TC NOTES

PRACTICAL **LEADERSHIP**
AND **GUIDANCE** FROM
TORONTO CENTRE

INTRODUCTION FOR SUPERVISORS TO SCENARIOS AND STRESS TESTS OF CLIMATE CHANGE RISKS

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INTRODUCTION FOR SUPERVISORS TO SCENARIOS AND STRESS TESTS OF CLIMATE CHANGE RISKS

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INTRODUCTION FOR SUPERVISORS TO SCENARIOS AND STRESS TESTS OF CLIMATE CHANGE RISKS

Introduction[1]

Climate-related events and their associated risks are subject to significant uncertainty in their timing, frequency, and severity. Forward-looking assessment approaches are crucial to adequately account for the unprecedented nature of climate change. Against this backdrop, scenario analysis and stress testing are critical tools for assessing the potential implications of climate change on economies, financial institutions, and financial systems.

As part of their oversight of financial institutions, markets or instruments, and financial stability, supervisors need to understand the uncertain nature of climate risks, and the tools available to assess these risks.[2] This Toronto Centre Note introduces financial sector supervisors to scenarios and stress testing of climate risks. The Note complements Toronto Centre (2020) on climate stress testing by providing detailed background on climate scenarios, and practical guidance on the design of climate stress tests.

The next section introduces the financial risks posed by climate change and explains the role of scenarios and stress testing in assessing those risks. The third section discusses the design of climate scenarios, including those developed by the Network for Greening the Financial System (NGFS). The fourth section examines the issues in the design of climate stress tests.

Climate change risks and the role of scenarios and stress tests

This section briefly reviews the types of financial risks posed by climate change and explains the role of scenario analysis and stress testing in identifying those risks.

Financial risks posed by climate change

As has been elaborated in other Toronto Centre Notes,[3] climate change poses financial risks. In particular:

- ***Transition risks.*** These risks are associated with the transition to a lower carbon emissions economy, which would affect the value of assets, the viability of industries and sectors, and the prosperity of regions and national economies. Transition risks lead to concerns about so-called "stranded assets" – assets that would lose their value in the transition to a low-carbon economy. For example, a decision to phase out coal-fired

[1] This Toronto Centre note was prepared by R. Barry Johnston. Please address any questions about this Note to publications@torontocentre.org.
[2] Basel Committee (2022a), International Association of Insurance Supervisors (2021), International Organisation of Securities Commissions (2020).
[3] See for example Toronto Centre (2022a, 2022b and 2023).

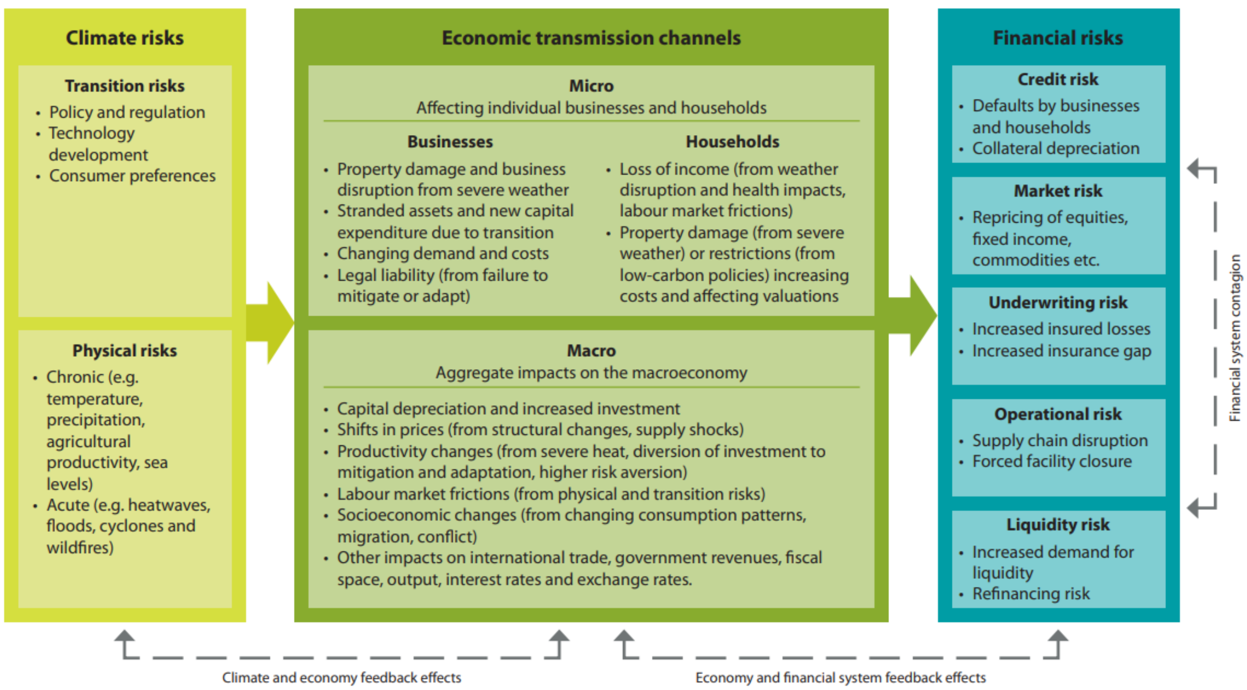
energy generation because of its carbon footprint may result in some coal extraction becoming nonviable.

- ***Physical risks***. These risks are associated with the damage caused by climate change to the physical environment and physical assets. An example is the impact of extreme weather events and sea level rise on higher insurance claims and lower collateral values in coastal communities.
- ***Systemic risks.*** These risks are associated with catastrophic tipping points due to potential non-linearities and feedback mechanisms. These risks have been characterized as "green swans", with many of the characteristics of "black swans" that are rare and unpredictable events that can trigger systemic financial crises due to complex interactions.

The above risks create microfinancial and macrofinancial risks, as reflected in the following chart showing the transmission of climate risks to financial risks.

Transmission channels

Climate risks to financial risks



Source: NGFS (2021).

As they oversee financial institutions, markets or instruments, financial supervisors will normally be concerned with how well financial institutions identify and manage financial risks (illustrated in the box to the right in the above chart).[4] Macroprudential authorities will be concerned with

[4] Supervisors may have other mandates, including for financial inclusion and gender equality, which may also be impacted by climate change. The chart illustrates the links between climate change and certain inherent risks and is not intended to provide a comprehensive overview of the transmission of climate risks to all areas of supervisory concern. As discussed later, climate stress testing has explored a subset of the inherent risks.

identifying and managing systemic risk associated with the feedbacks between the financial system, climate risks, and the macroeconomy.[5]

Traditionally, a range of techniques have been used to assess financial risks; many rely on historical data.[6] However, climate risks are subject to:

- an unusual degree of uncertainty;
- future risks that are likely to be very different from the past; and
- information gaps and methodological challenges.

