Network for Greening the Financial System

Technical document

Scenarios in Action

A progress report on global supervisory and central bank climate scenario exercises

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NGFS

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Analysis of the economic and financial impacts of climate change is fraught with challenges and uncertainty, and understanding how best to manage future climate-related risks requires a forward-looking approach. Against this background, scenario analysis is the pre-eminent tool that we have to size risks under a range of different future pathways.

The hurdles to the delivery of effective scenario analysis are high, and they are being experienced not just by central banks and supervisors, but by actors across the whole financial system. The NGFS is seeking to reduce these hurdles through a number of actions, including: the creation of extensive and free-to-use climate scenarios; the evaluation of different design choices for scenario analysis; and a state-of-play analysis of NGFS members' existing and planned exercises. This report updates on the latter two of these actions.

While conducting scenario analysis to understand the macroeconomic and financial impacts of climate change is no easy task, this report demonstrates that central banks and authorities are seeking to develop their capabilities at speed. Across six continents, authorities are investing heavily to launch domestic exercises, translating climate outcomes into financial risks largely utilising the fast-evolving NGFS scenarios.

This report shares 31 NGFS members' experiences of conducting climate scenario analysis, highlighting a diversity of design choices and approaches. The openness and transparency with which members have shared insights into the challenges they faced, and how they have overcome them is noteworthy, and make this a unique report. We believe that the resultant insights will assist not just central bankers and supervisors, but members of the wider financial sector as it develops its climate risk management capabilities. This report will also act as a key input into future phases of the NGFS scenarios, highlighting areas of key importance and focus as we refine the scenario package.

The need to move quickly in this space is well understood and there is clear momentum as institutions seek to learn whilst they implement. As we publish this report, we now have a suite of scenarios and associated models and methodologies, four completed and published exercises, and 21 exercises due to complete in the next 12 months. Reflecting the exploratory nature of these exercises, NGFS members are not planning to translate scenario results into quantitative prudential requirements at this time. But there is a shared view that more significant work and thinking is needed. These cross-member reports will therefore continue to be of value and the NGFS will work to provide similar updates in the future.

We are delighted to present this important report.

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Executive summary

This report sets out how 31 NGFS members are using climate scenarios to identify, assess and understand climate risks in their economies and financial systems. As a rapidly growing number of central banks and supervisors are conducting climate scenario analysis, this report takes stock of the current state of play, setting out methodological and design choices and challenges. For the purposes of this report, 31 NGFS members across six continents volunteered to share information by way of a survey of their completed, in progress, or planned climate scenario analysis. To date, four of these exercises have been completed and their findings published, and most exercises are expected to be completed by Q3 2022.

The NGFS scenarios are a foundational component in almost all of the climate scenario exercises undertaken by NGFS members to date. To facilitate the uptake of climate scenario analysis by central banks, financial regulators, and the larger financial community, the NGFS developed a global set of scenarios and published guidance on conducting such analysis. The NGFS scenarios are already being used in 22 exercises, and some members have adapted the scenarios to suit their specific needs.

As climate scenario analysis is a new and growing field of activity for central banks and supervisors, it raises a number of challenges. These pertain to various aspects of the analysis, for example, when making the NGFS scenarios more tailored to the specific needs of a jurisdiction. Enhancing the "off-the-shelf" usability therefore remains a key driver of the on-going work on the NGFS scenarios. Challenges have also arisen with respect to data gaps – doing climate scenario analysis can actually help generate relevant data and fill some of the gaps, but this is a gradual process. In light of these challenges, climate scenario analysis is a difficult task and should be approached with humility. By providing insight into the practices and experiences from a range of central banks and supervisors, this report helps to further our understanding of these issues.

Objectives of climate scenario exercises range from assessing microprudential, macroprudential and economic risks, to developing capabilities both internally and within the broader financial sector. As most NGFS members are conducting climate scenario analysis for the first time, many view developing awareness and capabilities around climate-related risks as equally important to assessing the risks themselves – and indeed see considerable value simply in conducting such an exercise, regardless of its results. Given this emphasis on learning, and in light of challenges posed by data gaps and methodological uncertainties, no members as of yet envisage calibrating prudential policies such as capital requirements on the basis of their exercise. However, some members did express interest in this topic and indicated that they may include it as an objective for future exercises.

All exercises surveyed for this report cover the banking sector, and about half of the exercises also involve insurers or other financial institutions. Exercises predominantly focus on climate risks to banks' credit portfolios, but exercises that include insurers and other financial institutions tend to also cover market risk and liability risk. To date, one NGFS member has included climate litigation risk within the scope of its exercise.

The exercises covered in this report are split evenly between bottom-up approaches (those that involve financial institutions directly) and top-down approaches (those conducted entirely by the financial authority), underscoring that each approach has distinct merits. Bottom-up approaches have a number of benefits: they allow financial authorities to gain insight into institutions' own methods and abilities to analyse climate-related risks; improve institutions' own capabilities to perform climate scenario analysis; foster data collection within institutions; and increase awareness of economic and financial implications of climate-related risks. On the other hand, benefits of top-down approaches include: ensuring a consistent methodology across financial institutions; room for sensitivity analysis as assumptions and parameters can be easily adjusted; and a lower resource cost. In practice, approaches vary considerably, and sometimes elements of bottom-up and top-down exercises are combined.

Most survey respondents consider a scenario time horizon of 30 years. A 30-year timeframe aligns with the need to reduce emissions considerably by the middle of

the century as per the Paris Agreement, and also with many jurisdictions' commitment to achieve net zero emissions by then. However, such a relatively long timeframe inevitably leads to significant uncertainties around estimates of macroeconomic and financial impacts. To mitigate these uncertainties most survey respondents consider multiple scenarios in their exercises. Sometimes, survey respondents used time horizons longer than 30 years to capture more severe physical risks, while exercises with shorter scenario time horizons aim to enhance the confidence level of the results and to align with existing supervisory stress tests.

Survey respondents noted that a dynamic balance sheet approach could provide realism to the results of exercises, but three quarters of survey respondents nonetheless used a static balance sheet as advantages include ease of implementation and, in the case of bottom up exercises, extra controls over submissions. A static balance sheet approach essentially assumes that financial institutions' portfolios are frozen in time. A key advantage of this approach is that it insures against underestimating financial impacts as financial institutions cannot mitigate risks through assumed management actions. By contrast, dynamic balance sheets can offer more realism to the results as they incorporate changes to financial institutions' exposures over time, but this would require adaptive behaviour to be captured accurately. Some survey respondents use a hybrid approach in their exercises, for example by constraining balance sheet changes to be consistent with projected changes in the structure of the economy.

Climate scenario exercises can be resource intensive depending on the design choices, and are likely to require significant upskilling and dissemination of knowledge within organisations. In terms of internal resources, survey respondents have anywhere from one to more than 30 FTE (Full Time Equivalent) working on their exercises, with most dedicating between one and ten FTE.

Around two-thirds of survey respondents also collaborate with external parties such as meteorological and academic institutions, external modelling teams and data providers, and other central banks and international organisations. As climate scenario analysis represents a relatively new area of activity for central banks and supervisors, there is typically a need for internal capacity building and it may take time for teams across the organisation to become sufficiently versed in climate issues to contribute meaningfully to work on the scenario exercise.

Ultimately, as climate scenario exercises develop, insights into the financial impacts from transition and physical risks will become increasingly comprehensive, based on a converging set of methodological practices, and will make use of more widely available data. Through sharing learnings as this report aims to do, there is likely to be an emergence of best practice over time. However, this report also highlights that objectives of scenario exercises vary and are likely to continue to do so in the future, and there are often good reasons for different design choices. The results from these various exercises will hence complement each other and will gradually give rise to a multi-faceted and global picture of the risks from climate change. The NGFS will facilitate this development by continuing to serve as a platform for knowledge sharing between central banks and supervisors, and will report on these findings as they emerge.

Overview of exercises

Member	Expected end date of the exercise	Balance sheet assumption	Approach	Level of granularity	Risk coverage	Time horizon
Autorité de contrôle prudentiel et de resolution (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 risk 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 exercise	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 / FINMA	First part: end September 2021 Rest: TBD	Static	Top-down	Counterparty, macroeconomic, sector	Transition	5 – 40 years

Blue indicates "concluded," yellow indicates "in progress" and grey indicates "in planning."

1. Introduction

Central banks and supervisors are increasingly undertaking scenario analysis to identify, assess and understand how best to mitigate climate risks in the financial system. Scenario analysis is a vital tool to develop views in these areas as it provides a flexible 'what-if' framework for exploring how the risks may evolve in the future.

To facilitate the uptake of climate scenario analysis by central banks, financial regulators, and the larger financial community, the NGFS developed a global set of scenarios and published guidance on conducting such analysis.[1, 2] The challenges and costs of creating global scenarios combining transition risks, physical risks and their economic implications are beyond most individual firms or institutions. It is against this background that the NGFS has developed a common set of scenarios, working jointly with a consortium of climate scientists, energy experts and economic modellers. Given the novelty of this work, further refinement of the scenarios continues and a substantial update to the original NGFS scenarios was published in June 2021. Already, the NGFS scenarios are a foundational component in most of the climate scenario analyses undertaken by central banks and supervisors to date.

This report aims to provide a comprehensive picture of the climate scenario exercises that NGFS members are undertaking. It provides insight into the objectives of these exercises, as well as into the design details, operational features and the challenges encountered. As such, this report contributes to the NGFS goal of sharing best practices across central banks and supervisors.

The details included in this report are based on a survey of 31 NGFS members who have completed, are currently doing, or are planning to do a climate scenario analysis. At the time of the survey, four survey respondents' exercises had concluded, while 19 had exercises in progress, and six exercises were in the planning stage (Figure 1)[3]. Most of the exercises in progress are expected to be completed by Q3 2022, and all survey respondents plan to publish their results at least at an aggregate level. Since climate scenario analysis is a relatively new field of activity for central banks and supervisors, further improvements and extensions will likely take place in the years to come.

