.en.pdf. [Accessed: 05.10.2021]

ECB (2021). *Patchy data is a good start: from Kuznets and Clark to supervisors and climate.* European Central Bank. Available at: bankingsupervision.europa.eu/press/speeches/date/2021/html/ssm.sp210616~a39a86eeb2.en.html. [Accessed: 05.10.2021]

ECB (2021). Shining a light on climate risks: the ECB's economy-wide climate stress test. European Central Bank. Available at: ecb.europa.eu/press/blog/date/2021/html/ecb.blog210318~3bbc68ffc5.en.html. [Accessed: 05.10.2021]

ECB (2021). *Occasional Paper Series. ECB economy-wide climate stress test. Methodology and results.* European Central Bank. Available at: ecb.europa.eu/pub/pdf/scpops/ecb.op281~05a7735b1c.en.pdf. [Accessed: 11.10.2021]

FCA (2020). *Guide 2020 Scenario Analysis Chapter.* Available at: fca.org.uk/publication/corporate/climate-financial-risk-forum-guide-2020-scenario-analysis-chapter.pdf. [Accessed: 05.10.2021]

FCA (2020). *Risk Management Chapter.* Available at: fca.org.uk/publication/corporate/climate-financial-risk-forum-guide-2020-risk-management-chapter.pdf. [Accessed: 05.10.2021]

FCA (2021). *Climate-related reporting requirements.* Available at: fca.org.uk/firms/climate-change-sustainable-finance/reporting-requirements. [Accessed: 05.10.2021]

FCA (2021). *FCA consults on further climate-related disclosure rules.* Available at: fca.org.uk/news/press-releases/fca-consults-further-climate-related-disclosure-rules. [Accessed: 05.10.2021]

Finbarr Bermingham (2021). *China's central bank chief Yi Gang says climate-related stress test results will be released.* South China Morning Post. Available at: scmp.com/knowledge/china-macro-economy?module=section_masthead&pgtype=article. [Accessed: 05.10.2021]

FSB (2017). *Technical Supplement. The use of scenario analysis in disclosure of climate-related risks and opportunities.* Available at: Technical-Supplement-1.pdf (fsb.org). [Accessed: 05.10.2021]

GOV.UK (2021). *Mandatory climate-related financial disclousres by publicly quoted companies, large private companies and LLP's*. Available at: gov.uk/government/consultations/mandatory-climate-related-financial-disclosures-by-publicly-quoted-companies-large-private-companies-and-llps. [Accessed: 05.10.2021]

Greenhouse Gas Protocol (2021). *Calculation tool.* Available at: ghgprotocol.org/ghg-emissions-calculation-tool. [Accessed: 05.10.2021]

HKMA (2020). *Climate risk stress test.* Available at: hkma.gov.hk/media/eng/doc/key-information/guidelines-and-circular/2020/20201204e1.pdf. [Accessed: 05.10.2021]

HKMA (2020). *Range of practices for management of climate risks.* Available at: hkma.gov.hk/media/eng/doc/key-information/guidelines-and-circular/2020/20200707e1a1.pdf. [Accessed: 05.10.2021]

I4CE (2021). *The integration of transition risk drivers at a sectoral level: new perspectives for climate stress tests and other climate risk management tools.* Institute for Climate Economics. Available at: i4ce.org/wp-core/wp-content/uploads/2021/07/Rapport-IntegrationFacteurRisque-VA.pdf. [Accessed: 11.10.2021]

IFRS (2021). *IFRS Foundation Trustees announce working group to accelerate convergence in global sustainability reporting standards focused on enterprise value.* Available at: ifrs.org/news-and-events/news/2021/03/trustees-announce-working-group/. [Accessed: 05.10.2021]

IIF (2021). *Navigating Climate Headwinds: Reference Approaches for scenario-based Climate Risk Measurement by banks and supervisors.* Available at: iif.com/Publications/ID/4506/Navigating-Climate-Headwinds-Reference-Approaches-for-Scenario-based-Climate-Risk-Measurement-by-Banks-and-Supervisors. [Accessed: 05.10.2021]

International Energy Agency (2020). *World Energy Model.* Available at: World Energy Model—Analysis—IEA. [Accessed: 05.10.2021]

International Energy Agency (2020). *World Energy Model Documentation.* Available at: iea.blob.core.windows.net/assets/bc4936dc-73f1-47c3-8064-0784ae6f85a3/WEM_Documentation_WEO2020.pdf. [Accessed: 05.10.2021]

International Energy Agency (2021). *Net zero by 2050.* Available at: Net Zero by 2050—Analysis—IEA. [Accessed: 05.10.2021]

International Energy Agency (2021). *Sustainable Development Scenario.* Available at: iea.org/reports/world-energy-model/sustainable-development-scenario#:~:text=The%20IEA%E2%80%99s%20Sustainable%20Development%20Scenario%20%28SDS%29%20outlines%20a,deliver%20on%20the%20three%20main%20energy-related%20SDGs%20simultaneously. [Accessed: 12.10.2021]

Investopia (2020). *Exposure at Deafault.* Available at: investopedia.com/terms/e/exposure_at_default.asp. [Accessed: 05.10.2021]

IPCC (2021). *Future Climate Changes, Risks and Impacts.* Available at: ar5-syr.ipcc.ch/topic_futurechanges.php. [Accessed: 05.10.2021]

IPCC (2021). Climate Change 2021: The Physical Science Basis. Available at: ipcc.ch/report/sixth-assessment-report-working-group-i/. [Accessed: 12.10.2021]

Laura Singleton (2020). *Business School establishes new Singapore Green Finance Centre*. Imperial College London. Available at: imperial.ac.uk/news/206473/business-school-establishes-singapore-green-finance/.[Accessed: 05.10.2021]