Two tools have become important to assess financial institutions' exposures to climate change risks: scenario analysis and stress testing. The climate scenarios explore the implications of a range of possible climate paths for physical and transition risks and for economic variables. The scenarios help investigate both the uncertainty and the future paths for climate risks. The scenarios provide input on variables that are presented in the first two boxes in the above chart: the physical and transition risks and the impact on economic variables.

Financial risks (illustrated in the box to the right in the chart) will be specific to financial institutions and portfolios, determined by individual balance sheets and asset/liability exposures. To assess the financial risks, the scenarios need to be mapped to the individual balance sheets/asset/liability exposures. This is the role of stress tests. The preparation of stress tests also helps identify the information needs and gaps for assessing climate risks, and since the assessment of climate risks is relatively new, to develop methodological techniques to assess those risks.

Uncertainty of climate risks

The first major source of climate risk uncertainty is associated with the future path of greenhouse gas (GHG) emissions. The pace and severity of climate change is driven primarily by the world's cumulative GHG emissions.[7] While cumulative GHG emissions are already causing global warming, their future path, and hence the path for global warming and climate change, is highly uncertain. It will depend on such factors as:

1. ***Public policy*** and the extent to which countries limit their GHG emissions to meet national and international climate objectives, including those set out in the 2015 Paris Climate Agreement (PCA) to keep global warming below two degrees centigrade. Countries make their climate commitments known in their Nationally Determined Commitments under the PCA. Public policy initiatives to limit GHG emissions include carbon taxes, subsidies for green (low-GHG-emitting) energy and technologies, including carbon capture, and laws banning or limiting brown (high-GHG-emitting) activities.

   The global nature of emissions policy adds to the nature of climate uncertainty. Effectively mitigating emissions, and the physical risk of climate change, requires global action, which is the rationale behind the PCA and subsequent negotiations. Transition risks, however, generally reflect policies at the national level. Thus, a firm could confront extremely tough national emissions reductions, creating significant transition risk, while

[5] See Toronto Centre (2022a).
[6] For a discussion of the relation between micro and macroprudential risks, see Toronto Centre (2021).
[7] IPCC (2021).

emissions overall continue a trajectory due to the inaction of other countries, leading to extreme physical risk.

2. ***Technological advances*** in green energy production, including technologies for carbon capture. Such technological advances will change the economics of using brown compared with green production processes. Advances in technologies would mean that brown technologies would increasingly be replaced with green technologies, and that a given level of output could be achieved with lower (potentially much lower) GHG emissions. For example, solar and wind power are replacing coal-produced electricity as they have become cheaper.

3. ***The level of economic activity.*** GHG emissions are closely associated with the overall level of economic activity. For example, GHG emissions fell in 2020 during the economic slowdown caused by the COVID-19 pandemic. The future path of GHG emissions will depend on the future level of economic growth, which itself will be impacted by climate change.

4. ***Consumer and business preferences.*** Consumers and businesses may value green products over brown in their purchases and lifestyle/production and investment choices. Examples include consumer preferences to drive electric vehicles (EVs), and business decisions to source their energy needs from renewables rather than fossil fuels.

The above factors are not only important in driving the path for GHG emissions and global warming, but also for the speed of transition from brown to green assets. This also affects the timing and size of the ***transition risks***, and over the longer term the magnitude of ***physical risks***.

The second major source of climate risk uncertainty is associated with the impact of climate change on weather patterns and sea level rise that create ***physical risks***. Extrapolating risks and losses associated with historical weather patterns may not accurately predict future weather-related risks and losses in the face of climate change.

The IPCC (2021) states that many changes in the climate system - including increases in the frequency and intensity of hot extremes, marine heatwaves, heavy precipitation, cyclones, and droughts - become larger in direct relation to global warming caused by concentrations of GHGs in the atmosphere. As global warming increases, chronic changes in climate may also amplify the impact of extreme events. For example, continued sea level rise may increase the typical levels of storm surge associated with a hurricane of a given intensity.

In addition, currently rare compound extreme events (separate extreme events affecting one location repeatedly or multiple locations simultaneously) may become more frequent, and there will be a higher likelihood of events with increased intensities, durations, frequencies, and/or spatial extents unprecedented in the observational record. Increasing physical risks are already becoming evident in many countries, and will intensify over time, but in ways that are hard to predict.

The third major source of uncertainty is associated with potential ***interdependencies and tipping points*** that amplify risk exposures because of the effects of climate change. Some of the interdependencies and tipping points result from interactions in the natural world, between higher global temperatures and factors impacting the major sources of physical risks, such as the speed of sea level rise. (These tipping points are discussed further below.)

Global warming is also a major cause of **biodiversity loss**, an additional source of physical and transition risk not explicitly accounted for in the current climate models. Other interdependencies are the result of policy actions, such as decisions to speed up the transition to a green economy because of intensifying physical risks. Still other interdependencies are the result of interconnections within the financial system. An example is the impact of climate change on coastal communities from the combination of sea level rise and exposure to more intense storms. If the exposure of these communities results in the withdrawal of property insurance coverage, this would transfer the risk of property losses from insurance companies to banks that have issued the household mortgages.