In addition to the survey results, this report also includes a series of deep dives covering key technical challenges and how NGFS members have addressed them. The four deep dives cover the issues of designing macroeconomic pathways, constructing sectoral pathways, conducting macroprudential analysis, and assumptions about the evolution of financial institutions' balance sheets. The aim of these deep dives is to provide a resource to those developing their own scenario exercise, by highlighting relevant considerations and approaches taken by NGFS members.

1 NGFS (2021), "NGFS Climate Scenarios for central banks and supervisors," *https://www.ngfs.net/en/ngfs-climate-scenarios-central-banks-and-supervisors-june-2021*.

2 NGFS (2020), "Guide to climate scenario analysis for central banks and supervisors," *https://www.ngfs.net/en/guide-climate-scenario-analysis-central-banks-and-supervisors*.

3 The exercises by the European Central Bank and the European Banking Authority have also concluded, but are not shown on the map. Most Eurozone authorities are not performing individual climate-scenario analyses, but will be taking part in the ECB Banking Supervision supervisory climate stress test that will be conducted in the course of 2022. The International Association of Insurance Supervisors, which is a NGFS observer, also carried out climate scenario analysis using the NGFS scenarios in a qualitative way. This exercise is not reflected in this report as only members' exercises were included.

Figure 1. **Status of survey respondents' exercises**

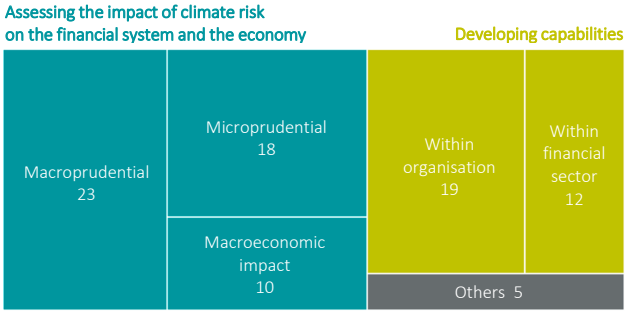
2. Key features of climate scenario analysis

This section explores the key features of scenario exercises as reported in the survey responses, drawing out similarities and differences between them, and reasons behind the design features.

2.1. Objectives

For most survey respondents, climate scenario analysis serves more than one purpose. At a high level, these various purposes are shown in figure 2. As most members are conducting climate scenario analysis for the first time, many view the development of awareness and capabilities around climate-related risks, both internally and within the financial sector, as important as assessing the risks themselves.

Figure 2. **Survey results on objectives of climate scenario analysis**



Note: areas are proportional to the number of responses that they represent

Survey respondents mostly use climate scenario analysis to assess the impact of climate risks on the financial system and the overall economy. Economic and risk assessment objectives of climate scenario analysis were previously identified in the *NGFS Guide to Climate Scenario Analysis,*[4] and can be defined as follows:

- Macroprudential assessment aims to understand and estimate financial system-wide risks, including the distribution of potential outcomes and systemic linkages;
- Microprudential assessment looks at specific risks to financial firms, including the impact on balance sheets and income statements; and,
- Macroeconomic impact represents effects of climate risks on economic growth, employment, inflation or trade.

As shown in figure 2, macroprudential assessment is the most commonly cited objective among survey respondents, followed by microprudential assessment and then macroeconomic impact assessment.

Many survey respondents indicated that the results of their exercises are subject to important uncertainties and should be taken with caution. Given the novelty of climate scenario analysis, survey respondents felt that their exercises could be improved further over time. An important issue in that respect is the persistence of data gaps. Whilst exercises can help to both identify and fill certain data gaps, challenges remain – these are elaborated further in Section 3.

Developing capabilities

Given that climate scenario analysis is a relatively new tool, several survey respondents highlighted that their exercises aim to improve methodologies and identify data gaps, as well as enhancing their understanding of climate risks. Developing capabilities within their organisations was the most prevalent answer, followed by developing capabilities within the financial sector.

Within organisations, climate scenario analysis is often considered a way to improve the understanding of how climate change might affect the economy and the financial system. In addition, most respondents identified data gaps that required them to develop methodologies or to engage with external data vendors. Some survey respondents adjusted their existing internal models to encompass climate risks or engaged with external modellers.

Half of the exercises involve participation by financial institutions (i.e. they are "bottom-up", see Section 2.2). In these cases, developing capabilities included the capabilities of those institutions, such as their modelling approaches and data gaps they face (e.g. information about carbon emissions from counterparties). In 2019, the Bank of England published a Discussion Paper

4 NGFS (2020), "Guide to climate scenario analysis for central banks and supervisors," *https://www.ngfs.net/en/guide-climate-scenario-analysis-central-banks-and-supervisors.*

setting out its initial proposal for such a bottom-up exercise, allowing financial institutions and other stakeholders to provide feedback on the methodology, as well as providing time to participating institutions to prepare for the exercise.[5] In this paper, the Bank of England was explicit that one of the aims of the exercise would be to "assist participants in enhancing their management of climate-related financial risks [including] embedding these risks in business-as-usual risk management, engaging counterparties to understand their vulnerability to climate change, and encouraging boards to take a strategic, long-term approach to managing these risks."

Some bottom-up exercises also aim explicitly at enhancing the comparability of results across financial institutions, and at raising awareness about climate risks within the financial sector. For instance, the ACPR/Banque de France included mobilising French banks and insurers and raising awareness about climate risks among the objectives of their exercise. Some survey respondents also expected the financial sector to take action: in particular, the objectives of the Australian Prudential Regulation Authority include understanding how banks react to the scenario analysis and think about factoring in the impacts from climate-risks in their business models.

Other objectives

Some central banks and supervisors indicated 'other' objectives tailored to economy-specific interests. For instance, one complementary aspect of the Banco de la República's exercise was to investigate the impact of climate-related risks on monetary policy. They explored how supply shocks due to climate-related disasters or steep increases of the carbon tax could bring about monetary policy dilemmas between supporting economic activity and reducing inflation. Banca d'Italia chose to initially focus their climate analysis on the effect of carbon taxation on a micro level index of the financial vulnerability of households and firms. This index will be used in subsequent exercises associated with sectoral probabilities of defaults and will be fed into a macro stress test.

Prudential policies

At this juncture no survey respondents envisage calibrating prudential policies such as capital requirements on the basis of their exercise. Among other reasons, this is because of the novel nature of climate scenario exercises, data gaps and methodological uncertainties. As the observations in this report illustrate, approaches to measuring climate risks vary widely, and there is not yet sufficient insight into how sensitive results are to the differences in underlying assumptions. As more exercises are completed, this knowledge gap will be narrowed and the basis for action should improve. Indeed, a number of survey respondents noted that policy calibration may be an objective of future exercises.

2.2. Scope of exercises

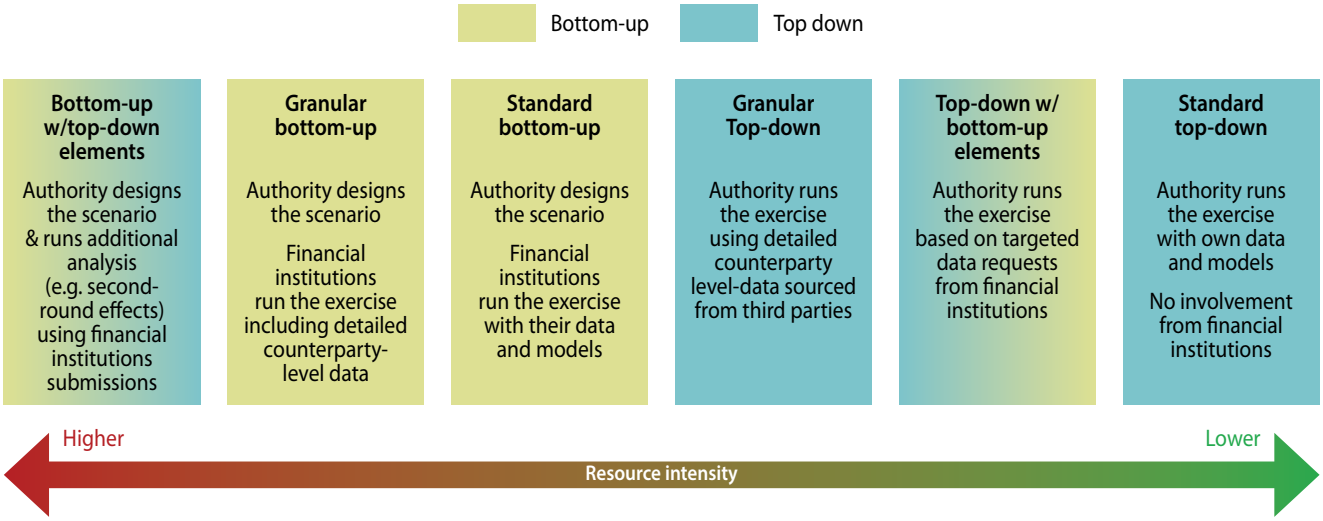
Top-down and bottom-up approaches

Broadly speaking, scenario analysis exercises can be grouped into two approaches: bottom-up and top-down. In bottom-up exercises, the central bank or supervisor sets out the scenario and a set of methodological rules. Financial institutions then run the scenarios against their balance sheet, using their internal data and models. By contrast, a top-down exercise is run entirely by the central bank or supervisor, without involvement of financial institutions. Figure 3 provides an overview of common types of bottom-up and top-down exercises, and lists key benefits of each.