MAS (2021). *"Being the Change We Want to See: A Sustainable Future". Speech by Mr Ravi Menon, Managing Director, Monetary Authority of Singapore, at Launch of Inaugural MAS Sustainability Report via Video Conference on 9 June 2021.* Available at: mas.gov.sg/news/speeches/2021/a-sustainable-future. [Accessed: 05.10.2021]

NGFS (2020). *Guide to climate scenario analysis for central banks and supervisors.* Available at: ngfs.net/sites/default/files/medias/documents/ngfs_guide_scenario_analysis_final.pdf. [Accessed: 05.10.2021]

NGFS (2021). *NGFS climate scenarios for central banks and supervisors.* Available at: ngfs.net/sites/default/files/media/2021/08/27/ngfs_climate_scenarios_phase2_june2021.pdf. [Accessed: 05.10.2021]

NGFS (2021). *Progress report on bridging data gaps.* Available at: ngfs.net/sites/default/files/medias/documents/progress_report_on_bridging_data_gaps.pdf. [Accessed: 05.10.2021]

NGFS (2021). *Scenarios in Action: a progress report on global supervisory and central bank climate scenario exercises*. Available at: ngfs.net/en/scenarios-action-progress-report-global-supervisory-and-central-bank-climate-scenario-exercises. [Accessed: 20.10.2021]

OSFI (2009). *Stress Testing.* Government of Canada. Available at: osfi-bsif.gc.ca/Eng/fi-if/rg-ro/gdn-ort/gl-ld/Pages/e18.aspx. [Accessed: 05.10.2021]

Open Risk Manuel (2016). *Bottom-Up versus Top-Down Stress Test.* Available at: openriskmanual.org/wiki/Bottom-Up_versus_Top-Down_Stress_Test. [Accessed: 11.10.2021]

PCAF (2020). *The Global GHG Accounting & Reporting Standard*. Available at: carbonaccountingfinancials.com/files/downloads/PCAF-Global-GHG-Standard.pdf. [Accessed: 05.10.2021]

Pierpaolo Grippa, Jochen Schmittmann, and Felix Suntheim (2019). *Climate Change and Financial Risk.* International Monetary Fund. Available at: imf.org/external/pubs/ft/fandd/2019/12/pdf/climate-change-central-banks-and-financial-risk-grippa.pdf. [Accessed: 11.10.2021]

Pierpaolo Grippa, Samuel Mann (2021). *Climate-Related Stress Testing: Transitions Risks in Norway.* International Monetary Fund. Available at: imf.org/en/Publications/WP/Issues/2020/11/08/Climate-Related-Stress-Testing-Transition-Risks-in-Norway-49835. [Accessed: 11.10.2021]

RCP Database (2021). *Version 2.0.* Available at: tntcat.iiasa.ac.at/RcpDb/dsd?Action=htmlpage&page=welcome. [Accessed: 05.10.2021]

SSRN (2020). *Climate-related scenarios for financial stability assessment: An application to France.* Available at: papers.ssrn.com/sol3/papers.cfm?abstract_id=3653131. [Accessed: 05.10.2021]

TCFD (2017). *Recommendations of the Task Force on Climate-related Financial Disclosures*. Available at: assets.bbhub.io/company/sites/60/2020/10/FINAL-2017-TCFD-Report-11052018.pdf. [Accessed: 05.10.2021]

TCFD (2017). *The use of Scenario analysis in disclosure of Climate-related risks and opportunities.* Available at: FINAL-TCFD-Technical-Supplement-062917.pdf (bbhub.io). [Accessed: 05.10.2021]

TCFD (2020). *Guidance on Risk Management Integration and Disclosure*. TCFD. Available at: assets.bbhub.io/company/sites/60/2020/09/2020-TCFD_Guidance-Risk-Management-Integration-and-Disclosure.pdf. [Accessed: 05.10.2021]

TCFD (2021). *Forward-looking financial metrics consultation.* Available at: assets.bbhub.io/company/sites/60/2021/03/Summary-of-Forward-Looking-Financial-Metrics-Consultation.pdf. [Accessed: 05.10.2021]

Thomson et. Al, (2011). *RCP4.5: A Pathway for Stabilization of Radiative Forcing by 2100*. Atmospheric System Research. Available at: ASR—Atmospheric System Research (energy.gov). [Accessed: 05.10.2021]

UNEP FI (2021). *Pathways to Paris*. Available at: unepfi.org/wordpress/wp-content/uploads/2021/02/UNEP-FI-Pathways-to-Paris.pdf. [Accessed: 05.10.2021]

Van Vuuren et. al., (2011). *The representative concentration pathways: an overview.* Springer Link. Available at: link.springer.com/article/10.1007/s10584-011-0148-z. [Accessed: 05.10.2021]

World Resources Institute & World Business Council for Sustainable Development (2004). *GHG Protocol Corporate Accounting and Reporting Standard.* Available at: ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf. [Accessed: 05.10.2021]

UN environment programme

finance initiative

United Nations Environment Programme Finance Initiative (UNEP FI) is a partnership between UNEP and the global financial sector to mobilise private sector finance for sustainable development. UNEP FI works with more than 400 members—banks, insurers, and investors—and over 100 supporting institutions– to help create a financial sector that serves people and planet while delivering positive impacts. We aim to inspire, inform and enable financial institutions to improve people's quality of life without compromising that of future generations. By leveraging the UN's role, UNEP FI accelerates sustainable finance.

unepfi.org

unepfi.org

info@unepfi.org

/UNEPFinanceInitiative

United Nations Environment Finance Initiative

@UNEP_FI