The future will be different from the past: limitations of statistical modelling

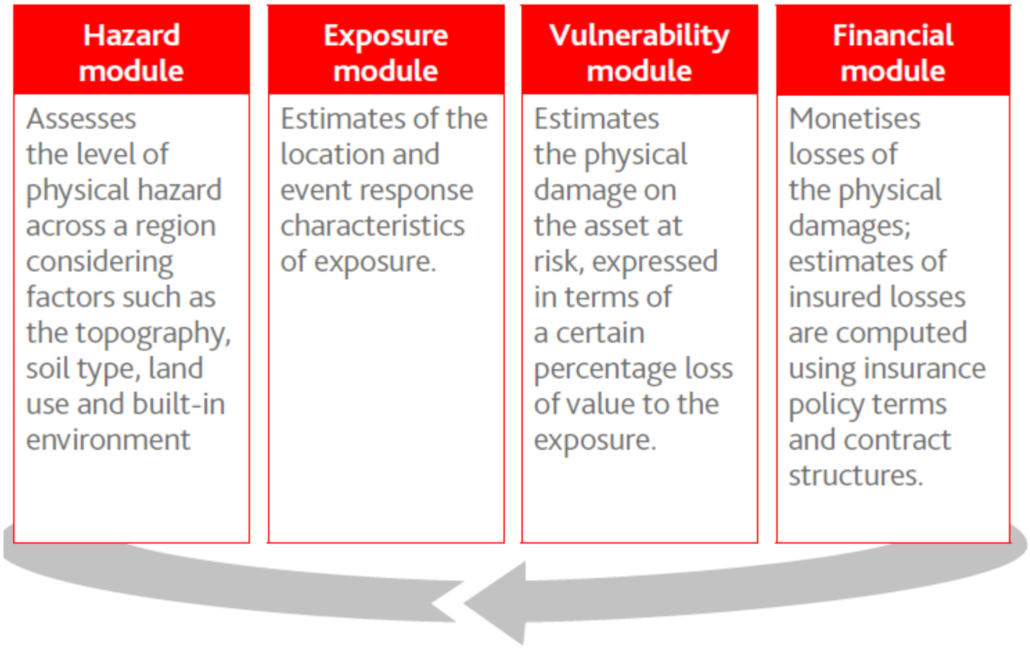
A critical tool in assessing financial risks is statistical modelling using historical data. Based on the assumption that the future will behave similarly to the past, historical data can be used to forecast future outcomes. Examples of statistical modelling include probabilities of default, expected losses given default, and value at risk. Statistical modelling underlies decisions on how much provisions to hold to cover expected losses on loans and capital to hold against unexpected losses.

An example of statistical modelling illustrating the considerations relevant to assessing the physical risks from climate change is the catastrophic loss (CAT) model used by (re)insurance companies. CAT models evolved in the 1980s because of:

- (i) scientific progress understanding natural hazards and their meteorological, hydrological, climatological, and geological characteristics;
- (ii) engineering research and testing relating to the impact of hazards on the built environment; and
- (iii) progress with geographic information systems.

Traditionally, CAT models have relied on statistical techniques using empirical (observed) historical data of physical events.

CAT models generally involve four elements:
(1) a hazard module assessing the level of physical hazard across a region;
(2) an exposure module reflecting location within the region;
(3) a vulnerability module that estimates the percentage loss of the asset at risk; and
(4) a financial module that monetizes the losses from physical damage based on insurance policy terms and contract structures.



Source: The Geneva Association

Conceptually, the CAT framework for modelling losses is useful for evaluating the losses from the physical risks of climate change. However, its applicability is restricted by the model's reliance on historical data to calibrate the losses, and by potential cascading effects and interdependencies of hazards and interaction between natural, technological, and critical infrastructure failures. Because the future risks of physical losses will be magnified by climate change, the use of historical data to calibrate the CAT models can significantly underestimate the financial losses.

Various proposals suggest ways to adapt the CAT modeling framework to the physical risks of climate change.[8] Actuarial recommendations to assess the impact of climate risks emphasize the importance of using scenarios and stress testing.[9]

While statistical modelling techniques are the backbone of traditional risk analysis, their applicability to climate risk is limited. As the risks from climate change have barely started to materialize, standard approaches to modelling financial climate risk using statistical techniques will lead to the mispricing of risks.

Use of scenarios in assessing climate risks

Scenario analysis is designed to build understanding of future risks. Scenarios describe ***hypothetical*** future paths. They are not predictions or forecasts, such as might be generated by a statistical model based on historical data. Scenarios explore emerging risks in an uncertain

[8] See Geneva Association (2018).
[9] International Actuarial Association (2021).

future. Using a variety of scenarios can enhance critical thinking about the future. Scenarios support both qualitative and quantitative analyses of risks, including stress testing.

Sensitivity analysis

Before discussing the design of climate scenarios, it is useful to mention the technique of sensitivity analysis, which could be applied to climate risks. Sensitivity analysis examines the impact of single or multiple factors on the balance sheets of financial institutions.

- **Sensitivity analysis:** One or more moves in a particular risk factor, or a small number of risk factors that impact the balance sheet of the financial institution. For example, an assumed change in the exchange rate or interest rate.
- **Scenario testing:** Simultaneous moves in several risk factors impacting the balance sheets of financial institutions, linked to explicit changes in the view of the world.

An example of a sensitivity stress test would be to ask financial institutions to assess the impact on their portfolio of a one notch down grade in the credit ratings of their clients, or for banks to assess the impact of a one notch down grade in the quality of their loan portfolio.

Sensitivity analysis can be used to capture some features of climate-related risks. For example, the Bank of England (2019b) requested that insurance companies examine the impact of three broad categories of climate scenarios on their asset portfolios. The scenarios comprised:

A: sudden and disorderly transition;

B: progressive and orderly transition;

C: no transition.

For each of these scenarios, the Bank of England assigned a change in the equity value of investments in the fuel extraction and power generation sectors (see the following table) and asked the insurance companies to assess the impact on the asset side of their portfolios. The results would help to inform potential insurance company exposures to the transition risks from climate change.

Sensitivity analysis

Sector	% of investment portfolio in following sectors	Assumptions	Transition risk		
			Scenario		
			A	B	C
Fuel extraction	Gas/coal/oil (incl crude)	Change in equity value for sections of the investment portfolio comprising material exposure to the energy sector as below			
		Coal	–45%	–40%	
		Oil	–42%	–38%	
		Gas	–25%	–15%	
Power generation		Coal	–65%	–55%	
		Oil	–35%	–30%	
		Gas	–20%	–15%	
		Renewables (incl nuclear)	+10%	+20%	

Source: Bank of England (2019b)

Sensitivity analysis is useful for peer group analysis, as the same stress assumptions are applied across financial institutions. It is also useful to examine idiosyncratic shocks that fall outside statistical parameters. The shortcoming is that the design of the shock may be considered arbitrary, as it may not be based on a scientific model.

For jurisdictions with limited implementation capacities, sensitivity analysis may nevertheless provide a good starting point to examine climate risks. The size of the shocks for the sensitivity test could be derived from climate scenario databases, where information is available for the jurisdiction (for example, the NGFS scenarios discussed below); or lacking this, data from other jurisdictions facing similar climate risks.

Scenario analysis

The benefits of scenario analysis as applied to climate change are that scenarios can:

- Explore the most significant effects of climate change likely to emerge over medium- to longer-term time horizons;
- Explore the consequences of different potential paths and outcomes that reflect the uncertainty over the timing and magnitude of adjustments to climate change;
- Take into account potential complex interactions between changes in the climate and the economic environment in adapting to climate change; and
- Integrate climate science with macroeconomic and financial sector analysis. This allows for the generation of economic and financial sector variables (GDP, interest rates, exchange rates, sectoral activity, agricultural and labor productivity, etc) consistent with the climate projections.