Among survey respondents there is an even split between top-down and bottom-up exercises. Within this, there is, however, significant variation in approaches, including in granularity of analysis and model outputs, and the amount of resource required. Often cited reasons for adopting a top-down approach are that they ensure a consistent methodology across financial institutions, allow for sensitivity analysis as assumptions and parameters can be easily adjusted, and are relatively resource light. Bottom-up approaches were chosen to gain insight into institutions' own methods and abilities to analyse climate-related risks, improve their capabilities to perform climate scenario analysis, and increase awareness

5 Bank of England (2019), Discussion Paper: The 2021 biennial exploratory scenario on the financial risks from climate change. *https://www.bankofengland.co.uk/paper/2019/biennial-exploratory-scenario-climate-change-discussion-paper*

Figure 3. **Types of bottom-up and top-down scenario exercises**



of economic and financial implications of climate-related risks. Central banks and regulators will also benefit from enhanced data from those institutions, particularly where they conduct counterparty level analysis.

Some survey respondents adopted a combination of top-down and bottom-up approaches. The Australian Prudential Regulation Authority chose a bottom-up approach to understand how banks would adjust their business models in response to each scenario, but also had a top-down dimension where global- and national-level modelling was used to inform the effects on bank balance sheets. Bank of Canada used a top-down approach for market risk assessment at the sectoral level, and both a top-down and bottom-up approach for credit risk assessment.

Institution and exposures coverage

All survey respondents included banks in their exercise, and most exercises also covered some other financial institutions including insurers and pension funds. An advantage of covering different types of financial institutions is that the exercise can potentially capture spill-over and interaction effects between them. A few exercises focused specifically on the impact on corporations, households, and central government.

All survey respondents are covering credit risk for banks in their exercise, and respondents also frequently cover market risk for insurers. As credit portfolios are often the largest asset class for banks and all exercises cover banks, the focus on credit risk is not surprising. Only five respondents explore market risk for banks. Respondents that did not include market risk for banks often cited modelling challenges and the long-term nature of climate-related risks, as market risk tends to respond more to short-term unexpected shocks. Respondents that did include market risk addressed these caveats in various ways. For example, the ACPR/ Banque de France asked banks to consider an instantaneous shock on asset prices alongside gradually materialising credit risk. Hong Kong Monetary Authority asked banks to assess their market exposures on a best-effort basis. Market risk is more frequently explored for insurers, however, and some respondents' exercises also cover insurer liabilities.

Risk coverage

All but one respondent are capturing transition risk in their exercises, with around half of respondents focusing on both physical and transition risk. Given that the most severe physical risks will materialise in the second half of the century, some survey respondents consider transition risks more pressing. Transition risk data (e.g. emissions statistics) may also be easier to obtain than physical risk data (e.g. detailed projections of local changes in weather-related hazards). However, survey respondents also noted the uncertainty around estimates of physical risks, which warrants a precautionary approach. For example, the Bank of England included physical

risks that are projected to materialise from 2050-2080 in its exercise to capture these more extreme impacts. Finally, the focus on physical versus transition risks may be driven by the materiality of each risk type to the domestic economy.

Climate litigation risks are less explored across exercises. The Bank of England covers climate litigation risk in addition to transition and physical risk. This analysis of climate litigation risk includes a quantitative assessment for general insurers, and a qualitative survey of banks' and life insurers' management of such risks.

Geographic and sectoral granularity

Slightly less than half of respondents targeted their exercise on all regions where domiciled financial institutions have material exposures. Other exercises covered domestic risks only. A few respondents focused on physical risk on a domestic level, but covered multiple regions for transition risks due to their financial institutions having international exposures. The Swiss National Bank and the Swiss Financial Market Supervisory Authority (FINMA) undertook an exercise focused on large international banks with no geographical limitations on exposures covered.

Three quarters of respondents considered risks at a sectoral level, and most of those considered risks at a macroeconomic level as well. Around half of respondents further consider risks at the counterparty level, meaning that participating financial institutions would complete additional analysis on their largest counterparties or those that are focused on the highest risk sectors as identified in that jurisdiction (this varied from dairy to energy and utilities).

2.3. Scenario design

Time horizons

The majority of survey respondents look at 30-year time horizons. This timeframe aligns with the Paris Agreement goal to limit global warming to well below 2° Celsius compared to pre-industrial levels, which requires substantial reductions in emissions by 2050. It also aligns with many jurisdictions' commitment to net zero emissions by the middle of the century.

Three respondents explored climate risks up to 80 years and four respondents adopted time horizons shorter than 30 years. Respondents with time horizons up to 80 years include the Bank of England and Japanese authorities (Japan FSA, Bank of Japan). They adopted this longer timeframe specifically for the analysis of physical risks, as the most material physical risks are expected to materialise later in the century.

The rationales for looking at shorter time periods are varied: De Nederlandsche Bank analysed flood (physical) risk over a one year horizon, while analysing transition risks over ten years; the South African Reserve Bank adopted a horizon of three years for the analysis of physical risk to match their solvency stress test time horizon; and the Banco Central de Chile looked at transition risk over five years as they considered that the data could be extrapolated with higher confidence for this timeframe.

Balance sheet assumptions

In general, balance sheet assumptions can be grouped into two broad categories:

- A **static balance sheet assumption** assumes that balance sheets are 'frozen' over time, allowing only balance sheet changes that result directly from risks materialising in the scenario (e.g. assets going into default).
- A **dynamic balance sheet assumption** allows balance sheets to change over time, either because counterparty characteristics change (they may reduce their emissions or gain market share for example), or because the financial institution divests from existing counterparties, or invests in new ones.

It is also possible to adopt a hybrid approach, combining elements of both static and dynamic balance sheet assumptions. Balance sheet assumptions are explored in more detail in Deep Dive 3.

Three quarters of survey respondents are using static balance sheet assumptions, owing mainly to ease of implementation and reduced risks of understating impacts. Static balance sheets require fewer assumptions to be made, which can ultimately improve data reliability and consistency. In particular, it insures against underestimating financial impacts, because under a static balance sheet approach financial institutions cannot mitigate risks through

assumed management actions. Many survey respondents indicated that current data limitations are a challenge to dynamic balance sheet modelling – but they would consider transitioning to hybrid or fully dynamic balance sheet models in the future.

Two survey respondents adopted a fully dynamic balance sheet assumption, in light of the higher extent of structural change expected in their economies. The South African Reserve Bank, for example, view static balance sheets as difficult to justify in an economy that is facing significant structural change as a result of the transition, particularly over a multi-year horizon.

Two survey respondents adopted a hybrid balance sheet assumption. The ACPR/ Banque de France assumed a static balance sheet for the first five years of its scenario (2020-2025) and dynamic for the remainder (2025-2050). This choice was motivated by the assumption that strategic management actions are not implemented before the materialisation of a certain amount of risk. Hence, the initial shock cannot be mitigated through climate actions, while from 2025 onwards – when management actions are permitted – the exercise provides insight into financial institutions' longer-term vision for coping with climate-related risks. The Australian Prudential Regulation Authority is running its exercise with both a static and a "proportional" dynamic balance sheet assumption. In the latter case, balance sheets are assumed to evolve in line with modelled changes in the sectoral composition of the economy, within certain pre-specified bounds. This constraint on the evolution of the balance sheet ensures that the results of the exercise are comparable across firms despite balance sheet changes.

The Bank of England and Japanese authorities apply a static balance sheet assumption and additionally ask financial institutions to provide qualitative information on the management actions they expect to implement in response to the risks. Japanese authorities also conduct supplemental micro-level sensitivity analysis of the successful transformation of the client's business structure against continuation of the current business structure.

Scenarios

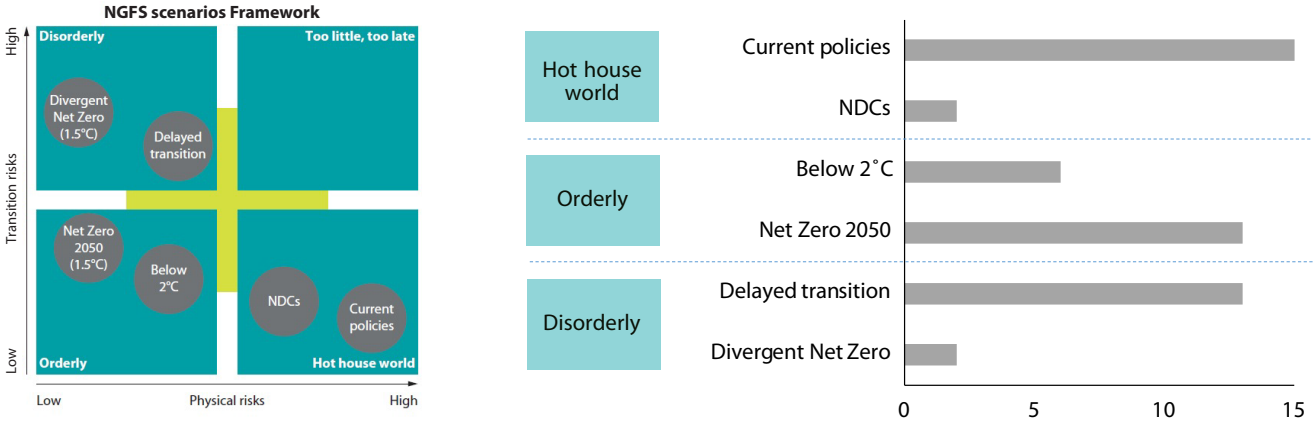
Three-quarters of survey respondents are using the NGFS scenarios in their analysis. Most survey respondents use a total of three scenarios in their climate scenario exercises, and five respondents are using more than five scenarios. Seven survey respondents did not use NGFS scenarios, usually because these exercises focused only on domestic or a limited number of risk factors. For example, De Nederlandsche Bank used third-party flood risk projections to assess the impact of physical risk on domestic mortgage exposures. Six survey respondents considered alternative scenarios in addition to those provided by the NGFS. For example, ACPR/ Banque de France considered a scenario where policy is delayed by 5 rather than 10 years (as is the case in the NGFS delayed transition scenario).

Of the six Phase II NGFS scenarios shown in Figure 4,[6] the most commonly used are: current policies, delayed transition, and net zero 2050. The current policies scenario is the most adverse regarding physical risks, whilst net zero 2050 reflects a relatively smooth transition to net zero emissions by 2050. In the delayed transition scenario, emissions are reduced but only after 2030, when they have to be reduced more rapidly in order to limit the most severe physical impacts.

The NGFS scenarios have been designed as a base scenario that can be adapted locally; in some cases, survey respondents adapted the NGFS scenarios to make them more severe. For example, in one scenario, the ACPR/ Banque de France assumed a less favourable evolution of productivity and renewable energy efficiency, implying higher energy prices and additional investment needs. The Bank of England built on the NGFS scenarios by including additional risk transmission channels to capture, inter alia, domestic climate policies, an extreme market reaction to the delayed transition, and more extreme physical risks. More details on such expansions are provided in Deep Dive 1.

6 Slide 7, NGFS (2021), "NGFS Climate Scenarios for central banks and supervisors," *https://www.ngfs.net/en/ngfs-climate-scenarios-central-banks-and-supervisors-june-2021*.

Figure 4. **Use of Phase II NGFS scenarios in survey respondents' exercises**



Source: NGFS (2021), "NGFS Climate Scenarios for central banks and supervisors".
Note: positioning of scenarios is approximate, based on an assessment of physical and transition risks out to 2100.

Some survey respondents created their own bespoke scenarios to address physical risk, typically in collaboration with domestic meteorological offices. For example, the South African Reserve Bank made its own high level, bespoke physical risk scenario based on severe drought. Bank of Canada did not use any NGFS data and developed their own scenarios by combining a computable general equilibrium model with internal macro-financial models to provide the required level of geographic and sectoral granularity. However the Bank of Canada's scenarios are broadly aligned with the NGFS current policies, below 2 °C, and net zero 2050 scenarios in terms of narratives and global emissions and carbon prices pathways.

2.4. Resourcing of exercises

In terms of internal resources, survey respondents spend anywhere from one to more than 30 FTE on their exercises, with most members dedicating between one and ten FTE. A key insight is that design features of the exercise have implications for the amount of resources and the time it takes to run the exercise. For example, top-down exercises are often relatively less resource-intensive, while exercises that include high levels of granularity of analysis, or exercises that include a second round to deepen or validate results, are often longer and more resource intensive.

More than half of respondents said that financial stability departments are leading the exercises. Banking and insurance supervision teams are involved in around a quarter of exercises; either leading the exercise or as part of a collaborative effort. Some exercises also involve specific risk analysis and climate-specific teams.

Around two-thirds of survey respondents are also collaborating with external parties. These include domestic climate/meteorological institutions, academic institutions and universities, external modelling teams and data providers, and other central banks and international financial institutions such as the International Monetary Fund. These external parties typically worked with the member to contextualise the scenarios to the respective socio-economic situations of each economy. The use of external parties was not linked to the number of people involved internally as collaboration was seen across the board.

3. Challenges and lessons learned

Most survey respondents have noted that building capabilities is one of the objectives of their exercise (Section 2.1). In that spirit, this section considers the challenges and some lessons learnt from survey respondents that have conducted climate scenario analysis so far. Common challenges experienced in climate exercises include: downscaling and linking different models and data provided by the NGFS scenarios; concerns with the uncertainty created by a long-time horizon of the climate exercise; guarding against risks being unduly assumed or modelled away; and developing adequate in-house climate-related scientific expertise.

Downscaling and linking NGFS scenarios with domestic models

Survey respondents cited challenges in translating NGFS scenarios into a shock to a specific economy, sector or a financial instrument, as this often involves expert judgement on additional modelling and downscaling. In addition, impacts of spill overs such as feedbacks between climate change and financial sectors, and risk transfers between sectors are also challenging to capture consistently. These challenges are a core focus of the work programme on the NGFS scenarios. For example, Phase II of the NGFS scenarios added additional macroeconomic variables and illustrated how the scenarios could be translated into "Risk Factor Pathways" for financial analysis.[7] In future work, the NGFS will continue to refine the scenarios to reduce the need for ad hoc assumptions by scenario users.

For exercises that are still in the preparatory stage, survey respondents noted that challenges arise in identifying climate-risk sensitive sectors. For some exercises, challenges lay in decomposing effects on aggregate economic activity in NGFS scenarios onto specific sectors. To address this, authorities often relied on calibrating bespoke internal and external models to assess impacts on different sectors and types of financial assets. Deep Dive 2 discusses in detail how different NGFS members have addressed such issues. Survey respondents also noted that assessing climate change impacts on different financial assets (especially non-equity assets such as corporate and sovereign bonds) requires expansion on the NGFS scenarios. Deep Dive 1 discusses in more detail how NGFS members conducted such scenario expansion.

Survey respondents further cited difficulties in linking NGFS scenarios with their domestic macroeconomic models, forecasts of relevant domestic economic variables, and assumptions used in internal models. In the case of bottom-up exercises, a lack of standardised assumptions and models made comparisons across participating financial institutions difficult. Survey respondents conducting bottom-up exercises also reported that financial institutions faced a similar challenge in terms of their internal models. In some cases, this was compounded by a lack of standardised modelling approaches and differences in assumptions from financial institutions in conducting the climate risk assessment. These challenges are, to some extent, inevitable given the novel nature of climate scenario exercises. As more regulators and financial institutions conduct exercises, standardisation of approaches is likely to increase.

Uncertainty of projections

Many exercises opt for a 30-year time horizon in order to capture the long-term nature of climate-related risks, but such a relatively long timeframe inevitably leads to significant uncertainties in the scenarios. These uncertainties relate to projections of climate change, the macroeconomic impacts from climate change, assumptions on the evolution of financial institutions' balance sheets (particularly in the case of a dynamic balance sheet assumption) and long-term mitigation strategies. To mitigate these uncertainties, most survey respondents consider more than one scenario. Within the NGFS scenarios, uncertainty is further managed by offering different models and thus a range of possible outcomes rather than a single estimate, as well as uncertainty bands for certain variables (e.g. temperature change). Survey respondents noted difficulty with adapting the shorter-term models used in traditional stress testing to cope with longer-term risks.

7 Slide 20, NGFS (2021), "NGFS Climate Scenarios for central banks and supervisors," *https://www.ngfs.net/en/ngfs-climate-scenarios-central-banks-and-supervisors-june-2021*.

Bottom-up exercises encountered some additional challenges. In some cases, for example, extending flexibility to market participants in terms of data requirements and disclosures, as well as consulting with market participants on modelling methodologies, had made it more difficult to ensure the scenario exercises yielded consistent and meaningful results. The People's Bank of China was concerned that, given the lack of historical data related to climate risks, using banks' internal rating models to assess corporate default rates might result in an underestimation of risks. The Bank of England aimed to mitigate these types of challenges in its exercise by offering specific guidance to participating firms. Among other things, this guidance called on firms to prepare their modelling capabilities for climate scenario analysis, and to engage with counterparties and data providers to fill data gaps. Ultimately, even if results are not modelled in mutually consistent ways between participants, bottom-up exercises can provide insight in the capabilities of financial institutions and can thus help in addressing capability and consistency gaps.

Guarding against risks being unduly assumed or modelled away

Due to the novelty of climate scenario exercises, survey respondents highlighted the risk of over- or understating the impacts on financial institutions. This point relates, for example, to the issues discussed above: projections over long time horizons are highly uncertain and methodologies for estimating climate risks vary widely between institutions. These issues are compounded by the complexity of balance sheet treatment and the degree to which the exercise allows for management actions, risk mitigation by counterparties and climate adaptation. Survey respondents addressed this challenge in various ways: ACPR/ Banque de France and the Australian Prudential Regulation Authority adopt a hybrid treatment of balance sheets; the Bank of England runs its exercise over two rounds to address inconsistencies; and half of respondents follow a top-down approach to ensure a consistent methodology for the estimation of impacts.

Capacity building and collaboration

Survey respondents noted the challenge of allocating sufficient resources to undertake a climate scenario exercise. As highlighted in Section 2.4, climate scenario analysis can be resource intensive depending on the design choices. In some cases, exercises involve cross-department collaborations, which require adequate governance arrangements, and around two-thirds of survey respondents are also collaborating with external parties. Furthermore, as climate exercises are novel, it is common that significant upskilling and dissemination of knowledge needs to take place within organisations. These complexities highlight the importance of setting realistic expectations as to how long it may take for teams across the organisation to become versed enough in climate issues to contribute meaningfully to work on the scenario exercise. Internal capacity building can be addressed by organising training provided by experts. The recently set up Climate Training Alliance further helps to institutionalise this type of training across regulators.

In the case of bottom-up exercises, survey respondents highlighted the importance of maintaining transparent communications and promoting sharing among industry participants and central banks and regulators. Fostering detailed engagements with participants of exercises, mutual exchange of information and setting realistic expectations for cooperation are critical to ensuring meaningful exercises and results. This can benefit banks in building up capabilities in climate risk management and foster understanding of the industry's practices and concerns. It also points to the benefits of developing commonly agreed approaches and methodologies to assess climate-related financial risks to facilitate comparability.

Survey respondents also acknowledged the need to pursue the development of macro-financial analytical tools that more consistently integrate the macro, sectoral and financial impacts. However, survey respondents highlighted that significant resources would need to be allocated to make major changes to the current frameworks used by supervisors or develop a new model. This is an important reason why the NGFS set out to centrally develop the NGFS scenarios. Through the further development of these scenarios, the macro, sectoral and financial impacts from climate should become increasingly integrated and linked up.

Addressing data gaps

Survey respondents and financial institutions tend to encounter similar data gaps when performing

scenario analysis. Some survey respondents have designed the climate exercise within working groups jointly with financial institutions to address data gaps collaboratively. Others opted for focusing on a few sectors for which data was more readily available, or extending flexibility to participating financial institutions to bridge data gaps. Common challenges and ways to address them are summarised in Table 1.