The scenarios can be seen as the best scientific effort to understand and model the effects of climate change on national economies. They go beyond sensitivity analysis to provide the scientific basis to calibrate the shocks and generate a consistent set of shocks that can be used to stress-test financial institutions.

Designing climate scenarios

The Task Force on Climate-Related Financial Disclosures issued guidance on the use of scenario analysis in the disclosure of climate related financial risks.[10] They outlined five desirable elements in designing climate scenarios, namely that the scenarios should be:

- Plausible – the events described in the scenarios are possible and the narratives are credible.
- Consistent – there is a strong internal logic in the scenarios.
- Relevant – the scenarios should contribute insights into the implications of climate change on the natural and economic environment.
- Challenging – the scenarios should challenge conventional wisdom and simplistic assumptions about the future (such as simple extrapolation of historical trends).
- Distinctive – the scenarios should allow for different combinations of key factors so as to explore the range of possible outcomes from climate change.

Plausibility and consistency in the scenarios can be established by building models to represent the economic, social, and natural environment. The model frameworks should reflect a consistent understanding of the functioning of the natural, social, and economic environments, with a strong internal logic.

Models are necessarily abstractions with many possible model designs. What is important is that the models are "fit for purpose" in both theory and practice, and have been thoroughly vetted in the scientific community, so the results generated (even if extreme) will be plausible.

The relevant and challenging characteristics of the scenarios can be introduced through the parameters and assumptions used in the simulation; for example, the path for GHG emissions. Distinctive features can be introduced as part of model design to explore different aspects of the effects of climate change and different interactions. The different models should include explanations of their significant limitations, since various trade-offs are inevitable in design.

Technical considerations in designing climate scenarios

Climate scenarios combine knowledge of the atmospheric and natural environment with that of the social and economic environment to project the impact of climate change on economic activity and exposures to transition and physical risks. The technical analysis provides a range of possible outcomes, which need to be prioritized for the purpose of implementing climate stress tests (see below).

Developing the scenarios involves various building blocks. The common starting point in analyzing physical and transition risks are ***climate projections.*** Projections of GHG emissions determine different [representative] climate pathways (RCPs, for example those derived from

[10] See Task Force on Climate-related Financial Disclosures (2017b).

the work of the Intergovernmental Panel on Climate Change (IPCC 2021)). These GHG concentration trajectories represent a widely referenced set of projections about the range of possible governmental policies and socioeconomic trends developed with input from domestic and international climate experts. The IPCC climate projections are the starting point for most climate scenario analysis.

The IPCC identified four key temperature pathways for future GHG emissions. These represent a reasonable range of possible future states:

- RCP 2.6 is consistent with an ambitious reduction in emissions to limit global warming to less than two degrees Celsius (2°C) above pre-industrial levels, the goal of the Paris Agreement.
- RCP 4.5 is an intermediate emissions scenario. Emissions would increase modestly until 2040 before declining. It is likely to produce warming of about 2.4°C.
- RCP 6.0 is a high-intermediate scenario, where emissions peak around 2060 and decline thereafter. It is likely to produce warming of about 2.8°C.
- RCP 8.5 is a scenario assuming little action to reduce emissions. It is likely to produce warming of about 4.3°C. While extreme, it is not intended to represent a worst-case scenario.

Physical risks are often modelled using damage functions that relate the RCPs to losses from physical damage. The projections of physical damage usually distinguish between:

- ***Acute impacts*** from extreme weather events, which can lead to business disruption and damages to property and infrastructure, increase underwriting risks for insurers, and impaired asset values; and

- ***Chronic impacts***, particularly from increased temperatures, sea level rise, and precipitation, affecting labor, capital, land, and natural capital These changes will require a significant level of investment and adaptation from companies, households, and governments.

The physical risks for specific jurisdictions are derived from projections of the weather patterns impacting those jurisdictions under the different RCPs.

The projections of transitions risks are typically modelled using ***Integrated Assessment Models*** (IAMs) that allow for the interactions between economic activity and emissions. IAMs combine macroeconomic, agriculture and land-use, energy, water, technological advances, and climate systems into a common numerical framework that enables the analysis of the complex and non-linear dynamics between these components. IAMs rely on calibration rather than econometric (historical data) estimation.[11]

A key variable linking the RCPs to economic variables in IAMs is the shadow price of carbon. More ambitious climate pathways imply lower GHG emissions and a higher shadow price of carbon. The advantage of IAMs is that they can calculate the shadow price of carbon along a reference path of output, emissions, and climate change. The shadow price of carbon is the key variable that drives the transition to a lower-carbon economy in the models and generates the transition risks in the scenarios.

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[11] See Nordhaus (2017).

Macroeconomic models use the output from the IAMs, including the shadow price of carbon, to generate projections for economic variables, GDP, interest rates, etc. The macroeconomic models may be designed at the national or regional level.

The scenario outputs generated through the above processes are model specific: the RCPs can lead to different projections of physical and transition risks and economic impacts depending on model design. For this reason, multiple scenario outputs may be generated for each RCP to account for different model designs and to reflect model uncertainty.

NGFS scenarios

The NGFS developed its climate scenarios to provide central banks and supervisors with a common starting point for analyzing climate risks under different future climate pathways. The NGFS scenarios reflect different combinations of economic, technological, and policy assumptions that generate projections for economic and financial variables like GDP growth and carbon prices.[12] Many financial authorities have used or adapted the NGFS scenarios for their climate scenario exercises.[13]