A specific challenge worth drawing out relates to the ability of companies outside of the supervisory scope of financial authorities to understand climate risks. This is particularly relevant for exercises that include counterparty-level analysis (cf. Section 2.2), as these exercises rely on climate-related data from individual companies, covering *inter alia* physical risk exposure, emissions, reliance on carbon-intensive inputs, and opportunities to substitute to low-carbon inputs. At present there is large variation in the extent to which companies can disclose information on these issues to financial institutions, for example due to knowledge or resource gaps within the company. Conducting climate scenario exercises with counterparty level data can foster dialogue between the financial sector and the real economy, which can help address this challenge. There could also be consideration for mandating relevant disclosures more broadly.

Table 1. **Common data gaps encountered by survey respondents**

Challenges related to data gaps encountered in the scenario exercise	Ways central banks and financial regulators have addressed them
• Lack of granular and sectoral counterparty-level emissions data	• Use third-party data sources • Ask financial institutions to engage directly with counterparties
• Lack of consistent and comparable data reporting standards for counterparties and for financial institutions	• Use third party data or inhouse modelling to 'correct' or fill in inconsistently reported or missing data • Stimulate converge on reporting standards
• Incomplete physical risk data, e.g. some physical hazards data is more difficult to obtain, and some data lacks sufficient geographical granularity	• Use third-party data sources, including domestic meteorological institutes, in addition to the NGFS Scenarios Climate Impact Explorer[1]
• Lack of sufficiently granular macrofinancial parameters/ transmission pathways from given climate scenarios to individual sectors, entities and financial assets	• Use economy-specific climate trajectories and external analysis • Develop bespoke models for scenario expansion to sectors and financial instruments
• Matching counterparties to specific sectors (e.g. NACE sectors and other industry classifications) from existing definitions (GICS and other in-house categories used by financial institutions)	• Third party data • Expert judgment

1 *http://climate-impact-explorer.climateanalytics.org/*

4. Conclusions

Climate scenario analysis is a fast-moving field: whereas to date only four exercises have been published, another 21 are expected to be published within a year. The broad spectrum of activity in this space creates a myriad of opportunities to learn and develop, and many survey respondents noted the motivation to build capabilities through running their exercises. This report aims to facilitate mutual learning by drawing out key insights from across these exercises.

The reported survey results highlight that there are many different ways of approaching climate scenario analysis, and design choices depend largely on the objectives of the exercise and circumstances individual to particular economies. Whilst it is still too early to identify unequivocal best practices – most exercises surveyed will not be completed until next year – certain trends stand out from the results:

- Scenario analysis is already conducted by financial authorities on six continents, and is likely to continue to be an indispensable tool for the assessment of climate risks.

- The availability of climate scenarios is a core building block for these exercises. To date, 22 survey respondents are using the NGFS scenarios in their exercise.

- At the current juncture, many central banks and supervisors consider that doing climate scenario analysis is as much about building capabilities as it is about assessing the risks. Data gaps are a particular area of attention, as the quality of data has a direct bearing on the quality of results. Doing climate scenario analysis can help generate relevant data and address gaps, but this is a gradual process.

- Top-down and bottom-up analyses are equally popular, and each have distinct benefits (including resource costs and granularity of analysis). Going forward, it is likely that a combination of these approaches remains valuable as they address different objectives (e.g. capability building within financial institutions versus consistency of results) and come at a varying resource cost.

- Despite challenges with implementation, many exercises consider a relatively long scenario time horizon to adequately capture climate-related risks. Going forward, there is scope to refine the treatment of uncertainty that is inevitable in long-term projections. As a practical matter, exercises often adopt a static balance sheet assumption, but many survey respondents thought a dynamic balance sheet assumption could be preferable if modelled reliably whilst controlling for risks being modelled away. This signals a clear prospect for further development of approaches.

- Collaboration is critical in climate scenario exercises. Many exercises include some degree of collaboration between central banks and supervisors, financial institutions, and third party model and data providers. The upshot is that there is an active dialogue around climate scenario exercises, which could promote convergence of practices over time.

- In light of the challenges in doing climate scenario analysis and the focus on learning and capacity building, no exercises have, to date, drawn out quantitative implications for prudential policy actions. This is in the spirit of these exercises being exploratory. However, there is interest in how future exercises could be used in such a way.

As climate scenario exercises develop, there is scope for convergence of practices. This would yield the benefit that exercises become: quicker to design (less 'reinventing of the wheel'); easier to run for participating financial institutions as they could adopt a single approach that would meet various regulators' and stakeholders' needs; and results would be more comparable. However, this report highlights that objectives of scenario exercises vary and are likely to continue to do so in the future, and there are often good reasons to vary design choices. As such, differences in approaches are likely to continue to exist even as climate scenario analysis becomes more commonplace.

5. Deep dive 1: macroeconomic modelling in scenario analysis

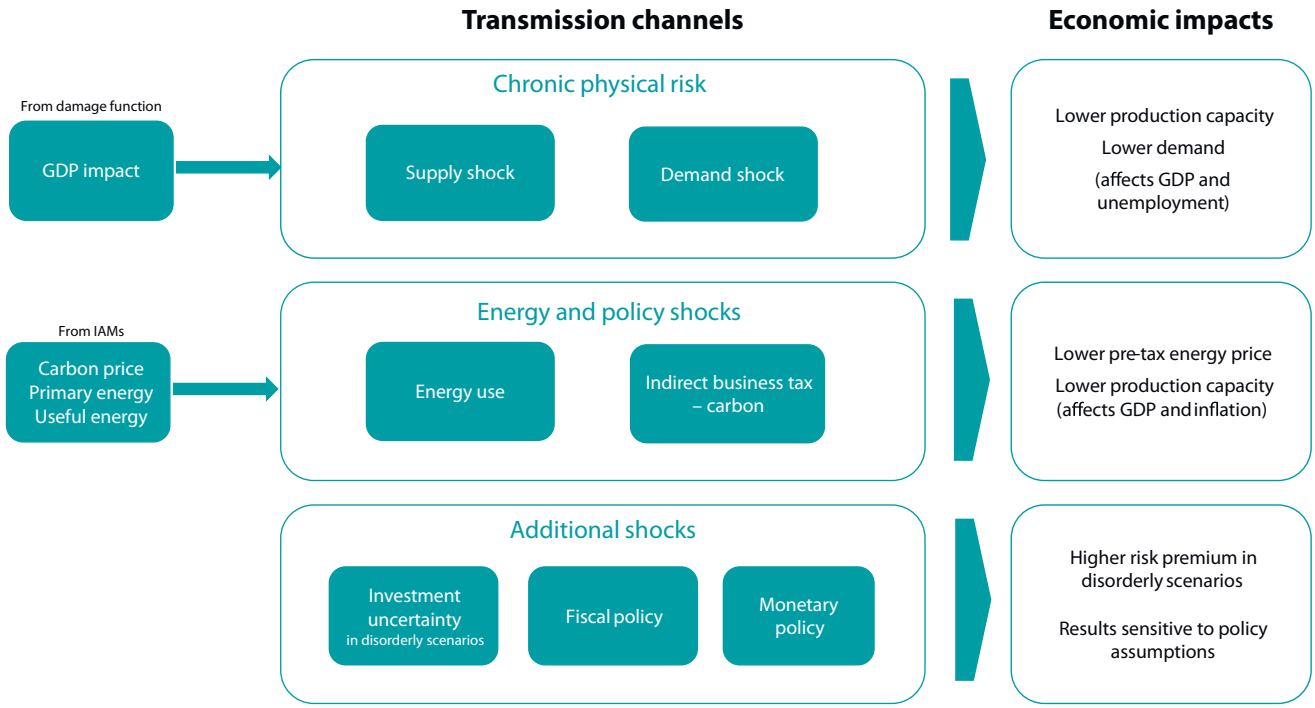
Why macroeconomic modelling?

Macroeconomic models are used to understand the impacts of the NGFS scenarios on the economy. Climate change will affect different economies in different ways, reflecting the unique nature of each economy's exposures to physical climate risks, differences in the mitigation policies, and differences in industry structure. Macroeconomic models provide internally consistent macroeconomic and financial variables that can be used by policymakers and firms to conduct scenario analysis.

For the purpose of scenario analysis, macroeconomic models need to describe the most important channels through which climate risks are transmitted within an economy. There needs to be a degree of customisation to ensure that the macroeconomic model provides a good description of the economy that is being analysed. The specific design of the macroeconomic model will also be informed by the purpose of the scenario. For example, if the scenario analysis is being conducted by banks with significant exposures to home mortgages, the consequences of climate change for unemployment rates and housing prices will be important outputs for a macroeconomic model to produce. For small commodity-exporting economies, macroeconomic models that provide more detail on global demand and projections for exports at a reasonable level of disaggregation are likely to help explain the transmission of climate change risks to domestic economic outcomes.

Macroeconomic models can also provide a useful top-down cross check on bottom-up modelling. The outputs of a macroeconomic model are an internally consistent set of variables that can impose a degree of discipline on other modelling exercises, such as the sectoral models described in Deep Dive 2. The outputs of macroeconomic models can also improve the comparability of scenario outputs across firm-level scenario exercises.

Figure 5. **Modelling economic impacts from physical risk and transition risk in the NGFS scenarios**[1]



1 Slide 35, NGFS (2021), "NGFS Climate Scenarios for central banks and supervisors," *https://www.ngfs.net/en/ngfs-climate-scenarios-central-banks-and-supervisors-june-2021*

The NGFS scenarios have used the macroeconomic model NiGEM since the second vintage was published in June 2021. NiGEM is a multi-region macroeconometric model that is widely used in the financial community for the forecasting of macroeconomic variables, such as GDP, unemployment or inflation rates. It models a large number of domestic economies to varying degrees of detail. This model includes endogenous policy responses from both the fiscal and monetary authorities for each region and includes some macro-financial variables, such as long-term interest rates. In the NGFS modelling framework, three integrated assessment models (IAMs) and a damage function are used to translate climate variables into a core set of macroeconomic variables, such as GDP, productivity growth and global carbon prices. NiGEM then translates these outputs into a large set of macroeconomic and financial variables[8]. Figure 5 summarises some of the economic impacts of shocks using transition inputs from the IAMs and estimates of chronic physical risk in the NiGEM model.[9]

Macroeconomic modelling in NGFS scenarios

Roughly half of the respondents report that they are using macroeconomic variables from NiGEM available in the NGFS scenarios, sometimes augmenting them with other modelling work. Several respondents report that they use additional modelling to augment the macroeconomic and financial variables available for the scenario analysis. This is clearly relevant in jurisdictions for which NiGEM does not provide economy-specific modelling. However, even in the cases where a relatively detailed set of variables is provided, some respondents indicate that additional modelling was required to meet the needs of their scenario exercise. For example, the Bank of England uses in-house models – calibrated on the basis of NiGEM outputs – to produce additional financial variables (e.g. bond yields). For respondents conducting bottom-up analyses, it is common to use additional modelling to provide more disaggregation by sector (see Deep Dive 2). Some respondents also note the importance of complementing the NiGEM results with additional physical risk impacts that are relevant to their economies.

Some respondents adjust the outputs from NiGEM to capture differences in how they expect the domestic economy to respond to the climate risks. For example, the People's Bank of China is adjusting the NiGEM output to account for the specific domestic policy targets that are in place. The Bank of England adjusted the NiGEM output to simulate a larger financial market shock, in response to sudden climate policies in the NGFS delayed transition scenario, and further incorporated labour market frictions resulting from the reallocation of labour towards low-carbon sectors.

Several respondents did not use macroeconomic pathways from the NGFS scenarios. In some cases, this is because the scenarios in-question do not require a macroeconomic overlay. For example, the Banca d'Italia assessed how firms' and households' financial vulnerability may be affected by different carbon tax values, which only required estimates of the social cost of carbon produced by the NGFS scenarios. Banco de España similarly assessed the impact of a rise in carbon prices using internal macroeconomic models, and therefore no further data was necessary. De Nederlandsche Bank is using scenario analysis to quantify flooding and transition risks for the real estate sector, and sourced data inputs from external providers that produced data specific to this sector.

A small number of respondents are using alternative macroeconomic models. For example, Australian Prudential Regulation Authority used alternative models to produce more detailed economy and sector-level outputs. Similar to the NGFS methodology, the Bank of Canada and the ACPR/ Banque de France used a suite of models approach to produce additional macroeconomic, financial and corporate variables. Hong Kong Monetary Authority's bottom-up exercise encourages banks to use the macroeconomic pathways implied by the NGFS scenarios, but allowed them to also use any existing alternative scenarios and models.

Where NiGEM is not used to provide the macroeconomic modelling, consistency with the NGFS scenarios is often achieved by matching certain outputs. For example, sometimes outputs from NGFS damage functions and IAMs are used to pin down at least some of the global variables.

8 More details of NiGEM and how it is integrated with other elements of the NGFS scenario ecosystem can be found in the *NGFS Climate Scenarios Technical Documentation*.

9 The first vintage of NGFS Scenarios only provided limited macroeconomic information, such as GDP, emission or commodity prices.

The Australian Prudential Regulation Authority used NGFS outputs, such as global emission pathways and GDP, as constraints for their macroeconomic models. The Swiss National Bank uses the energy and emissions-related data from the NGFS transition pathways as inputs to an external model to assess sectoral-level financial impacts. The European Central Bank used outputs from the NGFS damage functions, although additional data from third-party data providers were used to then disaggregate the outputs at a granular level. Bank of Korea used the IAM outputs, such as emission pathways and emission prices, to estimate GDP impacts from transition risks.

Remaining challenges

The survey responses highlighted several challenges associated with the macroeconomic modelling, as follows.

- Most respondents noted that they experience some **difficulty in aligning domestic models to global scenarios.** Alignment with the NGFS scenarios is desirable to achieve consistency, but customisation of the scenario to domestic circumstances is also important. For example, both the Bundesbank and the Banco de la República noted the difficulty of understanding the implications of the assumptions underlying the NGFS modelling (in particular in the IAMs) and of mapping NGFS scenario variables to their domestic models. As a means of addressing this challenge, the Bank of England compared the NGFS scenario pathways with other estimates for the UK, including those from governmental bodies, to ensure that the scenarios roughly matched up.

- Some respondents also noted **the challenges for macroeconomic modelling raised by the long horizon of the scenarios**. This contributes to model uncertainty and some of the issues around choosing between a static or dynamic balance sheet assumption (see Deep Dive 4).

6. Deep dive 2: designing sectoral pathways

Why sectoral analysis?

Climate change and mitigation policies will affect different sectors of an economy heterogeneously. The NGFS scenarios are designed to analyse the physical risks arising from climate change and the transition towards a green economy. As economic sectors rely heterogeneously on fossil fuels or on other natural resources (including agriculture), they are affected unevenly by climate change and climate change mitigation policies. These disruptions could be particularly impactful for sectors that can less easily reduce their carbon footprint. On the other hand, sectors with final goods and business models that support the transition, such as industries that produce batteries, renewables, and insulation materials, may actually benefit.

There are several further considerations that highlight the importance of sectoral analysis for understanding the macroeconomic impacts of climate-related risks:

- **Sectoral disaggregation is especially important for analysis of transition risks.** Fossil fuel-intensive sectors are affected primarily by climate mitigation policies, and then incrementally as economic structures, technology and consumer preferences change and adapt. However, some sectors may also be more affected by physical risks, with geography playing an important role (e.g. coastal regions).

- **Climate change policies can have heterogeneous impacts throughout value chains.** Processes of production often include many steps, from collecting raw materials to producing intermediate inputs and then final goods. At each step within these value chains, greenhouse gas emissions might be produced. Hence, a tax on emissions affects not only final goods (scope 1 emissions) but also respective intermediate goods (scope 2 emissions), and even some final goods, such as cars and aircrafts, which produce emissions when they themselves are used (scope 3 emissions). The embedded emissions (scope 1 and 2) of final products may also vary within and between sectors, particularly due to differences in production technologies. For physical risk, upstream producers may be exposed to climate hazards in ways that could ultimately have downstream impacts, e.g. through supply disruptions. Climate-related vulnerability analysis of economic sectors should therefore consider the whole production chain, as well as the consumption of final products. An important variable in such analysis is to what extent costs are absorbed by producers, or passed on downstream and to consumers.

- **Sectoral changes translate into a structural transformation of the whole economy.** In the NGFS scenarios, the transition towards a low-carbon economy is incentivised by imposing costs on emissions. In consequence, products that rely heavily on fossil fuels (directly or indirectly) will become relatively more expensive. Furthermore, as production technologies also differ within sectors, firms with less fossil fuel intensive technologies might experience rising demand. In second-order effects, firms with fossil-intensive technologies will adapt their production technologies as well as their demand for intermediate goods. The structure of the whole economy will change considerably, especially within fossil fuel-intensive sectors.

Overview of the sectoral information provided by the NGFS scenarios

Integrated assessment models (IAMs) used by the NGFS provide information for broad economic sectors. The information provided mainly relates to emissions, physical production, and prices. However, key economic metrics for economic and financial analysis such as gross value added (GVA), turnover and revenues are not included. Furthermore, the current suite of IAMs provide information for only seven economic sectors, and granular information on the structure of industries that might be most affected most by the transition is not always available. To overcome these shortcomings, a number of survey respondents have expanded the NGFS scenarios with sectoral downscaling.

The data available in the IAMs can be used to derive more granular financial metrics. A translation of scenario outputs into financial metrics can be achieved with Risk Factor Pathways (RFPs), developed by third parties such as UNEP-FI and Oliver Wyman.[10] RFPs are climate scenario outputs simplified as changes in revenue and thus represent

10 Carlin, D., Fischer, R. (2020). *Beyond the Horizon: New Tools and Frameworks for transition risk assessments from UNEP FI's TCFD Banking Program.* UNEP FI, September 2020

the types of financial pressures experienced by firms under the transition scenario. Direct and indirect emission costs, as well as investment in low-carbon technologies, can impact the revenue of a firm in a given sector. As changes in revenues vary between sectors, the risk factor pathways are provided for specific sectors. Scenarios are therefore used to calculate RFPs for the seven sectors reported in the NGFS database.

Approaches taken by survey respondents for increasing sectoral granularity

a) On transition risks:

The NGFS scenarios can be complemented by further analytical approaches to translate the information to a richer sectoral level. Survey respondents report different analytical approaches, which can be broadly grouped as top-down and bottom-up. Top-down approaches can be either of a general or partial equilibrium nature. Table 2 summarises the different approaches reported by survey respondents.

Many survey respondents used a general equilibrium model to map out sectoral pathways.

Examples of the models used include:

- Bundesbank builds on a multi-sector and multi-region dynamic general equilibrium model to investigate the impact of changes in macroeconomic aggregates, such as the introduction of a carbon price or technological progress. The approach thus captures sectoral heterogeneity in the production process, as well as the interconnectedness of production sectors and feedback effects from international linkages.

- The Bank of Canada uses a Computational General Equilibrium (CGE) model which represents the world in 14 sectors and 18 regions.[11] The most emission-intensive sectors are used to calculate details of net income (indirect costs, direct emission costs, capital expenditures and revenue) at the sectoral level. This information, leveraged by the participating financial institutions, is then used to assess financial impacts for counterparty in given sectors, combining top-down and bottom-up approaches.

- The Bank of Japan provides pathways of financial and macroeconomic variables, including sectoral GDPs and stock indices, that accord with NGFS scenarios, by using General Equilibrium models calibrated to Japan's economy and econometric models.