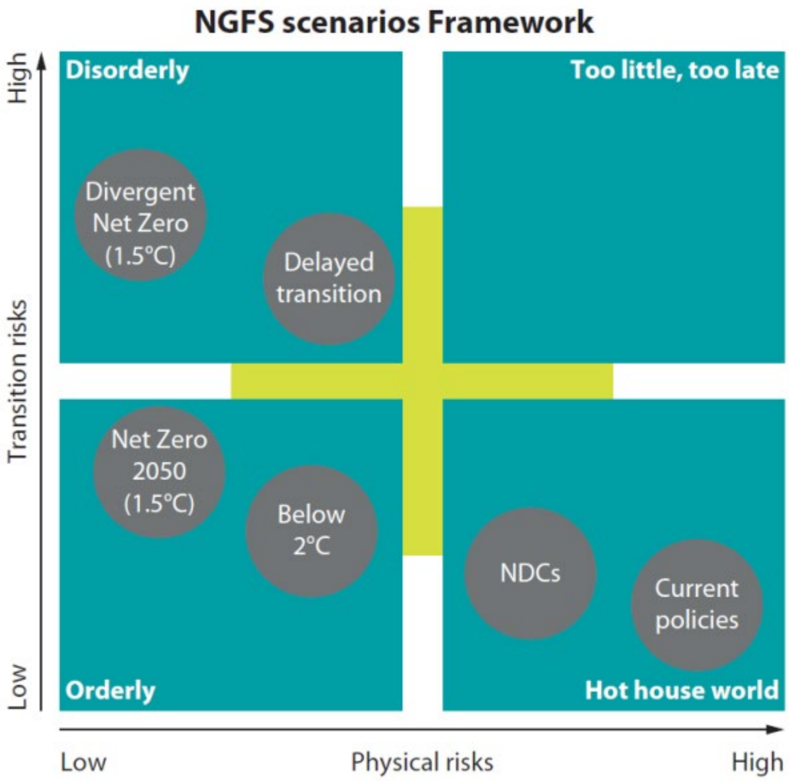
The NGFS scenarios represent different levels of physical and transition risks. These scenarios are neither forecasts nor policy prescriptions and do not necessarily represent the most likely future outcomes or a comprehensive set of possible outcomes. Rather, they represent a range of plausible future outcomes that can help build understanding of how certain climate-related financial risks could materialise, and how these risks may differ from the past.

NGFS distinguishes three main scenarios:

- ***Orderly***: Orderly scenarios assume climate policies are introduced early and become gradually more stringent. Both physical and transition risks are relatively subdued.
- ***Disorderly:*** Disorderly scenarios explore higher transition risk due to policies being delayed or divergent across countries and sectors. For example, carbon prices are typically higher for a given temperature outcome.
- ***Hot House World***: Hot House World scenarios assume that some climate policies are implemented in some jurisdictions, but efforts are insufficient globally to halt significant global warming. The scenarios result in severe physical risk, including irreversible impacts like sea-level rise.

The three main scenarios are further disaggregated (see graphic below). The implications of the different scenarios for the size of physical and transition risks are shown in the graphic.

[12] The NGFS developed its scenarios using three integrated assessment models (IAMs)—GCAM, MESSAGEix-GLOBIOM, and REMIND-MAgPIE—and a macroeconomic model, NiGEM. See NGFS (2021).
[13] Financial Stability Board (2022).



Source: NGFS (2021).

Each NGFS scenario explores a different set of assumptions for how climate policy, emissions, and temperatures evolve:

- **Net Zero 2050** limits global warming to 1.5°C through stringent climate policies and innovation, reaching global net zero CO2 emissions around 2050.
- **Below 2°C** gradually increases the stringency of climate policies, giving a 67% chance of limiting global warming to below 2°C.
- **Divergent Net Zero** reaches net zero around 2050 but with higher costs due to divergent policies introduced across sectors, leading to a quicker phase-out of oil use.
- **Delayed Transition** assumes annual emissions do not decrease until 2030. Strong policies are needed to limit warming to below 2°C. Negative emissions are limited.
- **Nationally Determined Commitments** include all pledged targets even if not yet backed up by implemented effective policies.
- **Current Policies** assumes that only currently implemented policies are preserved, leading to high physical risks.

The **Current Policies** scenario is the most adverse in terms of physical risks, while the **Net Zero 2050** scenario reflects a relatively smooth transition to net zero emissions by 2050. In the **Delayed Transition** scenario, emissions are only reduced after 2030, and hence require more rapid adjustments to limit the most severe physical impacts resulting in high transition risks.

The NGFS produces macroeconomic, financial, transition variables, and physical risk factors consistent with each scenario. These variables are available in the NGFS Scenarios Database hosted by the International Institute for Applied Systems Analysis and are available through the NGFS Scenarios Portal (2023).

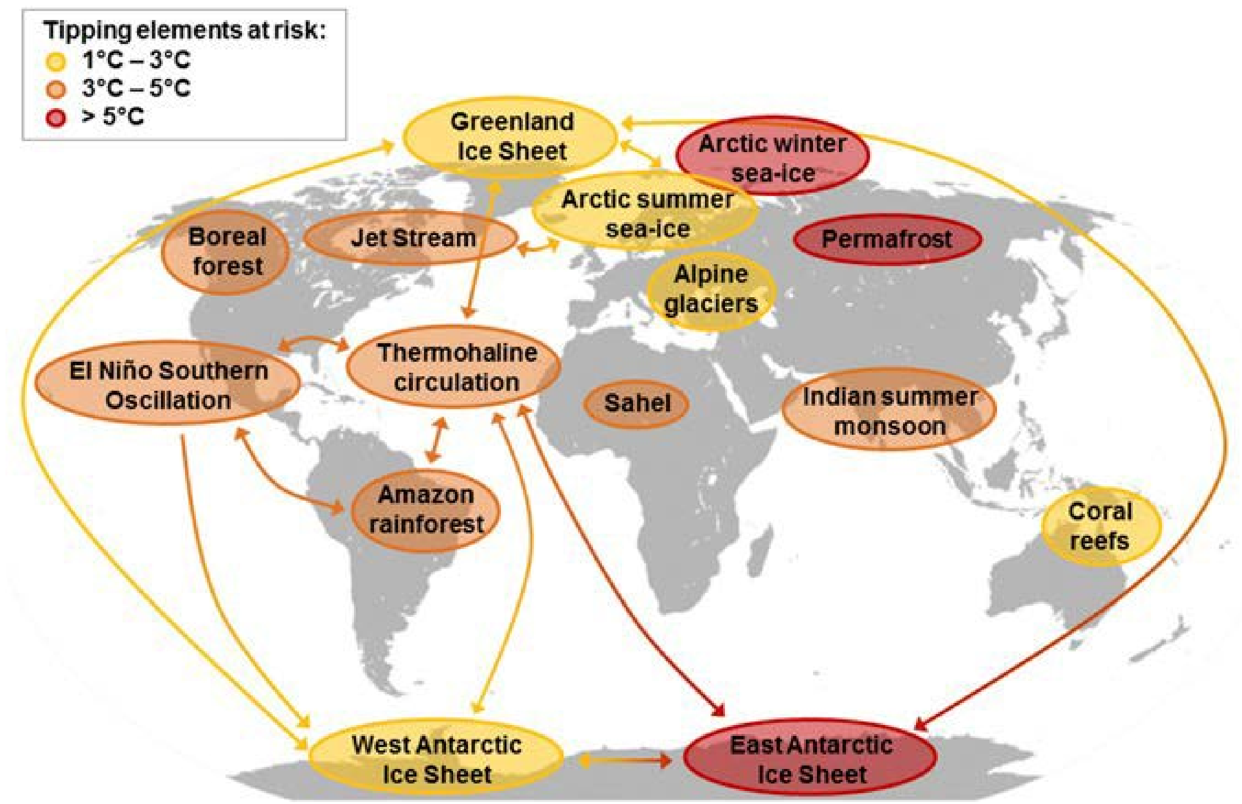
The exposures to physical risks are found on the ***NGFS Climate Impact Explorer***,[14] which provides data on a range of physical risks, such as exposures to extreme weather and impacts on agricultural yields, over different time horizons. The information is available for individual jurisdictions and in larger countries for sub regions. Transition and economic variables consistent with each NGFS scenario are available in the ***NGFS Scenarios Database.***[15] Detailed information on a range of economic and transition variables by jurisdiction is available for download.