- Australian Prudential Regulation Authority exercise is designed around a granular model that provides disaggregation by industry sectors and household sector resolution, reflecting the high mortgage exposures of Australian banks.

Table 2. **Survey results on objectives of climate scenario analysis**

Top-down		Bottom-up
General equilibrium	*Partial equilibrium*	
Australian Prudential Regulation Authority	Bank of England	Bank of Canada (complementary to top-down)
ACPR/ Banque de France	De Nederlandsche Bank	Hong Kong Monetary Authority
Bank of Canada		Japan FSA/ Bank of Japan (complementary to top-down)
Banco de España		Australian Prudential Regulation Authority (complementary to top-down)
Bundesbank		
Japan FSA/ Bank of Japan		
Oesterreichische Nationalbank		
The People's Bank of China		
Examples of approaches:	*Examples of approaches:*	
MIT-EPPA	Transition Vulnerability Factors (TVFs)	
Production network models		

11 Specifically, the Bank of Canada uses the MIT Economic Projection and Policy Analysis (EPPA) model.

- Banco de España extends the model by Baqaee and Fahri[12] by two energy sectors (electricity and fuels) and creates a further 51 non-energy sectors that can roughly depict the 2-digit-NACE sectors.[13]

- The People's Bank of China is considering to use an IAM model to simulate pathways of environmental and economic variables at sectoral level. These pathways will be scaled down to the sectoral level by using a model providing turnover, value added, profit, employment and other indicators of different industries under different scenarios.

Some respondents used models of input-output production networks, which are especially useful for the analysis of the propagation of carbon taxation. The ACPR/ Banque de France use a static multi-sector general equilibrium model with four regions (France, the rest of the European Union, the USA, and the rest of the world) to simulate the impact of carbon tax set at a level consistent with the shadow emission price of the NGFS scenarios.[14] They find that "the most affected sectors are generally the most polluting ones, but the tax also propagates across sectors via intermediate inputs."[15] This approach accounts for substitution effects across inputs, in particular energy inputs, hence providing a more complete assessment of the disruptive structural transformations associated with disorderly transitions. The Bundesbank currently works on a similar approach.

Transition vulnerability factors (TVF) scale the macroeconomic impact of a proposed climate mitigation policy down to the sectoral level. The approach chosen by De Nederlandsche Bank, builds on an input-output analysis to reflect the total embodied carbon emissions in the production process of a sector.[16] The underlying assumption is that a sector that uses twice as much fossil fuels in the production process or in the production of an intermediate good should be hit twice as much by carbon mitigating policies, such as a carbon tax. In a second step, it weights the carbon emissions of a sector by its share of final goods in GDP. This approach leads to a static view in which climate policies, such as a carbon tax, are impacting sectors proportionally to their GHG emissions. The larger the sectoral TVF, the larger the share of the macro impact imposed on the particular sector.

The Bank of England also uses TVFs, using historical input-output tables for the calibration. Unlike De Nederlandsche Bank, which looked at short-term scenarios (5 years), the Bank of England TVFs vary over the stress horizon (30 years), as sectors move away from reliance on fossil fuels. This dynamic component is modelled using the sectoral emission pathways provided by the NGFS scenarios. TVFs for financial companies are calculated differently, as their embodied emissions are low and risks from the transition stem from their exposure to fossil-intensive firms and funds. The Bank of England thus calculates separate TVFs for financial companies: a TVF is calculated as a representative stock market index by using TVFs for constituent sectors and the index weights, and is then applied to the financial sector.

Some survey respondents have reported conducting their analysis at the level of individual companies, in addition to or instead of across sectors, as transition policies will affect firms differently within sectors. The European Central Bank scales carbon emissions down to the company-level to investigate risks in bank exposures. This process requires very detailed balance sheet or profit and loss data of non-financial firms, which the European Central Bank sourced from third party data vendors. The vulnerability of a specific company does not only depend on its economic activity or sector, but also on the location of facilities and the geographical network of supply chains and sales markets to which it depends.[17] The European Central Bank disaggregates the NGFS scenario pathways to firm-level financial information proportionally to current emissions. Since current emissions are used, the approach misses the adaptation and substitution effects that would occur over the medium term.

12 Baqaee, D. R., & Farhi, E. (2019). The macroeconomic impact of microeconomic shocks: beyond Hulten's Theorem. *Econometrica*, *87*(4), 1155-1203.

13 NACE is an industry standard classification system used in the European Union.

14 Although the approach relies on a static model, it is used at various stages of the transition process hence resulting in time-varying sectoral impacts.

15 Allen, T., Dees, S., Caicedo Graciano, C. M., Chouard, V., Clerc, L., de Gaye, A., ... & Vernet, L. (2020). *Climate-related scenarios for financial stability assessment: An application to France*. Banque de France, Working paper n° 774, July 2020.

16 Vermeulen, R., Schets, E., Lohuis, M., Kolbl, B., Jansen, D. J., & Heeringa, W. (2018). *An energy transition risk stress test for the financial system of the Netherlands* (No. 1607). De Nederlandsche Bank Occasional Studies, Volume 16-7.

17 ECB (2021). *ECB economy-wide climate stress test*. Occasional Paper Series, No. 281, September 2021.

Further examples are as follows.

a) Banca d'Italia explores the sensitivity of households and businesses to climate risks. Energy demand, including the fuel mix, is estimated for each household and business, such that carbon taxes are directly translated into final goods prices.
b) Bank of Korea assesses company-level financial impacts to then project sector stock prices and default-rates, to identify how decarbonisation affects bank asset values.
c) Bundesbank's climate risk modelling framework entails climate risk scenarios at the sectoral level that impact firms heterogeneously, according to firm-level characteristics (i.e. information from balance sheets, and income statements, as well as emission intensities).

Sectoral or firm-level information can alternatively be retrieved from bottom-up counterparty analysis. Participants in the Bank of England exercise are required to conduct counterparty-level analysis for their largest corporate counterparties. This analysis should be based on detailed information about the counterparties' exposures to climate risk, and should also include counterparties' mitigation plans, provided that they are credible, already in motion and likely to succeed. Japanese authorities, the Bank of Canada, Hong Kong Monetary Authority, and APRA all take a similar approach. This approach helps financial institutions to embed counterparty climate risks in their risk management framework, and can also shed more light on risks at the sector-level.

b) On physical risks:

For physical risks, geographical disaggregation can be as important as sectoral disaggregation. The geographical location is an important input into the climate risk profile of businesses. In the European Central Bank's exercise, for example, the location of two million businesses in the Euro Area were geo-referenced to analyse risks to these businesses from river floods. Still, there can also be physical risk differentials at a sectoral level. For example, the agricultural sector might be especially sensitive to heatwaves, while sectors that rely on fragile supply-chains may be heavily affected by rising sea levels. To obtain sectoral pathways reflection physical risks, the Bank of England adapted the TVF approach to construct Physical Vulnerability Factors (PVFs). It identified five risk transmission channels (weighted according to expert judgement and evidence from the literature): direct physical damage to assets, supply chain sensitivity, market risk, macro environment, and a sector-specific resilience factor. Subsequently, physical risk scores were assigned to each risk transmission channel, which translated into an overall physical risk score by sector. PVFs are measured and applied in the same "units" as TVFs (e.g. weighted by a sector's value added) but assumed constant over time (no adaptation).

Addressing remaining challenges

Sectoral disaggregation, and the subsequent translation into the transformation of the whole economy, is as necessary as it is difficult. As showcased in this deep dive, significant strides have been made in the analysis of financial risks stemming from sectoral concentrations. Challenges remain, however, especially with regards to integrating all equilibrium effects (which requires an integrated model), incorporating all relevant risk factors, and accounting for the impact of technological changes on sectors over time. In addition, more company-level information is necessary as risks can also be heterogeneous within, and not only across sectors.

As part of its further work on the NGFS scenarios, the NGFS is considering options for increasing the sectoral granularity of the scenarios.

7. Deep dive 3: balance sheet assumptions

The role of balance sheet assumptions

To assess transition and physical risk impacts for financial institutions, one needs to make an assumption about how institutions' balance sheets evolve over the course of the scenario horizon. The key question such an assumption typically seeks to address is whether, and how, the balance sheets of financial institutions change over the time horizon of the scenario. An important corollary of such assumptions is whether financial institutions can assume that they change their balance sheet to mitigate the risks materialising under the scenario, e.g., by divesting from certain asset classes or investing strategically.

As mentioned in Section 2, balance sheet assumptions can be grouped into two broad categories: static and dynamic. Most NGFS survey respondents apply a static balance sheet assumption in their exercise, but some opt for a dynamic or hybrid approach.

Key reasons for assuming a static balance sheet

Traditionally, a static balance sheet assumption tends to be favoured in exercises with a relatively short scenario horizon (e.g. 3 years). Under longer time horizons, a static balance sheet assumption becomes increasingly more counterfactual, given that, in reality, balance sheets change constantly. Despite this, three quarters of NGFS survey respondents conducting climate scenario exercises (most of which use multi-decadal scenarios) have opted for a static balance sheet assumption. Survey respondents gave three key reasons for this choice, as follows.

- It is generally **simpler to implement a static balance sheet assumption** compared with the dynamic version, as there is no need to model the evolution of the balance sheet. Static balance sheets avoid the need for additional assumptions, methodologies or data to project balance sheets forwards.

- The **static balance sheet assumption ensures that the results of the exercise can be interpreted as pertaining to current business models.** For example, Bank of Korea assumes that banks model against a static balance sheet to identify the extent to which transition risk affects financial stability in case of no additional efforts by banks. By contrast, a dynamic balance sheet assumption would mean that the results of the exercise are conditional on the assumed evolution of balance sheets, adding a layer of uncertainty to the results.

- **Static balance sheet assumptions tend to insure against an underestimation of impacts.** A dynamic balance sheet assumption may lead to an underestimation of the financial impacts of the scenario, because it allows institutions to shrink their exposures to the most vulnerable counterparties over time. For example, depending on how the dynamic balance sheet assumption is defined, financial institutions may assume that they divest from coal-related assets if the scenario specifies a phase-out of coal. In such a case, the results of the exercise would not convey what the impact would be if the institution fails to divest. A static balance sheet assumption hedges against this possibility.

One downside of static balance sheets is that it could be considered unrealistic as, especially over longer time horizons, it is extremely unlikely that institutions' exposures stay the same.

Key reasons for assuming a dynamic balance sheet

Currently, only three NGFS survey respondents indicated that they are using a purely dynamic balance sheet approach. They mentioned two key reasons for choosing a dynamic balance sheet over a static balance sheet assumption, as follows.

- **Dynamic balance sheets present more realism to the results.** Static balance sheets are a hypothetical construct because, in reality, balance sheets change all the time. Financial institutions operate on the basis of forward-looking strategies and respond to changes in information about the future. Especially over longer time horizons, it is extremely unlikely that institutions' exposures stay exactly the same. Hence, provided that this adaptive behaviour can be accurately captured within the exercise, and be consistent with the projected structure

of the economy, a dynamic balance sheet assumption could lead to more realistic results.

- **Dynamic balance sheets shed light on debt dynamics and financing costs in the economy, and can help inform macroprudential policy.** The risks that are assumed to materialise under a climate scenario can affect lending and investment behaviour in the economy. Financial institutions may demand higher or lower risk premia on their investments, or they might change financing conditions, e.g., by providing cheaper funding to projects with lower emissions. By allowing for dynamic balance sheets and thus allowing financial institutions to adapt, the exercise can shed light on how financing conditions could alter over the course of a given scenario. In this way, the exercise can capture feedback loops between the financial sector and the real economy, which can in turn inform macroprudential policy considerations (also see Deep Dive 4).

Drawbacks of a dynamic balance sheet assumption are that it can be more resource intensive as it requires balance sheets to be projected forward, and there is a risk that impacts to financial institutions are underestimated as a result of assumed balance sheet adjustments.

A number of NGFS survey respondents indicated that they are interested in **exploring a dynamic balance sheet assumption in future work,** but are initially applying a static balance sheet assumption for the reasons outlined above.

Hybrid balance sheet assumptions

Several NGFS survey respondents have adopted a hybrid approach with the aim of capturing some of the benefits of both the static and dynamic balance sheet assumption. Below are two examples of hybrid approaches used by NGFS members.

- **Short-term static, long-term dynamic.** ACPR/ Banque de France assume a static balance sheet until 2025 and then dynamic through 2050. This choice was motivated by the assumption that strategic management actions are not implemented before the materialisation of a certain amount of risk. Thus, the impact of a public policy shock on the current structure of banks' and insurers' balance sheets is able to be evaluated. In the second step (2025-50), one is able to understand how the integration of management decisions may mitigate climate-related risks. The objective of this approach is to obtain a better understanding of financial institutions' longer-term vision for coping with climate-related risks.

- **Proportional dynamic balance sheet.** Australian Prudential Regulation Authority is running its exercise with both a static and a "proportional" dynamic balance sheet assumption. In the latter case, balance sheets are assumed to evolve in line with modelled changes in the sectoral composition of the economy, within certain pre-specified bounds. This constraint on the evolution of the balance sheet ensures that the results of the exercise are comparable across firms, despite the changes to balance sheets. Japanese authorities use a static balance sheet and conduct supplemental micro-level sensitivity analysis of the successful transformation of the client's business structure, against continuation of the current business structure, and include a consideration of qualitative information including management actions.

- **Qualitative management actions.** The Bank of England uses a static balance sheet assumption, but has included a qualitative questionnaire in their exercise, in which financial institutions are required to outline, at a high level, what management actions they expect to take under each scenario, and how that could impact the quantitative results.

8. Deep dive 4: using scenarios for macroprudential analysis

Why use scenarios for macroprudential analysis?

Climate risks may pose a systemic threat to financial stability beyond the idiosyncratic risks faced by individual institutions. As highlighted by several stress-test exercises and impact assessments, the consequences of climate risks in terms of financial losses can be severe. Importantly, such consequences can reach beyond individual financial institutions. For example, a sudden increase in carbon prices may trigger not only financial losses, but also a broader loss of confidence on financial markets and a sharp and disorderly repricing of assets. Furthermore, losses in a single financial institution can spill over to other institutions and the broader economy through financial interlinkages and second-round effects. Excessive credit growth and leverage, illiquidity, direct and indirect exposure concentrations and the misalignment of incentives all constitute generic channels through which systemic risk (including climate-related risks) can build up.

In addition, climate risks can trigger financial instability because of their unique features and systemic dimension. They will increase non-linearly if global warming is not mitigated, until reaching a point of irreversibility; they depend on complex interactions between economic and financial agents; and they materialise over long-time horizons. Climate change is a global phenomenon: if left unfettered, the materialisation of physical risk will affect many jurisdictions around the world, and at the same time.

The systemic dimensions of climate risks beyond idiosyncratic risk exposures may justify the application of complementary macroprudential policies alongside supervisory and disclosure measures, to limit the build-up of the systemic dimensions of climate risk and to increase the resilience of the financial system in the face of potential risk materialisation.[18] There is also a question over the extent to which current macroprudential policies capture elements of climate risk as systemic risk.

However, there are **limitations to traditional stress testing methodologies in assessing the impact of climate change to inform prudential policies.** First, the long-term and non-linear nature of climate risks challenges existing models, which typically assess financial risks over three to five years. Second, the uncertainty around the evolution of climate over the next decades (also depending on potential climate policies and their different implementation across jurisdictions) represents an additional source of variability to be tackled via forward-looking scenario analyses. Finally, a high degree of complexity derives from the interactions between a multitude of economic agents, and in particular between the real economy and the financial sector.[19] Such methodological limitations may also impair the usefulness of climate exercises to understand the need for targeted prudential policies to tackle climate risks, and to consequently calibrate possible prudential instruments.

NGFS members' use of scenario analysis for macroprudential purposes

Survey respondents acknowledge financial risks stemming from climate change, but are of the view that further work is needed before contemplating macroprudential measures. It is generally felt that more data and analysis is needed for the purpose, and traditional stress testing may not be appropriate and should thus be revised to capture the specificities of climate risks. For instance, the Hong Kong Monetary Authority, the ACPR/Banque de France and the Bank of England highlighted that their respective bottom-up stress tests were a learning exercise for the central banks themselves, but also for the financial sector, and mark the start of further work.

In particular, **respondents identified several methodological gaps that need to be filled,** including improving the measurement of capital loss and change in lending behaviours due to such losses, capturing the interconnectedness between financial institutions, common exposures and the possibility of fire-sales or feedback effects

18 See Baranović et al. (2021). "The challenge to capturing climate risks in the banking regulatory framework: is there a need for a macroprudential response?", ECB Macroprudential Bulletin, Article 1, October.

19 See Budnik, K. (2021). "Towards a macroprudential stress test and growth-at-risk perspective for climate-related risks", ECB Macroprudential Bulletin, Box 2, October.

from financial sector to the economy. Another challenge lies in identifying the part of climate risk that affects the financial system and is not yet addressed by existing micro- and macroprudential regulation. In the case of its bottom up exercise, the ACPR/ Banque de France also noted that the lack of comparability across financial institutions due to various data sources or methodologies, which hampers calibration of macroprudential measures.

Respondents cited **various macroprudential policies that could be considered in the future,** once methodological gaps are relatively more closed and the institutions improve their understanding and expertise of climate-related risks. Possible measures included additional capital requirements or sectoral systemic risk buffers. Discussions on the potential revision of the prudential framework, including through macroprudential measures, are ongoing in some specific jurisdictions (for example in Europe).

Generally, **insights from climate scenario analysis will be used to improve the understanding of the financial and economic implications of climate change, and could inform future macroprudential considerations.** The Bank of England's exercise will help understand whether risks concentrated in specific institutions could spill over to the broader financial system: it will also assess which management actions could generate systemic risks and undermine financial stability (for instance if many firms choose to divest from certain sectors of the economy, leading to fire-sale dynamics). The Banco de México exercise aims at identifying financial vulnerabilities that may lead to systemic events. The Bank of Korea's analysis aims at assessing the banking system's vulnerability to transition risks, and considered the impact on the capital adequacy ratio of banks. Some survey respondents also answered that their exercise would assess the evolution of insurance coverage (with some assets becoming uninsurable due to increasing climate risks), and how that could impair bank lending.

The European Central Bank has published the methodology and results of an economy-wide climate stress test of the euro area financial and non-financial sectors. The outcomes point to the potential systemic implications of climate change in the long-run, driven by the severe impact of physical risk on banks' losses, which is further amplified by its concentration in certain areas.[20] Notably, the European Central Bank has also proposed a methodology to conduct a macroprudential climate stress test of euro area banks, based on the growth-at-risk perspective.[21] This approach could be used to inform a timely and well-founded policy response (including capital requirements). Finally, the European Central Bank Banking Supervision will conduct a supervisory climate stress test in the course of 2022 to test banks' preparedness to assess climate risks, and understand potential vulnerabilities. The results of this exercise will also be used to inform the subsequent Supervisory Review and Evaluation Process (SREP).[22]

20 See Alogoskoufis, S. et al. (2021). "ECB's economy-wide climate stress test: Methodology and results", ECB Occasional Paper No 281, September.

21 See Budnik, K. (2021). "Towards a macroprudential stress test and growth-at-risk perspective for climate-related risks", ECB Macroprudential Bulletin, Box 2, October.

22 See Elderson, F. (2021). "Patchy data is a good start: from Kuznets and Clark to supervisors and climate", Keynote speech, June.

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