Scenario limitations

The earth's climate is a complex, nonlinear system. Highly nonlinear systems can lead to chaotic dynamics, which are extremely difficult to model with any accuracy and confidence. As global warming continues, the world faces a situation of deep uncertainty related to the biogeochemical processes that can be triggered by climate change.

Various potential tipping points could dramatically worsen the effects of global warming (see graphic below). In the graphic, the individual tipping elements are colour-coded according to estimated thresholds in global average surface temperature. Arrows show the potential interactions that could generate cascades, based on expert assessment. Some potential tipping cascades are more likely to occur if there is global warming of between 1°C and 3°C, while others are more likely to occur if global warming exceeds 3°C or 5°C. Many tipping points may occur even if the world manages to keep global warming below 2°C.

[14] NGFS Scenarios Portal (2023).
[15] NGFS Scenarios Portal (2023).



Source: Adapted from Steffen et al (2018).

The risks of tipping points are not factored into current scenarios, nor are other potentially large sources of risk. For example, these might stem from an abrupt correction in asset prices when transition shocks result in fire sales of assets in exposed sectors.

Another consideration not explicitly considered in current climate scenarios is the relationship between climate change and biodiversity loss. While climate change is a recognized factor in biodiversity loss, and biodiversity loss creates both physical and transition risks, the relationship between climate change and biodiversity loss is analytically complex. The NGFS (2022) has recommended developing biodiversity scenarios drawing on experience with climate scenarios and taking more explicit account of biodiversity loss in climate scenarios.

Use of stress testing in assessing climate risk exposures

Stress testing is a risk management technique used to evaluate the potential effects on an institution's financial condition of a set of specified changes in risk elements, corresponding to exceptional but plausible factors. In the context of assessing climate risks, the exceptional risk factors are reflected in the climate scenarios. Stress testing is used to assess both financial institution specific risk (microprudential risks) and risks to the financial system (macroprudential risks.)

In designing climate stress tests, several issues need to be considered, including:

- Who should conduct the stress tests?
- What should be the objective and scope of the stress tests?
- What climate scenarios should be used as the basis for designing the stress tests?
- What information and methodologies should be used?
- What use should be made of the results of the stress tests?

As stress testing climate risks is still relatively new, the answers to some of these questions are being explored through pilot stress testing exercises.

Who should conduct the stress test?

Two types of stress testing are distinguished: "bottom-up" and "top-down." In a ***bottom-up*** exercise, the stress tests are performed by individual financial institutions using the information a financial institution possesses on the exposures on its own balance sheet, including proprietary information. In a ***top-down*** exercise, the stress test is performed by the supervisory authority (or the macroprudential authority to assess financial stability risk), using information it possesses on the individual financial institutions. Bottom-up and top-down stress tests are not mutually exclusive and may be combined as part of hybrid stress tests.

The bottom-up stress test can be based either on assumptions provided by the supervisory authority, or generated by the financial institution itself. The top-down stress test is based on assumptions generated by the supervisory (macroprudential) authority. Pilot climate stress tests discussed here have generally been based on assumptions provided by the authorities.

A bottom-up stress test is potentially richer, as it should incorporate a financial institution's proprietary information on exposures, hedges, and risk management strategies. For large and complex financial institutions, bottom-up stress tests are preferred. However, the consistency of the stress tests across financial institutions is harder to control in a bottom-up test than in a top-down test, and the results are more difficult to interpret across financial institutions because the specific stress testing techniques may vary between institutions. In the context of pilot climate stress tests, the learning aspects of the exercise may favor exploring different approaches and this may initially outweigh the benefits of imposing consistency. The supervisory authority should nevertheless ensure that stress testing techniques have been appropriately applied.

Whether bottom-up or top-down, stress test exercises provide learning opportunities. Bottom-up exercises will require a financial institution to develop an understanding of how climate risks will impact its business model and risk exposures, and to develop information and techniques to assess its climate risk exposures. Supervisors will likely be expected to provide guidance on how the financial institutions should conduct its stress tests and will also learn greatly from these exercises. In a top-down stress test, the supervisory/macroprudential authority will need to identify the relevant exposures to conduct the test and to develop the methodologies to be applied.

The choice between bottom-up and top-down may reflect objectives and resources. Where the primary objective is financial stability, this may be served initially by a top-down assessment. A top-down stress test to identify balance sheet weaknesses can be followed up with more detailed analysis involving individual financial institutions. Where expertise and resources are limited among financial institutions, as in some developing countries, the supervisor (macroprudential authority) may have to rely on top-down tests.

Objective and scope of stress testing exercises

Climate stress tests have varied widely in terms of scope and objectives, and have explored a range of physical and transition risk drivers to identify potential financial system vulnerabilities. As this area remains relatively new, most of the exercises have aimed to raise awareness and develop capabilities and capacity in climate risks assessment. While many authorities have included the assessment of financial stability as an explicit objective of their exercises, most have also identified data and methodological limitations that posed hurdles in conducting such assessments robustly.[16]

Generally, major banks (and to a less extent, large insurers) have been included in pilot stress tests run by the authorities. This reflects the importance of these institutions to financial stability, as well as the learning nature of the exercises. Climate stress tests that explore specific climate risks have examined broader groups of financial institutions to reach a more comprehensive assessment of exposures to those risks.[17]

Stress tests have explored banks' credit risks and insurers' liability and asset exposures. Banks are exposed to credit risks through the impact of physical and transitions risks on their clients' earnings and profitability, credit worthiness, collateral values, and the broader economic effects of climate change on their credit portfolios. Insurers are exposed to physical risk through claims on insured events and to physical and transition risks through the investment value of their asset portfolios and the assessment of credit risk. Physical risks may also have an impact on health and mortality rates.

What climate scenarios should be used as the basis for designing stress tests?

While jurisdictions can explore their own climate scenarios, the NGFS Scenarios (described above) play a critical role in supporting financial authorities' climate stress tests. Where jurisdictions use their own climate scenarios, the IPCC climate pathways are a common starting point, and the relationship with the NGFS scenarios is usually made explicit. The latter allow for cross-referencing to the NGFS scenario data base to support and enrich the national assessment.

In designing their climate stress tests, supervisors/macroprudential authorities will need to decide which of the range of possible climate pathways/scenarios to use for calibrating the stress tests. The IPCC offers a range of climate pathways, and the NGFS offers six climate scenarios.

As with other stress testing exercises, the authorities may be guided in their choice of scenarios by an assessment of the major tail (extreme but plausible) risks confronting their jurisdiction from climate change:

- In jurisdictions with large exposures to physical risks, the NGFS "Hot House World – Current Policies" scenario would capture potential tail risks from physical damage confronting the jurisdiction. However, in view of potential tipping points, even this scenario may not be considered extreme.

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[16] FSB-NGFS (2022)

[17] See, for example, the Banco Central do Brazil (2022) stress test of the exposure of credit portfolios to extreme drought.

- In jurisdictions with large exposures to transition risks, the NGFS "Disorderly – Divergent Net Zero" scenario could capture the tail risks. As transition risk is most closely associated with national climate polices, transition risk stress tests are often tailored to reflect potential major policy shifts to reduce GHG emissions.

The FSB-NGFS (2022) survey found that the most commonly used NGFS scenarios are Current Policies (Hot House World), Delayed Transition (Disorderly) and Net Zero 2050 (Orderly).

Physical and transition risks will emerge over time (and at different times, depending on mitigation actions taken), so future time frames should be specified when specific risks are evaluated. As physical risks will generally emerge over long time horizons, questions on the relevant time frame would include: what future point in time should be used to calibrate the physical risks, and what balance sheets should be used to assess those risks? As dynamic balance sheet projections are complicated, the physical (and transition) risks are generally assessed against current balance sheets. The future point in time used to calibrate the physical risks should allow for sufficiently severe physical risk. For example, the stress test could be based on potential future climate-related events in 2050 when the effects of physical risk drivers are likely to be more severe. This approach would test the resilience of participants' current balance sheets to a range of potential future climate outcomes.[18]

As for transition risks, shorter scenario horizons would be more suited for transition risks arising from abrupt policy changes and longer scenario horizons for medium-term structural shifts arising from a climate transition. The ECB (2022) climate stress test provides an example of a stress test that assessed short-term disorderly transition risk triggered by a sharp increase in the price of carbon emissions over a time horizon of three years. The objective of this analysis was to identify potential vulnerabilities connected to a disorderly transition. This scenario aimed to capture tail risks and was considered as a severe but plausible representation of a disorderly transition. The Bank of England pilot stress test discussed below included both orderly and disorderly transitions over longer time horizons.

What information and methodologies should be used?

The preparation of climate stress tests poses several methodological and data issues. The most fundamental question is how to measure climate exposures. A broad estimate of exposure to transition risks may be provided by the carbon footprint of the portfolios of financial institutions, as this indicates the overall change to the portfolio consistent with meeting climate targets (for example, a target of net zero by 2050).

However, meeting climate targets may have diverse effects across the portfolio of a financial institution, depending on individual client exposures and activities. An approximation could be provided by the sectoral composition of the portfolio, as clients within sectors might be expected to be similarly impacted by climate risks. A fuller assessment would require granular data on the exposures and activities of individual clients.

The scope of the stress test is likely to be determined by resources and data availability. The stress test can be proportionate by, for example, examining granular data for large clients where risks are concentrated, and sectoral data for other exposures (such as mortgages). A prioritized focus on larger clients will allow for a deeper dive into the assessment of individual climate exposures, taking account of clients' business models and plans.

[18] See Federal Reserve Board (2023) for an example of such an approach.

The sectoral assessment can be based on broader indicators. However, it may be important to disaggregate within the sector. For example, the climate risk to mortgages may vary by geographical location because of different exposures to extreme weather events. The stress tests may then need to be based on granular data, if available, combining information on the spatial distribution of risks to extreme weather with the geographical location of mortgage exposures.

The assessment of climate exposures will also need to include how much attention to give to current climate exposures and plans for adaptation and mitigation of climate risks. Stress tests are usually based on financial institutions' current balance sheets, and adapting their business plans is considered part of their response to climate risks. However, clients' adaptation and mitigation plans may need to be considered as part of the assessment of exposures, especially where the stress test is conducted over a longer time horizon. For example, if the transport sector promotes electric vehicles over the use of fossil fuels, the current carbon footprint would overestimate climate exposures in the future. Some of the adaptation and mitigation plans may be made explicit as assumptions when conducting the stress tests; others may need to be elaborated based on discussion and direct input from clients.

Another methodological question is how the stress test should account for system-wide and systemic effects: the possibility that actions by one firm to address its climate-related risk may create risk for another. An example is the interaction of insurers and mortgage lenders in response to more frequent extreme events. Property insurers could mitigate their financial risk by raising prices, but that might have an adverse effect on mortgage lenders in terms of the ability of their borrowers to repay loans. Mortgage lenders might react by reducing loan offerings in high-risk areas, affecting the pool of customers for the property insurer. The stress tests should make explicit the assumptions made on the treatment of system-wide effects.

A key issue identified in many of the pilot exercises is the lack of adequate information to assess the risks from climate change. The climate stress tests will increase transparency about information needs and data gaps to assess climate risks, and thus encourage follow up actions.[19]

In the absence of specific data, assumptions and approximations can be used to calibrate stress tests. For example, where the carbon footprints of individual firms are unavailable, they could be approximated using technical information on greenhouse gas emissions in industrial activities in which the firm is active. Alternatively, total sectoral emissions could be assigned to individual firms based on their importance in the sector. Lack of information on adaptation and mitigation plans can be handled by making the assumptions on the plans explicit. Reaching out to experts with technical knowledge can help fill in information and data gaps.[20]

What use should be made of the stress tests?

Reflecting the data limitations and methodological challenges, the climate stress tests conducted to date are generally considered to provide initial estimates of exposures to climate

[19] Task Force on Climate-related Financial Disclosures (2017a).
[20] See, for example, recommendations by the Bank of England (2019).

risks. So far, the exercises have not been considered sufficiently advanced to be used to set regulatory requirements, such as provisions or minimum capital standards.[21]

Nevertheless, the bottom-up stress tests provide a vehicle for supervisors to exercise oversight of the practices and processes used by financial institutions to manage climate risks, and to promote good practices. The estimates of exposures provide the basis for the discussion of the risks confronting a financial institution and how it plans to adopt its strategy and business model in response to those risks.

Consideration of climate-related risks is increasingly part of the management of risk for any financial institution. A comprehensive risk management framework should therefore include climate-related risks (as well as other increasing risks, such as cyber and technology risks). The reporting information accompanying the stress test results should be designed to explore the institution's response to climate risks. Does the institution:

- Have appropriate governance and leadership to address climate-related risks?
- Understand the financial and strategic risk associated with climate change?
- Have an effective plan or strategy to assess and address climate-related risks, including where appropriate holding additional capital against these risks?
- Have a process to evaluate customer and counterpart considerations and reputation risk?[22]

A top-down stress test should indicate the financial stability implications and balance sheet weakness from climate risks. Top-down stress tests thus provide a starting point for follow-up with financial institutions on their exposures to climate risks and their responses, exploring the issues outlined above.

As supervisors' and financial institutions' experience with climate scenarios and stress testing advances, they should become a regular component of a forward-looking climate risk assessment tool kit, as part of financial institutions' internal climate risk assessments. Where the financial institution designs its own stress tests, questions to ask include:

- Has the financial institution correctly identified the climate tail risks relevant to its exposures and reflected these in scenarios and stress tests that are sufficiently severe?
- Are the information and methodologies adequate to assess the exposures to climate risks?
- How are the results of the stress tests used for managing climate risks?

Example of a pilot stress test of financial risks from climate change

The Bank of England (2021a) exploratory scenario on the financial risks from climate change illustrates the approaches, issues and challenges in the use of scenarios and stress tests to assess the financial risks of climate change.

The Bank of England outlined the objectives of the exploratory exercise as being to:

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[21] For a discussion of the potential use of stress tests in setting capital requirements, see Bank of England (2022b) and Basel Committee (2022b).

[22] See International Actuarial Association (2021).

- Assess the size of participants' financial exposures and the financial system to climate-related risks;
- Understand the challenges to participants' business models from these risks;
- Assist participants in enhancing their management of climate-related financial risks; and
- Develop supervisory and participant expertise in modelling and understanding climate-related risks.

The results of the exercise were to be used to help guide supervisory and system-wide policy approaches to climate risks.

The exploratory exercise examined three scenarios to explore transition and physical risks from climate change:

- An **orderly transition**: The transition to a net-zero GHG emissions economy in 2050 starts in 2021, and carbon taxes and other policies intensify relatively gradually over the scenario horizon. The impact on GDP is muted.
- A **disorderly transition**: The implementation of policies to reduce GHG emissions to net zero by 2050 is delayed until 2031 and is then more sudden and disorderly. The impact on GDP and carbon intensive sectors is significant.
- **Current policies**: With no change in current polices to limit GHG emissions, global temperature increases significantly, resulting in new physical risks from chronic changes in precipitation, ecosystems, and sea level. There are permanent impacts on living and working conditions, buildings and infrastructure. With the sharp increase in physical damage, GDP growth is permanently lower.

The above scenarios were translated into specific paths for carbon prices, macroeconomic and sectoral variables. The scenarios were mapped to NGFS scenarios so participants could draw on the NGFS scenario database to inform their analysis.

The exercise was applied by seven major banks, five large life and six large general insurers. Participants were asked to assess the vulnerability of their current business models, approximated by their end-of-2020 balance sheets, to the climate scenarios outline above.

Banks were asked to explore credit risk, with an emphasis on their large corporate counterparties, though other sectors were also covered (for example, household mortgages). The cumulative total of provisions against credit-impaired loans was used as the key metric to measure the increase in credit risk. Traded risk and non-traded market risk were not covered.

Insurers were asked to explore changes in the values of invested assets and insurance liabilities in response to the climate scenarios.

In arriving at their estimates, participants were encouraged to engage with their counterparts directly, including to understand their adaptation and mitigation plans in response to the climate risks.

A detailed guidance document explained how participants should implement the stress test.[23] Data templates provided the detailed frameworks for the recording of results. Additional

[23] Bank of England (2021b). The detailed guidance covered issues such as the list of assets and sectors to be assessed, procedures for accounting and reporting results, treatment of counterparties' climate

templates requested responses on a menu of actions that financial institutions could take to the climate risks.

An extensive qualitative questionnaire explored a range of topics to enrich the quantitative reporting, including:

- Management actions in response to the climate risks to understand how business models could change, how participants will improve risk management of climate-related risks, and to inform the broader financial stability impact of these changes (for example, on the availability of financial services);
- Qualitative views of climate-related risks, including questions on risks and opportunities from climate change, operational risks, and litigation risks;
- Methodologies used for projecting losses by asset type and counterparties;
- Data gaps and the plans to fill them; and
- Counterparty adaptation plans.

The exercise achieved its overall objectives, including developing estimates of the magnitude of climate risks. However, it also identified that the lack of adequate information on counterparties' current emissions and future transition plans limited the ability to assess those risks.[24] The exercise was followed up with an examination of whether the results of this and similar exercises could or should be used in setting capital and other regulatory requirements.[25]

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mitigation and adaptation plans, techniques for modelling losses from physical risks, and key transmission channels and techniques for the assessment of transition risks.

[24] Bank of England (2022a) The report provides useful examples of good practices in assessing climate risks.

[25] Bank of England (2022b).

Conclusions

Climate-related events and their associated risks are subject to significant uncertainty in terms of their timing, frequency, and severity. Forward-looking assessment approaches are crucial to adequately account for the unprecedented nature of climate change. Against this backdrop, scenario analysis and stress testing are critical tools for assessing the potential risks that climate change poses for financial institutions.

Supervisors have an important role to play in the analysis of climate-related financial risks, including scenario analysis and stress testing. Supervisors can promote scenario analysis and stress testing of climate-related risks by running their own climate stress tests, by specifying climate stress tests to be conducted by financial institutions, and by requiring financial institutions to design and run their own stress tests.

Most stress tests of climate change risks have to date been conducted as pilot exercises. These have helped raise awareness of the risks, identify information needs and data gaps, build expertise, develop methodologies, and offer first evaluations of the financial risks posed by climate change. The pilot exercises have also provided a vehicle for supervisors to exercise oversight over financial institutions processes for identifying and managing the risks posed by climate change. The stress tests have not been considered sufficiently advanced to set regulatory requirements such as provisions or minimum capital standards.

As supervisors' and financial institutions' experience with climate stress testing advances, scenario analysis and climate stress testing should become a regular part of a forward-looking climate risk assessment toolkit.

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